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Project Report

Guidelines for Petroleum Exploration & Developmental Projects in Offshore Areas beyond 12 Nautical miles (incl. Monitoring & Mitigation Measures).

Submitted to:

Directorate General of Hydrocarbons
Ministry of Petroleum & Natural Gas
Government of India

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MESSAGE FROM DIRECTOR GENERAL, DGH

The Government of India continues to place a high focus on energy, and the country's reliance on hydrocarbons is critical for guaranteeing energy security while keeping up with the growing economy. Oil and gas will continue to anchor India's fundamentals on energy mix as the world shifts toward transformation.

For the foreseeable future, India's energy security is dependent on oil and gas. The upstream sector of India is currently supplying energy and will be funding the country's future energy transition.

The Indian government has set strong targets for oil production of 40 million metric tonnes and gas production of 50 billion cubic meters by 2024, as well as even tougher ambitions for growing exploration acreage to 5,00,000 square kilometers by 2025 and 10,00,000 square kilometers by 2030. The government is collecting geoscientific data in less studied sedimentary basins to meet exploration aims in a mission mode.

It is vital for India to explore both onshore and offshore areas in search of hydrocarbons to make the country self-sufficient by increasing domestic oil and gas output. In this backdrop, office of DGH, MoPNG hired the services of CSIR-NIO to conduct a research on the environmental impacts of petroleum exploration and development projects in offshore areas beyond 12 nautical miles. DGH under the aegis of MoPNG, GoI aims to formulate a proposal for international bidding rounds of oil/gas fields for appraising a significant volume of offshore sedimentary basin areas within the Exclusive Economic Zone (EEZ).

The environmental clearance for projects within the territorial water is examined by the Ministry of Environment, Forests and Climate Change (MoEFCC); however, the approval beyond territorial water is not within the jurisdiction of MoEFCC. International standards and benchmarks define the rights and responsibilities of nations w.r.t. their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. With the standard conventions and agreements in place, it is imperative to lay down the necessary Environmental standards and safeguards for protecting marine ecology and preventing marine pollution in respect of offshore areas beyond 12 nautical miles from the coastline for adequately addressing the environmental concerns and their incorporation in the Management Plans.

DGH has envisioned the introduction of standardized guidelines/checklists for compliance by the Operator on Self-Regulated/Certification basis for the hydrocarbon exploration in the areas beyond 12 NM. Accordingly, the study report and handbook on environmental impacts in offshore areas beyond 12 NM have been prepared in collaboration with CSIR-NIO (National Institute of Oceanography) in conjunction with major offshore players of our country.

The Report/Handbook/Guideline titled "*Guidelines for Environmental Impact Assessment Studies on Petroleum Exploration and Developmental Projects in Offshore Areas beyond 12 Nautical miles*" provides a succinct/comprehensive review of E&P activities as well as the guidelines needed to assess, mitigate, and monitor potential environmental impacts from upstream oil and gas exploration and development projects.

DGH congratulates the entire team of CSIR-NIO, experts from upstream E&P sector who were involved in the preparation of the handbook in the form of ready-referral and the detailed report.

DGH is confident that the above endeavors will benefit the new incumbents as well as seasoned professionals involved in offshore exploration and drilling in the areas beyond 12 nautical miles.

Shri S C L Das, IAS
DG, DGH

Acknowledgements

The Report/Handbook/Guideline titled "*Guidelines for Environmental Impact Assessment Studies on Petroleum Exploration and Developmental Projects in Offshore Areas beyond 12 Nautical miles*" is prepared from a series of meetings/discussions of an interdisciplinary team of indigenous professionals in the Oil and Gas sector and scientific experts in the Oceanographic background between June 2021 and March 2022. The project was facilitated by the Directorate General of Hydrocarbons, under the Ministry of Petroleum and Natural Gas.

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We would also like to record our appreciation for the people who worked together towards the materialisation of the Report/Handbook/Guideline to the situation of contemporary vision and expect that this guide will prove to be a real and effective contribution to the healthy and sustainable oceanic environment. My hearty appreciation to the professionals from the Oil and Gas sector is as follows

Oil Industry Safety Directorate (OISD)
Reliance Industries Limited (RIL)
Oil and Natural Gas Corporation (ONGC)
Oil India Limited (OIL)
Vedanta Limited

Last but not least, we are incredibly grateful to the Directorate General of Hydrocarbons (DGH), Ministry of Petroleum and Natural Gas, for financing this project and their continuous support in finalising this report.

Sd-
Project leader-NIO

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Abbreviations

AERB	Atomic Energy Regulatory Board
BAT	Best Available Techniques
BOD	Biochemical Oxygen Demand
CMFRI	Central Marine Fisheries Research Institute
COD	Chemical Oxygen Demand
COP	Conference of Parties
CPCB	Central Pollution Control Board
CRZ	Coastal Regulation Zone
CTD	Conductivity Temperature Depth
DGH	Directorate General of Hydrocarbons
DGMS	Directorate General of Mines Safety
DO	Dissolved Oxygen
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMP	Environmental Management Plan
ETA	Event Tree Analysis
FMEA	Failure Modes and Effects Analysis
FTA	Fault Tree Analysis
GC	Geneva Convention
GCF	Green Climate Fund
GIPIP	Good International Petroleum Industry Practices
GIS	Geographic Information Systems
HAZID	Hazard Identification technique
HAZOP	Hazard and Operability Analysis
HC	Hydrocarbon
HHWL	Highest High-Water Level
HSE-MS	Health, Safety and Environmental Management Systems
IAEA	International Atomic Energy
ICRZ	Island Coastal Regulation Zone
IMD	India Meteorological Department
IMDG Code	International Maritime Dangerous Goods Code
IMO	International Maritime Organization

IUCN	**International Union for Conservation of Nature**
LAG	**Local Action Group**
LLWL	**Lowest Low -Water Level**
MARPOL	**International Convention for the Prevention of Pollution from Ships**
MoEFCC	**Ministry of Environment, Forests and Climate Change**
MoPNG	**Ministry of Petroleum and Natural Gas**
MPAs	**Marine Protected Areas**
MSL	**Mean Sea Level**
NDC	**Nationally Determined Contribution**
NGT	**National Green Tribunal**
NOAA	**National Oceanic and Atmospheric Administration**
NORM	**Naturally Occurring Radioactive Materials**
NOSDCP	**National Oil-spill Disaster Contingency Plan**
OISD	**Oil Industry Safety Directorate**
OSCP	**Oil Spill Contingency Plan**
OSPAR	**Convention for the Protection of the Marine Environment of the North-East Atlantic**
PEL	**Petroleum Exploration License**
PML	**Petroleum Mining Lease**
PNG Rules	**Petroleum and Natural Gas Rules 1959**
PNGRB	**Petroleum and Natural Gas Regulatory Board**
PSCs	**Production Sharing Contracts**
RA	**Risk Assessment**
RSCs	**Revenue Sharing Contracts**
SAR	**Synthetic Aperture Radar**
SBM	**Synthetic Based Muds**
SOLAS	**Convention for the Safety of Life at Sea**
SOP	**Standard Operating Procedure**
SS	**Suspended Sediment**
UNCLOS	**United Nations Convention for the Law of the Sea**
UNFCCC	**United Nations Climate Change Framework Convention**
WCCP	**Well Control Contingency Plan**
WOMP	**Well Operations Management Plan**

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Executive Summary

- Office of the Directorate General of Hydrocarbon, Ministry of Petroleum & Natural Gas, Government of India, requested CSIR-NIO to carry out the Study of Environmental Impact of Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles and suggest means for protecting marine ecology and prevention of marine pollution through a proper monitoring and mitigation plan.
- To enhance the hydrocarbon (HC) exploration activities towards the country's growing energy requirements, the Ministry of Petroleum and Natural Gas is formulating a proposal for international bidding rounds of oil/gas fields for appraising a significant volume of offshore sedimentary basin areas within the Exclusive Economic Zone (EEZ).
- The environmental clearance for projects within the territorial water is considered by the Ministry of Environment, Forests and Climate Change (MoEFCC); however, the approval beyond territorial water is not within the jurisdiction of MoEFCC. The unexplored area has come down significantly due to the surveys carried out by DGH in unexplored/poorly explored areas of the country by including deep waters.
- Baseline data of the major sedimentary basin (Gulf of Kutch, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery Basin, Krishna Godavari, Mahanadi Basin, and Andaman Basin) has been prepared by comprehensive analysis of Marine EIA/ monitoring work carried out in the oil fields within the EEZ of India in shallow and deep offshore blocks. We have compiled most of the available reports related to the oil field in the western & eastern offshore blocks, books, journal papers, thesis and other documents. For each basin, Meteorological parameters (wind speed, relative humidity barometric pressure, air temperature, solar radiation), physical parameters (currents, wave, temperature, salinity, density, turbidity/TSM), chemical

parameters (Dissolved oxygen (DO), BOD, COD, Nutrients (nitrate- NO_3^-, silicate - SiO_4^- and phosphate – PO_4^{3-}), Dissolved petroleum hydrocarbon, Dissolved heavy metals), sediment parameters, heavy metals, phytoplankton, zooplankton, benthos, the abundance of fish etc., were tabulated through the compilation of the documents. Ultimately for each basin, the minimum, maximum, with average values of entire parameters were calculated, which can be further used to study the impact of the Oil and Gas project on the marine environment.

- Permissible Limit of effluent discharge and the oil content related to the Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles in the Indian EEZ has been prepared and listed in Table 5.2a of the report.
- Permissible Limit/baseline values of the water column and sediment parameters related to the Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles in the Indian EEZ have been prepared and listed in Table 5.2b of the report.
- The chemicals used for hydro testing must be easily biodegradable. Toxicity (96 hr LC50 > 30,000 mg/l for most abundant biota and IUCN red list organism as in the Annexure-4, if any) should be minimum as per the criteria; effluent can be discharged off-shore intermittently, at an average rate of 50 bbl/hr/well from a platform so as to have proper dilution & dispersion without any adverse impact on the marine environment.
- The Marine Protected Areas are natural marine resources for biodiversity conservation and the well-being of the people dependent on them. India has designated four legal categories of protected areas: National Park, Wildlife Sanctuary, Conservation Reserve and Community Reserve. If Oil and Gas project activity extends to the limit of any of these Marine Protected Areas (MPAs), it is suggested to prepare a detailed biodiversity action plan to protect and sustain a healthy ecosystem of concerned

- Environmental impacts of oil and gas operations could impact water quality and affect species, populations, assemblages, or ecosystems by modifying various ecological parameters (e.g., biodiversity, biomass, productivity, etc.). Potential impacts are generally assessed at the project level through some formal process, termed an environmental impact assessment (EIA). Various project activities such as Seismic survey, vessel operations, Exploratory & appraisal drilling, Development and Production to the Decommissioning stages were assessed, and which impact on the marine environment has been anticipated. Together with baseline information and anticipated impact, mitigation measures to negate the adverse effect on the environment has been suggested.
- The offshore environmental monitoring provides an overview of the environmental status combined with baseline data that trends over time due to offshore oil and gas activities. Sampling location, parameters, frequency and strategies were discussed to monitor the environment during the various stages of the project activity, intending whether the environmental status of the offshore oceanic environment is stable, deteriorating or improving due to operators' activities. It is important that results from environmental monitoring can be used to verify predictions and conclusions of the environmental impact assessment study for the respective field or the region.
- Risk Assessment by identifying, analysing, assessing, and communicating risk and accepting, avoiding, transferring or controlling it to an acceptable level by considering associated costs and benefits of any actions taken.
- A disaster management plan related to the offshore Oil and Gas projects has been outlined to set out the appropriate course of action to mitigate the impact of an emergency event. This is to respond immediately to an emergency event to prevent its escalation to a disaster and the early response in such an escalation.

- Natural hazards like cyclones, Tsunamis, earthquakes and Oil Spills have been discussed, and an action plan has been formulated for early response to such events.
- Various stages in decommissioning offshore oil and Gas projects and related environmental impacts have been identified. The best minimum footage for the environment has been suggested.
- The possibility of Naturally Occurring Radioactive Materials (NORM) during the project activity has been identified, and its Mitigation measures were suggested.
- IUCN Red List Marine species in the Indian Ocean Waters has been listed; if any of these organisms were identified in the project domain during the survey, a detailed biodiversity action should be prepared to conserve the organism and its habitat.
- Environmental Management Plan (EMP) discussed HSE-MS, standards, procedures, programmes, practices, guidelines, goals, and targets must be established and where necessary, agreed with regulators and other stakeholders. Monitoring and auditing will show how well an operation performs and provide a measure of effectiveness. Checklist/SOP and Guidelines for the operators engaging E&P activities beyond 12 nm have been prepared to adopt better environmental management to negate adverse impact due to project activity.
  - Guidelines for Oil and Gas fields beyond 12 nautical miles
  - Guidelines for Seismic operations
  - Guidelines for Exploration and appraisal drilling
  - Guidelines for Development and Production
  - Guidelines for the Decommissioning of offshore oil and gas structures
  - Guidelines for Environmental Monitoring program
  - Guidelines for discharge of gaseous emissions

  - Guidelines to the Management Techniques for Drilling Wastes and Production Effluents
  - Guidelines for Oil Spill Response Plan
- Considering the paucity of data pertaining to the region of Kerala-Konkan, Mahanadi and Andaman sedimentary basins around India, NIO recommends that more studies should be undertaken to generate adequate baseline environmental data to facilitate the preparation of the EIA report.
- The study also recommends some actionable items for all the blocks beyond 12 nm for E&P activities, such as Exploratory surveys, Exploratory/appraisal Drilling, Development/Production phase, Operation Phase and Decommissioning Phase.

Chapter 1: Introduction

1.1 Introduction

To enhance the hydrocarbon (HC) exploration activities towards the country's growing energy requirements, the Ministry of Petroleum and Natural Gas is formulating a proposal for international bidding rounds of oil/gas fields for appraising a significant volume of offshore sedimentary basin areas within the Exclusive Economic Zone (EEZ). While, there is a need to enhance oil and gas production, including EEZ areas, environmental safeguards for protecting marine ecology and preventing marine pollution are essential. The environmental clearance for projects within the territorial water is considered by the Ministry of Environment, Forest and Climate Change (MoEFCC); however, the approval beyond territorial water is not within the jurisdiction of MoEFCC. International standards and benchmarks define the rights and responsibilities of nations, w.r.t. their use of the world's oceans, establishing guidelines for businesses, the environment, and the management of marine natural resources. Although, environmental standards and safeguards are in place within the territorial waters, it is imperative to lay down the policy for protecting marine ecology and preventing marine pollution in offshore areas beyond 12 nautical miles (NM) to address environmental concerns and incorporate them into the Management Plans adequately. DGH envisions introducing some efficient, standardized checklist/SOPs for compliance by the Operator on Self-Regulated/Certification basis for the HC exploration in the areas beyond 12 NM.

India has an estimated sedimentary area of 3.36 million sq. km, comprising of 26 sedimentary basins, out of which, 1.63 million sq km area is in the land, shallow offshore up to 400 m isobaths with an aerial extent of 0.41 million sq. km and deep water beyond 400 m isobaths with the sedimentary area of 1.32 million sq. km as per renewed categorization of sedimentary basins. Over the last few years, there has been a significant forward leap in exploring the hydrocarbon potential of the sedimentary basins of India. The unexplored area has come down significantly due to the surveys carried out by DGH in unexplored/poorly explored areas of the country by including deep waters and acreages awarded for exploration under NELP/OALP rounds. Concerned efforts are continuously being made to reduce the unexplored area further.

Office of the Directorate General of Hydrocarbons, Ministry of Petroleum & Natural Gas, Government of India, requested CSIR- NIO to carry out the Study of Environmental Impact of Petroleum Exploration and Developmental projects in offshore areas beyond 12 Nautical miles and suggest means for protecting marine ecology and prevention of marine pollution through a proper monitoring and mitigation plan.

1.2 Scope of work

Baseline information of the marine environment for the proposed work has been prepared by CSIR- NIO by exploring various marine EIA reports, published articles, and other available data sources, which will portray the present environmental condition that prevails over the Indian EEZ.

Environmental Impact Assessment assesses the possible impact, whether positive or negative, that a proposed project may have on the environment and the natural, social and economic aspects, i.e., aiming at “Sustainable Development” due to the project activities. The possibilities of modifying these statutory requirements, which are applicable beyond 12 Nautical miles, will be explored by considering offshore environmental conditions and practical options for ensuring Marine Environment protection. Further, the applicability of international regulations, such as 1. The UN Convention on the Law of the Sea 1982, 2. The Barcelona Convention, 1976, 3. OPRC Convention, 1990, 4. OSPAR Convention, 1992, 5. The Espoo Convention 2001 and the Kiev Protocol 2003, 6. Kyoto Protocol (1997/2005), 7. Paris Agreement 2016 to prepare a comprehensive report that protects the marine environment beyond 12 Nautical miles during the oil exploration similar to GIPIP (Good International Petroleum Industry Practices) will also be explored.

Due to the oil exploration activities, the project’s likely impact on the environment will be assessed based on the baseline data collection and the oil/gas exploration methods. Mitigation methods to minimise the impact of the project on the marine environment will be prepared. All mitigation and avoidance measures will be designed or formulated to negate the predicted possible and probable impacts described for all relevant environmental parameters, including ecological and physical, biological, geological, and chemical components. The nature and type of the expected potential impacts on the physical, biological, and chemical components will be assessed to the extent possible during the whole process. Further, international regulations on mitigation measures will address all possible environmental enhancement measures in the report, which generally could improve the project's adverse impact

The environmental monitoring program aims to formulate a systematic, site-specific plan to monitor the environmental parameters within the impact area during and after commissioning the project. This would aid in assessing the effectiveness of Mitigation and environmental protection measures implemented for the proposed project based on the existing ecological scenario and the probable environmental impacts appraisal. The assessment of impacts (primary surveys, secondary surveys, field visits, and stakeholder consultations) relating to various environmental components will be utilized. For each environmental attribute, the monitoring plan will specify the monitoring parameters, the location of monitoring sites, frequency and duration of monitoring, and the applicable standards, implementation, and supervising responsibilities. The efficacy of the mitigation measures is followed during the preparatory and operational phases of the oil/gas exploratory works, which can be assessed and revised based on the monitored results. The environmental attributes to be monitored during the preparatory and operational phases of the project, specific description, and technical details of environmental monitoring, including the monitoring parameters, methodology, sampling locations, and frequency of monitoring, will be prepared in detail in the report.

Risk Analysis (RA) is an extensive hazard analysis that involves identifying and quantifying hazards related to the oil field. RA consists of assessing the damage, injuries, and financial costs likely to be sustained in a geographic area over a given period. The guidelines related to the Oil Spill Contingency Plan will be delineated and reviewed by the Indian Coastal Guard. According to the National Oil Spill Disaster Contingency Plan (NOS-DCP), this Oil Spill Contingency Plan will be prepared.

The preparation of the impact assessment report will be based on all the above considerations and all possible impact assessment stages with a broad vision of sustainable development.

1.3 Objectives

The proposed study of Environmental Impacts of Petroleum Exploration and Developmental projects in offshore areas beyond 12 Nautical miles, including monitoring & Mitigation Measures, in general, will have the following broad objectives:

(I) Baseline data of the marine environment by comprehensive analysis of Marine EIA/ monitoring work carried out in the oil fields within the EEZ of India in deep and shallow offshore blocks.

(II) To document present legal/statutory requirements related to environmental impact within & beyond 12 NM for ensuring the protection of the Marine Environment

(III) Anticipated Impact of the project on the marine environment and its mitigation methods

(IV) Environmental monitoring, risk assessment, and contingency plan

(V) To suggest SOP for adoption by operators for addressing the environmental concerns.

Chapter 2: The Law- Oil and Gas Sector

2.1 Introduction

In India, overlapping responsibilities and jurisdiction in the maritime sector and the absence of a central coordinating body have inadvertently led to the exploitation of the provisions governing the law of the sea. Activities in the maritime zones of India are managed by various governmental ministries, such as the Ministry of Shipping, Road Transport and Highways, External Affairs, Defence, Earth Sciences, Petroleum & Natural Gas Law and Justice, etc., with differing rights, interests, mandates and responsibilities. Which has led to the drafting and enactment of very general worded statutes in the maritime sector, which has subsequently led to frail enforcement provisions, which are a bit of a stumbling block of this chapter

2.2 The Administration

India has a federal constitution, where legislative powers are distributed between the central and the state legislatures. Under Article 246 of the Constitution of India, the regulation and development of oil fields, mineral oil resources, petroleum, and petroleum products fall within the jurisdiction of the Union Parliament, i.e. the federal legislative body of India. On the other hand, the state governments have the power to regulate matters such as the right of use and access to land, labour, water, and local government.

2.2.1 Legislation - Domestic Oil and Gas

The following are the critical pieces of legislation pertaining to the upstream oil and gas sector:

a. The Oilfields (Regulation and Development) Act 1948 (the Oilfields Act, 1948): the Oilfields Act is the primary legislation governing the upstream oil and gas sector. The Oilfields Act incorporates provisions relating to licensing and leasing of oil and gas blocks. In this regard, the Oilfields Act provides for rule-making power of the Indian government concerning mining leases and mineral oil development (Oilfield Act, Section 5 and 6) and royalty rates to be paid by the holder of a mining lease; (Oilfield Act, Section 6A)

b. The Petroleum and Natural Gas Rules 1959 (the PNG Rules): the PNG Rules enacted under the Oilfields Act provide detailed provisions for granting licences and leases for offshore and onshore areas. The PNG Rules prohibit prospecting or mining of petroleum except in pursuance of a PEL or a PML granted under the PNG Rules (PNG Rules, 4). By an amendment of July 2018, the definition of 'petroleum' under the PNG Rules has been amended to include shale and other hydrocarbons. The amendment is in line with the HELP regime under which the licensing for conventional and non-conventional hydrocarbons has been unified;

c. The Mines Act 1952 (the Mines Act) and Oil Mines Regulations 2017: these detail provisions relating to workers' health, safety, and welfare in oil mines. The Mines Act also highlights the duties of owners, agents and managers and the penalties in contravention of the provisions.

d. The Petroleum and Natural Gas (Safety in Offshore Operations) Rules 2008 (the PNG Safety Rules): the PNG Safety Rules have been framed under the Oilfields Act and prescribe safety standards and measures to be taken for the safety of offshore oil and gas operations. The PNG Safety Rules provide the manner of preparing information and records, various consents and intimations concerning the offshore installations, safety, health and environment measures, etc., and prescribe the penalties for infringement of the PNG Safety Rules.

Apart from the above legislation, the Indian government, from time to time, promulgates policies, standards, directives and guidelines for governing various aspects of the upstream oil and gas sector.

2.2.2 Legislation - International Oil and Gas

2.2.2.1 MARPOL

The International Convention for the Prevention of Pollution from Ships (MARPOL) is the leading international convention covering the prevention of marine environment pollution by ships from operational or accidental causes. The MARPOL

Convention was adopted on 2nd November 1973 at the IMO. The Protocol of 1978 was adopted in response to tanker accidents in the 1976–1977 period. In 1997, a Protocol was adopted to amend the Convention, and a new Annex VI was added, which entered into force on 19th May 2005. The Convention includes regulations to prevent and minimise pollution from ships, both accidental pollution and routine operations, with several technical Annexes.

The main objective of MARPOL is to reduce the discharge of oil products by maritime traffic during usual operations. Certain tankers are allowed to discharge a limited amount of oil contained in ballast water and tank washings into the sea. Regulation 9 of MARPOL 73/78 limits the amount of discharge of oil into the sea to 1/30,000 of the total volume of the crude oil cargo. The additional requirement is that the oil content of the discharged effluent cannot exceed 10 ppm (1 mg/l is approximately 1 ppm) and, in effect, limits the operational discharge to amounts much less than the specified maximum value. In addition, the release of oil-bearing wastewater within 50 nautical miles from the shoreline is strictly prohibited.

Under regulation 13 of MARPOL 73/78, oil tankers of 20,000 tonnes deadweight and above are required to have segregated ballast tanks (SBTs), dedicated clean ballast tanks (CBTs), and/or clean oil washing systems (COW), depending on the vessels type, when they were built, and their size. These ballast tanks are completely separated from the cargo and fuel oil systems and are exclusively allocated to carry ballast water. This system greatly reduces the likelihood of oil-containing ballast water discharge, and tankers with a CBT system have a pipe system connected with the crude oil cargo pump and piping system. Discharge of fuel oil sludge from machinery room is strictly forbidden anywhere in the world by MARPOL, and the sludge oil should be discharged at reception facilities in ports.

The Convention includes regulations mainly aimed at preventing and minimizing pollution from ships - both accidental pollution and routine operations -

and currently has six technical Annexes. Particular areas with strict controls on operational discharges are included in most Annexes.

Annex I Regulations for the Prevention of Pollution by Oil (entered into force 2 October 1983)

Covers prevention of pollution by oil from operational measures as well as from accidental discharges; the 1992 amendments to Annex I made it mandatory for new oil tankers to have double hulls and brought in a phase-in schedule for existing tankers to fit double hulls, which was subsequently revised in 2001 and 2003.

Annex II Regulations for the Control of Pollution by Noxious Liquid Substances in Bulk (entered into force 2 October 1983)

Details the discharge criteria and measures for the control of pollution by noxious liquid substances carried in bulk; some 250 substances were evaluated and included in the list appended to the Convention; the discharge of their residues is allowed only to reception facilities until certain concentrations and conditions (which vary with the category of substances) are complied with. In any case, no discharge of residues containing noxious substances is permitted within 12 miles of the nearest land.

Annex III Prevention of Pollution by Harmful Substances Carried by Sea in Packaged Form (entered into force 1 July 1992)

Contains general requirements for issuing detailed standards on packing, marking, labelling, documentation, stowage, quantity limitations, exceptions, and notifications. For this Annex, "harmful substances" are those substances that are identified as marine pollutants in the International Maritime Dangerous Goods Code (IMDG Code) or which meet the criteria in the Appendix of Annex III.

Annex IV Prevention of Pollution by Sewage from Ships (entered into force 27 September 2003)

Contains requirements to control pollution of the sea by sewage; the discharge of sewage into the sea is prohibited, except when the ship has in operation an approved sewage treatment plant or when the ship is discharging comminuted and disinfected sewage using an approved system at a distance of more than three nautical miles from the nearest land; sewage which is not comminuted or disinfected has to be discharged at a distance of more than 12 nautical miles from the nearest land.

Annex V Prevention of Pollution by Garbage from Ships (entered into force 31 December 1988)

Deals with different types of garbage specify the distances from land and how they may be disposed of; the most important feature of the Annex is the complete ban imposed on the disposal into the sea of all forms of plastics.

Annex VI Prevention of Air Pollution from Ships (entered into force 19 May 2005)

Sets limits on sulphur oxide and nitrogen oxide emissions from ship exhausts and prohibits deliberate emissions of ozone-depleting substances; designated emission control areas set more stringent standards for SOx, NOx and particulate matter. A chapter adopted in 2011 covers mandatory technical and operational energy efficiency measures aimed at reducing greenhouse gas emissions from ships.

2.2.2.2 Paris Agreement 2015

At Conference of Parties (COP) 21 in Paris, Parties to the United Nations Climate Change Framework Convention (UNFCCC) reached a landmark agreement to combat climate change and to accelerate and intensify the actions and investments needed for a sustainable low carbon future. The Paris Agreement builds upon the Convention and – for the first time – brings all nations into a common cause to undertake ambitious efforts to combat climate change and adapt to its effects, with enhanced support to assist developing countries to do so. As such, it charts a new course in the global climate effort.

The Paris Agreement's central aim is to strengthen the global response to the threat of climate change by keeping a global temperature rise this century well below 2 °C above pre-industrial levels and to pursue efforts to limit the temperature increase even further to 1.5 degrees Celsius. Additionally, the agreement aims to strengthen the ability of countries to deal with the impacts of climate change. Appropriate financial flows, a new technology framework, and an enhanced capacity-building framework will be put in place to reach these ambitious goals, thus supporting action by developing countries and the most vulnerable countries in line with their national objectives. The Agreement also provides for enhanced transparency of action and support through a more robust transparency framework.

The Paris Agreement adopted crucial areas necessary to combat climate change. Some of the key aspects of the agreement are set out below:

- Long-term temperature goal (Art. 2) – The Paris Agreement, in seeking to strengthen the global response to climate change, reaffirms the goal of limiting global temperature increase to well below 2 °C while pursuing efforts to limit the increase to 1.5 °C.
- Global peaking (Art. 4) –To achieve this temperature goal, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing peaking will take longer for developing country Parties so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of the century.
- Mitigation (Art. 4) – The Paris Agreement establishes binding commitments by all Parties to prepare, communicate and maintain a nationally determined contribution (NDC) and to pursue domestic measures to achieve them. It also prescribes that Parties shall communicate their NDCs every 5 years and provide information necessary for clarity and transparency. Each successive NDC will represent a progression beyond the previous one and reflect the highest possible ambition to set a firm foundation for higher ambition.

Developed countries should continue to take the lead by undertaking absolute economy-wide reduction targets while developing countries should continue enhancing their mitigation efforts and are encouraged to move toward economy-wide targets over time in the light of different national circumstances.

- Sinks and reservoirs (Art.5) –The Paris Agreement also encourages Parties to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases as referred to in Article 4, paragraph 1(d) of the Convention, including forests.
- Market and non-market (Art. 6) – The Paris Agreement establishes a mechanism to mitigate greenhouse gas emissions, support sustainable development, and define a framework for non-market approaches to sustainable development.
- Adaptation (Art. 7) – The Paris Agreement establishes a global goal to significantly strengthen national adaptation efforts – enhancing adaptive capacity, strengthening 0resilience and reduction of vulnerability to climate change – through support and international cooperation. It also recognizes that adaptation is a global challenge faced by all. All Parties should submit and update an adaptation communication periodically on their priorities, implementation and support needs, plans and actions. Developing country Parties will receive enhanced support for adaptation actions.
- Loss and damage (Art. 8) – The Paris Agreement significantly enhances the Warsaw International Mechanism on Loss and Damage, which will develop approaches to help vulnerable countries cope with the adverse effects of climate change, including extreme weather events slow-onset events such as sea-level rise. The Agreement now provides a framework for Parties to enhance understanding, action, and support regarding loss and damage.
- Support (Art. 9, 10 and 11) – The Paris Agreement reaffirms the obligations of developed countries to support the efforts of developing country Parties to

build clean, climate-resilient futures, while for the first time encouraging voluntary contributions by other Parties. The provision of resources should also aim to achieve a balance between adaptation and mitigation. In addition to reporting on finance already provided, developed country Parties commit to submit indicative information on future support every two years, including projected levels of public finance. The agreement also provides that the Financial Mechanism of the Convention, including the Green Climate Fund (GCF), shall serve the Agreement. International cooperation on climate-safe technology development and transfer and building capacity in the developing world are also strengthened: a technology framework is established under the agreement, and capacity building activities will be enhanced through, inter alia, enhanced support for capacity building actions in developing country parties and appropriate institutional arrangements.

- Transparency (Art. 13) – The Paris Agreement relies on a robust transparency and accounting system to provide clarity on action and support by Parties, with flexibility for their differing capabilities. In addition to reporting information on mitigation, adaptation and support, the agreement requires that the information submitted by each Party undergoes international review. The Agreement also includes a mechanism that will facilitate implementation and promote compliance in a non-adversarial and nonpunitive manner and report annually to the COP.

- Global Stocktake (Art. 14) – A "global stocktake" to take place in 2023 and every five years thereafter will assess collective progress toward meeting the purpose of the Agreement in a comprehensive and facilitative manner. Its outcomes will inform Parties in updating and enhancing their actions and support and enhancing international cooperation.

2.2.2.3 SOLAS Convention

The first international conference on the safety of life at sea was held in London in January 1914. the SOLAS Convention would certainly have been decisive, years later, to establish the International Maritime Organization. The first SOLAS Convention was adopted on 20 January of 1914, with a view to entry into force in July of 1915. However, it came into force later because of the war that broke out in Europe. Since then, there have been four other SOLAS conventions: the second was adopted in 1929 and entered into force in 1933, the third was adopted in 1948 and entered into force in 1952, the fourth was adopted in 1960, already under the auspices of the IMO and entered in force in 1965, and the current version was adopted in 1974 and entered into force in 1980. The SOLAS version of 1960 was the first major task for IMO since the Organization's founding and represented a significant step in the modernisation of the regulations and in the monitoring of technical developments in the shipping industry.

SOLAS Protocol 1978 covers the important amendments pertaining to tanker safety and pollution prevention, particularly the requirement and acceptable exemption for inert gas systems and the requirement for radar and steering gear control systems. SOLAS Protocol 1988 covers the changes to SOLAS Chapter V, such as the details of the navigational systems and equipment referred to in the records of equipment attached to the certificates and also introduces a new Harmonized System of Survey and Certification (HSSC) to harmonize two (2) Conventions, namely: the International Convention on Load Lines and the International Convention for the Prevention of Pollution from Ships, 1973 as modified by the Protocol of 1978 (MARPOL 73/78).

SOLAS Convention applicable for,

The inspection and survey of ships are carried out by officers of the country in which the ships are registered.

A passenger ship shall be subjected to the following surveys:

a. A survey before the ship is put in service;

b. A periodical survey once every twelve months; and

c. Additional surveys, as the occasion arises.

In the case of cargo ships, after the initial survey, the ship is subject to a subsequent survey:

a. Every two years in respect of life-saving appliances and other equipment;

b. Once every year in respect of radio installation; and

c. In respect of hull, machinery and equipment, at such intervals, as the Administration may consider necessary to ensure that the ship's condition is satisfactory.

Other surveys include:

a. Surveys of life-saving appliances and other equipment of cargo ships;

b. Surveys of radio and radar installations of cargo ships; and

c. Surveys of hull, machinery and equipment of cargo ships.

After any survey of the ship, no change shall be made in the structural arrangements, machinery, equipment, etc., covered by the survey, without the sanction of the Administration.

The SOLAS Convention shall not apply to the following:

a. Ships of war and troopships

b. Cargo ships of less than 500 gross tonnage

c. Ships not propelled by mechanical means

d. Wooden ships of primitive built

e. Pleasure yachts not engaged in trade

f. Fishing vessels

2.2.2.4 Treaties

India is a signatory to the Convention on the Recognition and Enforcement of Foreign Arbitral Awards 1958 (the New York Convention) and the Geneva Convention on the Execution of Foreign Arbitral Awards 1927. If a party receives a binding award from a country that is a signatory to either of the conventions and is notified as a convention country by India, the award would then be enforceable in India subject to the satisfaction of the Indian courts of the enforceability of such awards. For enforcement of a foreign award, under either of the aforementioned conventions, the enforcing party must fulfil certain requirements prescribed under the (Indian) Arbitration and Conciliation Act 1996, such as the production of the arbitration award, etc.

2.2.3 Regulation

The following are the key regulatory and administrative agencies concerned with the upstream oil and sector in India:

a. The Ministry of Petroleum and Natural Gas (MoPNG): this is the nodal ministry at the federal government level that supervises the exploration and production activities of petroleum and natural gas and administers various pieces of legislation, including the Oilfields Act;

b. The Directorate General of Hydrocarbons (DGH): according to its resolution dated 8th April 1993, the MoPNG established the DGH to regulate and oversee the upstream activities in the petroleum and natural gas sector and advise MoPNG in these areas. The primary responsibilities of the DGH include technical advisory to the MoPNG concerning exploration and optimal exploitation of hydrocarbons and adequacy of development plans proposed by companies, review of exploration programmes, reassessment of reserves as discovered and estimated by companies and advising the Indian government on formulation of safety norms and regulations in oilfield operations. The DGH is not an independent regulator and works under the administrative control of the MoPNG;

c. The Oil Industry Safety Directorate (OISD): the OISD is the safety regulator for offshore blocks operating under the MoPNG. It has been designated as the 'competent authority' for implementation of the Petroleum Safety Rules and exercises powers and functions under the PNG Safety Rules;

d. The Directorate General of Mines Safety (DGMS): this is the regulatory agency under the Indian government's Ministry of Labour and Employment and is responsible for the safety of the onshore blocks; and

e. The Petroleum and Natural Gas Regulatory Board (PNGRB): this is the regulator for the midstream and downstream sector and has been empowered to regulate the refining, storage, transportation, distribution, marketing and sale of petroleum, petroleum products and natural gas. Therefore, transportation and evacuation of petroleum by pipelines outside the delivery point is subject to the PNGRB's oversight and regulations concerning, among others, tariffs and technical safety standards.

Accordingly, while the Indian government executes the contract for exploration and production of hydrocarbons, the licences and approvals for undertaking activities relating to exploration and production for onshore blocks must be obtained from state governments. For the offshore blocks, the Indian government has licensing powers.

Table 2. 1 Regulatory framework for environmental protection and safety in offshore oil and gas

Regulatory bodies, agencies, departments	Function	Important applicable laws, acts, rules, standards, regulations, policies etc. (as amended or updated periodically)	Relevance for environmental protection and offshore oil activities
Directorate General of Hydrocarbons (DGH)	• A key regulator (and promoter) under the Ministry of Petroleum and Natural Gas of offshore oil development. • Supervisor of oil block allotment, exploration and production through various auctions and agreements. • Establishes contracts for exploration and development with Public and private players. • Charged with monitoring and enforcing numerous rules and also acts as an advisory body to the government. • Also researches oil prospects and	• Petroleum Act • Petroleum and Natural Gas Rules • The Oilfields Act and Rules • The Petroleum Pipelines Act and Rules • The Oil Industry Act • New Exploration Licensing Policy • Production Sharing Contracts • New policies being considered for revenue models and release of open acreage.	Operators bid on access to exploration and development blocks and enter into production contracts with DGH; whether exploration or production is environmentally sound, feasible or otherwise appropriate is determined after the contracting process.

	collects data.		
Oil Industry Safety Directorate (OISD)	• In charge of formulating safety standards to reduce risk of accident and hazard to employees, investments and environment; in this aspect oversees all aspects of petroleum and natural gas industry, including exploration and drilling, processing, transport, refining, storage, marketing, etc.	• More than 100 OISD-developed Safety Standards • Petroleum and Natural Gas (Safety in Offshore Operations) • Rules Oilfields (Regulation and Development) Act and Rules	Some safety standards govern specific practices to reduce the risk of environmental hazards, spills and the like. Safety management plans must be developed for each project, and consent for offshore installations must formally be obtained for carrying out exploration, production and development according to OISD rules.
Ministry of Environment, Forest and Climate Change (MoEFCC)	• Chief regulatory ability is to grant environmental clearance for various "projects" based on an impact assessment and terms of reference decided by an expert committee. • Approves coastal zone clearance as well for any near-shore or onshore facilities. • Also monitors compliance	• Environment (Protection) Act and Rules • Environmental Impact Assessment Notification •Wildlife Protection Act (WPA) • Ozone Depleting Substances Regulation and Control Rules	Oil and gas developers must adhere to the environmental clearance process, which includes generating an environmental impact assessment, public consultation, mitigation plan, emergency management plan and other monitoring and regulation. MoEFCC oversees and grants final clearance. Developers are

	statements from operators.		required to submit six-month statements of compliance. MoEFCC also monitors compliance with the WPA, which protects scheduled marine biotas such as various fish, marine mammals, corals, turtles and sea cucumbers.
Coastal Zone Management Authorities (CZMA)	• Gives approval and recommendations for the MoEFCC clearance when projects have coastal zone components.	• Coastal Regulation Zone (CRZ) Notification	The CZMA governs prohibited or constrained activities nearest to shore and in various sensitive areas. Notably, pipelines and some petroleum and gas storage structures are allowed in some sections of the CRZ. In addition, CRZ-IV covers the entirety of state territorial waters (up to 12 miles from the shoreline)
Central Pollution Control Board (CPCB)	• Regulates various forms of pollution and maintains standards for numerous types of pollutants that operations may generate	• The Air (Prevention and Control of Pollution Act) • The Water (Prevention and Control of Pollution) Act • Hazardous	Operators must conform to central and state pollution and emissions norms and standards. CPCB and SPCB jurisdictions depend on the location of installation and pollution incidents.

		Waste (Management, Handling and Transboundary Movement) Rules • Manufacture Storage and Import of Hazardous Chemicals Rules • Environmental (Protection) Act and Rules • The Noise Pollution (Regulation & Control) Rules • International Convention for the Prevention of Pollution from Ships (MARPOL)	Fines and payments are possible for violations. Hazardous wastes, in particular, invoke many rules and may require permissions related to collection, storage and disposal. Specific environmental protection standards exist for liquid discharge from the oil and gas industry. International MARPOL rules also apply for some pollution discharges.
State Pollution Control Boards (SPCB)	• Typically oversees adherence to numerous central and state environmental regulations; also give consent to operations within near-shore waters. • May also investigate marine pollution near to shore.	• The Air (Prevention and Control of Pollution) Act • The Water (Prevention and Control of Pollution) Act • Hazardous Waste (Management, Handling and Transboundary Movement) Rules	Operators require specific consent to establish and operate from SPCB. State regulations set similar or additional standards to central pollution requirements. Laws also may permit to punish or fine. Operators also make annual cess payments to the SPCB (or CPCB) for water

		• Environmental (Protection) Act and Rules • Manufacture Storage and Import of Hazardous Chemicals Rules • The Bio-Medical Waste (Management and Handling) Rules • The Noise Pollution (Regulation & Control) Rules • International Convention for the Prevention of Pollution from Ships (MARPOL) • State regulations that often are similar to central regulations.	consumption, wastewater and pollution. International MARPOL rules also apply for some pollution discharges.
State environment / ecology / forest departments	• Typically responsible for oversight of any protected areas as well as other rules related to biodiversity and conservation	• Wildlife Protection Act • Forest (Conservation) Act • State rules and laws	Rules governing marine and terrestrial protected areas (parks, reserves and sanctuaries) may affect activities or set up protection regimes for specific coastal habitats such as mangroves. The WPA also protects

			some scheduled marine biota such as several species of fish, corals, sea cucumbers and turtles.
Department of Animal Husbandry, Dairying & Fisheries (DAHDF)	• Under the Ministry of Agriculture, DAHDF establishes rules specifically to protect and govern fisheries, primarily beyond individual state territorial waters. May also coordinate or influence rules within state waters.	• Indian Fisheries Act • Marine Fishing Regulation Act (and Rules)	While generally having no specific authority over offshore oil and gas, potential cooperation between agencies may restrict some activities (seismic operations, for example) that may specifically impact fisheries. Departments also regulate fisheries and may do so to benefit oil and gas operators. Theoretically, fisheries governing bodies may be involved in compensation determination in the case of fishery losses.
State fisheries departments	• Loosely regulates fishing operations in territorial waters. Legislation is typically modelled after the framework laid down by DAHDF.	• State marine fishing acts	State departments may monitor impacts of oil operations, specifically within state territorial waters. While generally having no specific authority over offshore oil and

			gas, potential cooperation between agencies may restrict some activities (seismic operations, for example) that may specifically impact fisheries. Theoretically may be involved in compensation determination in the case of fishery losses.
National Green Tribunal (NGT)	• Investigates and decides legal cases related to environmental protection, resources and legal rights. Able to order compensation or relief to people who suffer environmental losses or damages	• National Green Tribunal Act	The NGT is the likely arbiter of disputes arising from environmental impacts, damages or pollution from oil and gas operations.
Indian Coast Guard	• Responsible for monitoring and security activity within the EEZ, protecting ocean wealth and enforcing laws at sea. • May work with the Indian Navy and may also respond in case of	• Coast Guards Act • National Oil Spill Contingency Plan	Coast Guards may enforce other rules (as far as possible), including prohibitions on activities. The Coast Guards are also responsible for coordinating and implementing oil spill response with roles in site-specific plans developed by every

	emergency or disaster scenarios.		oil facility
Indian Navy Offshore Defense Advisory Group	• Coordinates examine and propose appropriate security in offshore water, particularly related to shipping traffic. • Also inspects and clears all ships employed in offshore work. • Naval forces may also take action or command roles in security and patrol.	• Maritime Zones of India Act	All vessels used undergo a security inspection at least one month in advance of deployment that should also theoretically lead to some environmental protection by ensuring seaworthy ships are used safely. Formal defence clearance is also required prior to the start of any offshore activities.
Ministry of Shipping	• Regulates the shipping and port industries.	• Indian Port Act • Maritime Zones of India Act • Merchant Shipping Act • International Convention for the Prevention of Pollution from Ships (MARPOL) • International Convention for the Safety of Life at Sea	State-level maritime boards manage navigation for vessels, including oil and gas transport, one of the largest potential environmental hazards involved in offshore oil and gas production.
State Department of Ports	• Governs ports where projects may be shipped,	• Indian Port Act • Maritime Zones of India Act	Port authorities (including local bodies) may

	including a single point mooring system (SPM) for oil or gas delivery. It also regulates navigation safety and traffic at sea.	• Merchant Shipping Act • State port and shipping regulations	supervise activity in addition to state departments, and operators must comply with all SPM and port guidelines.
Directorate General of Mines Safety	• In addition to OISD, the directorate is in charge of safety and health standards in the "upstream" component of mining (and oil production)	• Mines and Minerals Development and Regulation Act • Oil Mines Regulations • Manufacture Storage and Import of Hazardous Chemicals Rules	Periodic reporting of safety-related information is required under regulations.
Petroleum Explosives and Safety Organization	• Subsidiary to the Ministry of Commerce and Industry. • Responsible for numerous regulations related to the use and storage of explosives or potentially explosive material	• The Explosives Act and Rules • The Petroleum Act and Rules • The Static and Mobile Pressure Vessels Rules, • The Gas Cylinder Rules, •The Manufacture, Storage and Import of Hazardous Chemicals Rules	Operators require permits and must comply with rules governing the use of explosives for drilling activities and capping and decommissioning. Storage of petroleum and gas products also require licenses under many conditions.
Central Crisis Group	• They are composed of various officials that manage the	• Chemical Accidents (Emergency	Operators must conform to the CCG plans' requirements

	response to a chemical disaster or accident.	Planning, Preparedness and Response) Rules	and have their disaster management protocols.
Atomic Energy Regulatory Board	• Governs the handling and use of radioactive materials and sources.	• Atomic Energy Act • Environmental Protection Act • Atomic Energy Radiation Protection Rules	Oil and gas drillings typically use radiation or radioactive materials in "well logging," a technical process that records the drilled bore's various geological and structural features. Operators must obtain licenses for the use of such materials and procedures.
Directorate General of Civil Aviation (DGCA)	• It oversees civil air standards, regulations and approvals.	• The Aircraft Act and Rules	Oil stations and ships require prior approval for the operation of helipads from DGCA. Chimneys higher than 30 meters for air emissions also require approval.
Other	• Other laws or regimes — from the constitution, court precedent, common law or local regulations may govern aspects of the oil and gas exploration and production process.	• Constitution of India • Public Liability Insurance Act	Articles 21, 48A and 51A guarantee the right to life and a healthy environment as well as enshrining responsibilities of states and citizens to safeguard and improve the environment. Public Interest Litigation has become a

			constitutional means to challenge social and environmental injustice. Oil operators are also required to meet insurance regulations to cover their potential actions in case of environmental harm.
Sources: IL&FS Ecosmart Ltd., "Technical EIA guidance manual for offshore and onshore oil and gas exploration, development and production," Ministry of Environment and Forests Series (2010) [online] http://environmentclearance.nic.in/writereaddata/FormA/HomeLinks/TGM_Offshore%20Onshore_010910_NK.pdf; ERM India Private Ltd., "Environmental impact assessment of proposed oil and gas development in existing Ravva offshore field, PKGM-1 block, off Surasaniyanam in Bay of Bengal, East Godavari District, Andhra Pradesh, India," (Cairn India Ltd. EIA reports, 2014), 1-725; Madduri, V "An environmental assessment of oil and gas exploration," (EERC Working Paper Series: IPP- 8, Environmental Economics Research Committee, 2003); numerous websites of various departments, agencies and organizations of the Government of India.			

2.2.4 Licensing

The Indian government has been empowered to grant PEL or PML in respect of any land vested in the union or in offshore areas, and the state governments have the power to grant PEL or PML over the lands vested with the state government. The Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act 1976 provides for granting a licence by the Indian government to explore and exploit the resources of the continental shelf and exclusive economic zone (Act of Parliament, 1976).

The Indian government, from time to time, has adopted various licensing regimes intending to enhance domestic production. As a general principle, an acreage awarded under a licensing regime continues to be regulated under such a regime, and any subsequently amended regime applies to acreages granted under such regime (Strong, C. B. (Ed.), 2020). Therefore, different blocks are governed by different licensing regimes (depending on when they were awarded). The four broad categories of a licensing regime that are presently applicable are discussed below.

1 Nomination regime (for blocks awarded till the late 1970s)

Under this regime, the petroleum exploration licence (PEL) was granted to the two national oil companies – Oil India Limited (OIL) and Oil and Natural Gas Corporation Limited (ONGC) on a nomination basis.

2 Pre-NELP regime (for blocks awarded between 1980 and 1995)

In the pre-NELP discovered field or development rounds of the small, medium-sized and discovered fields (proven reserves as discovered by ONGC and OIL), petroleum mining lease (PML) was granted to private parties for these fields. The Indian government has signed 28 contracts for 29 discovered fields. Out of these, 21 contracts are active (MoPNG Report). During the pre-New Exploration Licensing Policy (NELP) Exploration Rounds, 28 exploration blocks were awarded to private companies. OIL and ONGC were given the right to participate in the blocks after discovery. Currently, 11 pre-NELP production sharing contracts (PSCs) are active (DGH report, 2019-20).

3 NELP regime (for blocks awarded between 1997 and 2010)

The new exploration licensing policy (NELP) was implemented in 1999. where blocks were awarded to companies (including private and foreign companies) through an international competitive bidding process. The NELP regime was based on the 'production sharing model' (i.e., the Indian government is paid a part of the profits after deducting the costs incurred by the contractor). The percentage of profit proposed to be paid by the contract was a biddable criterion. About 254 production-sharing contracts were signed under nine licensing rounds; out of these, 45 are active (MoPNG report, 1999). One of the main issues with the regime is that there is an excessive oversight by the Indian government (through the management committee), as the costs incurred by the contractors have to be approved by the Indian government (DGH report 2019-20).

4 HELP Regime (for blocks to be awarded after 2016)

To further attract private participation and foreign investments, in 2016, the Indian government introduced the hydrocarbon exploration and licensing policy (HELP, Hydrocarbon exploration and licensing policy, 2016).

The key features of HELP include:

a. Uniform licence for exploration and production of all forms of hydrocarbon including non-conventional hydrocarbons such as shale gas, coal-bed methane, tight gas, gas hydrates, etc.;
b. An open acreage licensing policy (OALP) under which prospective bidders have the option to carve out exploration blocks;
c. A revenue-sharing model;
d. Marketing and pricing freedom for the crude oil and natural gas produced;
e. Reduced royalty rates; and
f. Exploration rights on all of the retained areas for the entire life of the contract.

In February 2019, the government approved a 'Policy framework on reforms in exploration and production of oil and gas' pursuant to which the parameters under the policy are applicable from the fourth bidding round under OALP. The policy focuses on exploration and highlights a shift from revenue maximisation to production maximisation (Niti Aayog, 2019). Some of the key reforms include the following:

a. *For Category I basins (that have established production):* an increase in weightage of minimum work programme and decrease in weightage of revenue share for evaluation of bids, a ceiling of 50 per cent on revenue share at higher revenue point and a reduction in timelines for completion of minimum work programme;

b. *For Category II and III basins (that have contingent and prospective resources respectively):* the award of exploration blocks solely on the work programme and no production and revenue sharing (except in case of windfall gain);
c. *The grant of concessional royalty*: if production commences within four years in the case of onshore and shallow water blocks, and within five years for deepwater and ultra-deepwater blocks; and
d. *The constitution of a committee of external eminent persons or experts for dispute resolution.* Parties under existing contracts may also choose to refer disputes and differences to the committee provided that the parties agree in writing and agree not to invoke arbitration under the applicable host government contract.

To date, four OALP bid rounds have been completed under the HELP regime, wherein 94 blocks have been awarded (MoPNG, 2018). In addition to the above, the Indian government also formulated the marginal field policy in 2015, intending to bring the national oil companies' marginal oil and gas fields to production at the earliest (Marginal field policy, 2015).

One significant change that has been introduced by the Indian government recently has been the unification of licensing regimes as applicable to conventional and non-conventional resources. Before the HELP regime, under the NELP regime, the contractors could explore and produce only conventional resources (i.e., crude oil, condensate and natural gas) but not CBM or shale. For unconventional resources, separate policies were formulated by the Indian government, such as the CBM policy (1997) (DGH report, 2013). and policy dated 14 October 2013 granting permission for shale gas and oil exploration and exploitation to national oil companies, for blocks awarded to these companies on a nomination basis (PIB, Aug 2018). Under HELP, the contractors would explore and produce unconventional resources under a single licence for the block. Further, the Indian government in August 2018 approved the policy on an exploration of unconventional hydrocarbons policy to permit exploration and exploitation of unconventional hydrocarbons such as shale oil and gas and coal bed methane (CBM) under the existing PSCs, CBM contracts and nomination fields (PIB, Aug 2018). Despite these aforementioned efforts of the Indian government, low levels of domestic production and failure to attract investments from foreign players are some of the key issues currently plaguing the sector.

Post the award of blocks and execution of the contract, and the contractor is required to obtain a PEL for the entire contract area as per the provisions of the Oilfields Act and the PNG Rules. Under the terms of the PEL, the licensee is granted an exclusive right to operations relating to the information drilling or test drilling and the right to lease over any part of the licence area (PNG Rules, Rule 7(i)). Subsequently, for carrying out development and production activities, the contractor is required to obtain a PML for parts of the contract area encompassing discoveries. Under the PML, the lessee has an exclusive right in the leased land to conduct mining operations for petroleum and natural gas and has the right to carry out construction in the leased area for full enjoyment of the lease or to fulfil the obligations under the lease (PNG Rules, Rule 5).

2.2.5 AERB Regulations

The oil and gas exploration industry uses well logging to obtain a continuous record of a formation's rock properties. These can then be used to infer properties, such as hydrocarbon saturation and formation pressure and make further drilling and production decisions. Wire-line logging is performed by lowering a 'logging tool' on the end of a wire-line into an oil well (or borehole) and recording petrophysical properties using a variety of sensors. Information about the sub-soil strata such as porosity, salinity, moisture content and the presence of oil and natural gas can be obtained by well logging techniques. Some logging tools use a gamma source (^{137}Cs) and a neutron source (commonly used source: ^{241}Am-Be) with appropriate detectors. The methods of compliance with regulatory requirements apply only to those stipulated in the Atomic Energy (Radiation Protection) Rules, 2004, Atomic Energy (Safe Disposal of Radioactive Waste) Rules 1987 and the notifications, orders, safety standards and safety guides issued thereunder.

2.2.6 Environmental impact and decommissioning

The environmental approvals and permissions required to undertake oil and gas operations in India include general environmental approvals as provided under the environmental legislation and specific approvals based on the location of the oilfield.

The general environment approvals include:

a. *Environmental clearance:* under the Environmental Impact Assessment Notification of 2006, as notified under the Environment (Protection) Act 1986 and the Environment (Protection) Rules 1986, it was mandatory to obtain environmental clearance to undertake exploration and production activity in the oilfield. However, recently the Indian government categorised onshore and offshore oil and gas exploration activities as 'B2 category' for seeking prior environmental clearance. By this change, the exploration activities will now require environmental clearance from the states concerned and also, an environmental impact assessment report or public hearing will not be required. However, the development or production activities for offshore or onshore fields will continue to be covered under category A and require an assessment; (GoI Notification 2020)

b. *Consent to establish and consent to operate:* under the Water (Prevention and Control of Pollution) Act 1974 and Air (Prevention and Control of Pollution) Act 1981, the consent to establish and consent to operate are required to be obtained by the respective state pollution control board.

c. *Authorisation for handling hazardous waste:* under the Hazardous Wastes (Management, Handling and Transboundary Movement) Rules 2016, authorisation from the state pollution control board is required for generating, processing, treating, packaging, storing and transporting waste (generated from drilling for oil and gas production).

2.2.6.1 Environmental requirements specific to PSCs and RSCs

Apart from the obligation contained under the environmental laws, the Production Sharing Contracts (PSCs) and Revenue Sharing Contracts (RSCs) also provide for certain additional obligations in relation to the protection of the environment. The terms of the contracts stipulate that the contractor shall conduct the petroleum operations with due regard to environmental protection concerns. In this regard, the contractors are required to adopt modern oilfield and petroleum industry practices and standards (under the terms of PSC) or good international petroleum industry practices and standards (under the terms of RSC), including advanced technologies, practices and methods of operations for the prevention of environmental damage. The relevant clause further provides that in the event of an emergency, such as an accident, oil spill and fire, the contractor shall implement a relevant contingency plan and perform such site restoration as may be necessary.

2.2.6.2 Decommissioning and site restoration

In relation to decommissioning and site restoration, the PNG Rules provide that on termination of the exploration licence or mining lease, the area and any wells contained in it must be delivered in good order and condition (PNG Rules, Rule 22). For six months after the licence or lease ends, the former licensee or lessee can remove or dispose of any petroleum recovered during the licence or lease period, along with stores, equipment, tools and machinery and any improvements on the land covered by the licence or lease that the state government permits (PNG Rules, Rule 22).

As per the terms of the PSCs and RSCs, the contractors are required to remove all equipment and installations from the contract area in a manner as agreed with the Indian government pursuant to an abandonment plan. The contractor is required to prepare and submit a proposal to the Indian government for site restoration, including abandonment plan and requirement of funds for site restoration and annual contribution. Further, the contractor is obligated to perform all necessary site restoration activities under any specific guidelines, rules or regulations that the Indian government has formulated in relation to site restoration. In this regard, the site restoration and abandonment guidelines for petroleum operations have been issued by the Indian government, which prescribes provisions for obligations regarding decommissioning offshore and onshore production sites (Model RSC, Article 4).

2.2.7 Ocean/Marine Management- Pollution Prevention and Response

The provincial and central governments share the responsibility for the prevention of pollution. The pollution control boards of the maritime provinces/union territories work in close coordination with the central government's Ministry of Surface Transport (MST) through the Indian Merchant Shipping Act (1958) (for control of pollution from ships and offshore platforms in the EEZ), and the Indian Ports Act (1963); the Ministry of Petroleum and Natural Gas (MPNG) (concerning pollution up to 500 metres from oil platforms and structures); and the Ministry of Environment and Forests' (MoEF). Coast Guard was made directly responsible for combatting marine pollution. In 1996, the Coast Guard formulated National Oil Spill Disaster Contingency Plan (NOS-DCP) also came into force. This lays down a series of actions to be taken in the event of a major disaster of this nature. It also contains standard formats for reporting spills as well as forwarding data on equipment holding in the country. Since the late 1970s, the Coast Guard has undertaken 29 oil spill operations."[18] It maintains pollution response equipment and approximately 20,000 tonnes of chemicals. In addition, the MoPNG also maintains minor stocks of anti-pollution chemicals. A critical aspect of environment protection and preservation relates to regulating and prohibiting various activities in coastal areas. Major developments in this area are currently underway, which give rise to optimism concerning a pro-active policy towards integrated ocean/ marine management.

2.2.8 Transformative Initiatives/Developments in Upstream E&P Sector

The Central Government has made a number of revolutionary steps to create a favourable business climate for the exploration and production (E&P) sector's expansion.

The hydrocarbon sector reforms are guided by the goals of boosting domestic oil and gas output, expanding investment, creating significant jobs, improving transparency, and eliminating administrative discretion. The government has devised ground-breaking measures to overhaul the E&P sector, which include, among other things:

- **Reform Initiatives** to enhance Domestic Production: Various Policy interventions, Geoscientific Data Initiatives and DSF Policy Introduction are a slew of initiatives undertaken in upstream E&P sector
- **HELP** coupled with operationalization of **OALP**: has helped in increased exploration acreages in India.
- **DSF Policy**: has helped in giving operational autonomy to the operators and reduced micromanagement by the Government is also in line with ease of doing business in India where Govt's take is based only on bid revenue share.
- Policy for grant of extensions to Pre-NELP DSF and Exploration Blocks Hydrocarbon **Vision 2025 for North East**: will help to ensure energy security by achieving self-reliance through indigenous production and investment, thereby help in enhancing standard of living particularly in North East.
- **National Seismic Programme** of Un-appraised areas: help in conducting assessment of unapprised areas for potential O&G reserves.
- **National Data Repository**: helps to validate, store, maintain and reproduce high quality and reliable geo-scientific data alongwith facilitating efficient data reporting, data exchange and data trading between DGH and existing players including geo-scientific agencies and academia.
- Policy framework for **streamlining** the working of **PSCs**: will reduce the regulatory burden of cost auditing and provide full marketing and pricing freedom of gas to the entities.
- **Gas Pricing Reforms**: have given a stimulus to domestic production and also the clean production mechanisms

- Policy Framework for **Early Monetization of CBM**: Aims at generating economic activities which in turn will be beneficial for creating more employment opportunities and also incentivize the domestic gas production.
- **Permission of Extraction** of CBM to CIL & its subsidiaries in **Coal Mining area**: will boost the energy security of the country.
- Policy framework to permit exploration and exploitation of **unconventional hydrocarbons** in existing acreage of PSCs, CBMs and Nomination fields: will provide an impetus to the hydrocarbon production in the country.
- Policy framework to **incentivise enhanced recovery methods** for oil and gas: This will improve hydrocarbon output in ageing fields.

2.3 The Environment

2.3.1 The Oil and Gas Law Review: India

2.3.1.1 Wildlife Protection Act, 1972

This Act provides for the protection of the country's wild animals, birds, and plant species, in order to ensure environmental and ecological security. Among other things, the Act lays down restrictions on hunting many animal species. The Act was last amended in the year 2006. An Amendment bill was introduced in the Rajya Sabha in 2013 and referred to a Standing Committee, but it was withdrawn in 2015.

Constitutional Provisions for the Wildlife Act

Article 48A of the Constitution of India directs the State to protect and improve the environment and safeguard wildlife and forests. This article was added to the Constitution by the 42nd Amendment in 1976.

Article 51A imposes certain fundamental duties for the people of India. One of them is protecting and improving the natural environment, including forests, lakes, rivers, wildlife, and compassion for living creatures.

History of wildlife protection legislation in India

- The British Indian Government passed the first such law in 1887 called the Wild Birds Protection Act, 1887. The law sought to prohibit the possession and sale of specified wild birds that were either killed or captured during a breeding session.
- A second law was enacted in 1912 called the Wild Birds and Animals Protection Act. This was amended in 1935 when the Wild Birds and Animals Protection (Amendment) Act 1935 was passed.
- During the British Raj, wildlife protection was not accorded a priority. It was only in 1960 that the issue of protecting wildlife and preventing certain species from becoming extinct came to the fore.

2.3.1.2 Need for the Wildlife Protection Act

Wildlife is a part of 'forests', and this was a state subject until Parliament passed this law in 1972. Now it is Concurrent List. Reasons for a nationwide law in the domain of the environment, particularly wildlife, include the following:

1. India is a treasure-trove of varied flora and fauna. Many species were seeing a rapid decline in numbers.
2. A drastic decrease in flora and fauna can cause ecological imbalance, which affects many aspects of climate and the ecosystem.
3. The most recent Act passed during the British era in this regard was the Wild Birds and Animals Protection, 1935. This needed to be upgraded as the punishments awarded to poachers and traders of wildlife products were disproportionate to the huge financial benefits that accrue to them.
4. There were only five national parks in India prior to the enactment of this Act.

2.3.1.3 Salient Features of Wildlife Protection Act

This Act provides for the protection of a listed species of animals, birds, and plants and the establishment of a network of ecologically important protected areas in the country.

- The Act provides for forming wildlife advisory boards, wildlife wardens, specifies their powers and duties, etc.
- It helped India become a party to the Convention on International Trade in Endangered Species of Wild Fauna and Flora (**CITES**).
    - CITES is a multilateral treaty to protect endangered animals and plants.
    - It is also known as the **Washington Convention** and was adopted as a result of a meeting of IUCN members.
- For the first time, a comprehensive list of the endangered wildlife of the country was prepared.
- The Act **prohibited the hunting of endangered species**.
- Scheduled animals are prohibited from being traded as per the Act's provisions.
- The Act provides for licenses for the sale, transfer, and possession of some wildlife species.
- It provides for the establishment of wildlife sanctuaries, national parks, etc.
- Its provisions paved the way for the formation of the **Central Zoo Authority**. This is the central body responsible for the oversight of zoos in India. It was established in 1992.
- The Act created **six schedules** that gave varying degrees of protection to classes of flora and fauna.
    - Schedule I and Schedule II (Part II) get absolute protection, and offences under these schedules attract the maximum penalties.
    - The schedules also include species that may be hunted.
- The **National Board for Wildlife** was constituted as a statutory organization under the provisions of this Act.
    - This is an advisory board that offers advice to the central government on wildlife conservation issues in India.

- It is also the apex body to review and approve all matters related to wildlife, projects of national parks, sanctuaries, etc.
- The chief function of the Board is to promote the conservation and development of wildlife and forests.
- It is chaired by the Prime Minister.

2.3.1.4 Protected Areas under the Wildlife Protection Act

There are five types of protected areas as provided under the Act. They are described below.

1. Sanctuaries: "Sanctuary is a place of refuge where injured, abandoned, and abused wildlife is allowed to live in peace in their natural environment without any human intervention."

1. They are naturally occurring areas where endangered species are protected from poaching, hunting, and predation.
2. Here, animals are not bred for commercial exploitation.
3. The species are protected from any sort of disturbance.
4. Animals are not allowed to be captured or killed inside the sanctuaries.
5. A wildlife sanctuary is declared by the State government by a Notification. Boundaries can be altered by a Resolution of the State Legislature.
6. Human activities such as timber harvesting, collecting minor forest products, and private ownership rights are permitted as long as they do not interfere with the animals' well-being. **Limited human activity is permitted.**
7. They are open to the general public. But people are not allowed unescorted. There are restrictions as to who can enter and/or reside within the limits of the sanctuary. Only public servants (and his/her family), persons who own immovable property inside, etc., are allowed. People using the highways which pass through sanctuaries are also allowed inside.

8. Boundaries of sanctuaries are not generally fixed and defined.
9. Biologists and researchers are permitted inside so that they can study the area and its inhabitants.
10. The **Chief Wildlife Warden (who is the authority to control, manage and maintain all sanctuaries)** may grant permission to persons for entry or residence in the sanctuary for the study of wildlife, scientific research, photography, the transaction of any lawful business with persons residing inside, and tourism.
11. Sanctuaries can be upgraded to the status of a 'National Park'.

2. National Parks: "National Parks are the areas that the government sets to conserve the natural environment."

1. A national park has more restrictions as compared to a wildlife sanctuary.
2. National parks can be declared by the State government by Notification. No alteration of the boundaries of a national park shall be made except on a resolution passed by the State Legislature.
3. The main objective of a national park is to protect the natural environment of the area and biodiversity conservation.
4. The landscape, fauna, and flora are present in their natural state in national parks.
5. Their boundaries are fixed and defined.
6. Here, **no human activity is allowed.**
7. Grazing of livestock and private tenurial rights are not permitted here.
8. Species mentioned in the Schedules of the Wildlife Act are not allowed to be hunted or captured.

9. No person shall destroy, remove, or exploit any wildlife from a National Park or destroy or damage the habitat of any wild animal or deprive any wild animal of its habitat within a national park.

10. They cannot be downgraded to the status of a 'sanctuary'.

3. Conservation Reserves: The State government may declare an area (particularly those adjacent to sanctuaries or parks) as conservation reserves after consulting with local communities.

4. Community Reserves: The State government may declare any private or community land as a community reserve after consultation with the local community or an individual who has volunteered to conserve the wildlife.

The amended Wildlife Act doesn't allow any commercial exploitation of forest produce in both wildlife sanctuaries and national parks, and local communities are allowed to collect forest produce only for their bona fide requirements.

2.3.1.5 Schedules of the Wildlife Protection Act

There are six schedules provided in the Wildlife Protection Act. They are discussed in table 2.2 below.

Table 2. 2 Schedules of the wildlife protection act

Schedule I	Schedule II
• This Schedule covers **endangered species**. • These species need rigorous protection and therefore, the harshest penalties for violation of the law are under this Schedule. • Species under this Schedule are prohibited to be hunted throughout India, except under threat to human life. • Absolute protection is accorded to	• Animals under this list are also accorded high protection. • Their trade is prohibited. • They cannot be hunted except under threat to human life.

species on this list. • The Trade of these animals is prohibited.	
Schedule III & IV • This list is for species that are not endangered. • This includes protected species but the penalty for any violation is less compared to the first two schedules.	**Schedule V** • This schedule contains animals that can be hunted.
Schedule VI • This list contains plants that are forbidden from cultivation.	

2.3.1.6 The Wild Life (Protection) Act, 1972 relevant to Waterbodies

The act was enacted to effectively protect this country's wildlife and control poaching, smuggling, and illegal trade in wildlife and its derivatives. The Act was amended in January 2003, and punishment and penalty for offences under the Act have been made more stringent. The Ministry has proposed further amendments in the law by introducing more rigid measures to strengthen the Act. The objective is to provide protection to the listed endangered flora and fauna and ecologically important protected areas.

Declaration of sanctuary- The State Government may, by notification, declare its intention to constitute any area other than an area comprised within any reserve forest or the territorial waters as a sanctuary if it considers that such area is of adequate ecological, faunal, floral, geomorphological, natural or zoological significance, for the purpose of protecting, propagating or developing wildlife or its environment.

Declaration of National Parks- Whenever it appears to the State Government that an area, whether within a sanctuary or not, is, because of its ecological, faunal, floral, geomorphological or zoological association of importance, need to be constituted as a National Park for the purpose of protecting, propagating or developing wildlife therein or its environment, it may, by notification, declare its intention to constitute such area as a National Park.

Maritime Zones Act, 1976

The **United Nations Convention for the Law of the Sea ("UNCLOS")**, also identified as the Law of the Sea, is an international treaty structuring and establishing rules and regulations safeguarding the usage of oceans and seas worldwide. This convention introduced maritime zones that are the territorial sea, contiguous zone, exclusive economic zone, and continental shelf. This convention articulates state jurisdiction in maritime areas. **The Territorial Waters, Continental Shelf, Exclusive Economic Zones and Maritime Zones Act, 1976 ("the Act"):** For years, India's territorial waters and continental shelf were governed by proclamations issued by the President of India. In 1976, consequent upon the Third UNCLOS, held at Geneva, the Act was enacted in India. Hereunder, land, minerals and other resources underlying the ocean, within the territorial waters, the continental shelf or the Exclusive Economic Zone ("EEZ") are vested with the Union of India. The Act categorically prescribes the limits of the territorial waters, continental shelf, EEZ and other maritime zones of India. It also provides the legal framework specifying the nature, scope and extent of India's rights, jurisdiction and control of various maritime zones; the maritime boundaries between India and its neighbouring countries; and the exploitation, exploration, conservation and management of natural resources within the maritime zones. Further, the Act proposed to undertake separate legislation in future, as and when required, to deal with the regulations for exploration and exploitation of particular resources in which India has jurisdiction. Thus, the Act by its very nature is umbrella legislation on maritime issues.

Section of the Territorial Waters, Continental Shelf, Exclusive Economic Zone and other Maritime Zones Act 1976 notifies the sovereignty of the Indian states over the respective territorial waters. Foreign ships, submarines, warships, and so on can utilize the territorial waters but only with the approval of the Central Government. Further, the distance of 24 nautical miles towards the sea, measured from the baseline, is considered to be the Contiguous zone. It lies between the territorial seas and the high seas. The contiguous zone provides the state with control and jurisdiction over the surface and floor of the ocean, but it does not include air space rights. According to Article 33 of the convention, the coastal states can take steps to punish infringement of customs, immigration protocols, etc., whose commission took place within the territory or territorial sea, concerning the contiguous zone.

The exclusive economic zone beside the territorial sea is 200 nautical miles away from the baseline. The exclusive economic zone is crucial in trade-offs related to UNCLOS. Protection of the exclusive economic zones retains the Indian maritime interests. India has an almost 2.172-million km^2 exclusive economic zone along the 7500 km long coastline of the nation. Coastal states have the right to carry out procedures for producing energy from water and wind. They can also explore, manage, maintain, utilize, and conserve natural resources.

India has been endowed with a vast marine ecosystem and biodiversity, which sustains a large number of species and the coastal populace is dependent on the resources from this marine eco-system. The need for the protection of this ecosystem has been acknowledged worldwide, and UNCLOS 1982 prescribes the responsibility of the Coastal States in preserving and protecting the marine environment and associated resources. The Maritime Zones of India Act 1976 enables the Government to take measures for the protection of the marine environment.

Several environment protection legislations existed even before the Independence of India. However, the true thrust for putting in force a well-developed framework came only after the UN Conference on the Human Environment (Stockholm, 1972). After the Stockholm Conference, the National Council for

Environmental Policy and Planning was set up in 1972 within the Department of Science and Technology to establish a regulatory body to look after the environment-related issues. This Council later evolved into a full-fledged Ministry of Environment and Forests (MoEF). MoEF was established in 1985, which today is the apex administrative body in the country for regulating and ensuring environmental protection and lays down the legal and regulatory framework for the same. Since the 1970s, a number of environmental legislations have been put in place. The MoEF and the pollution control boards ("CPCB", i.e., Central Pollution Control Board and "SPCBs", i.e., State Pollution Control Boards) together form the regulatory and administrative core of the sector.

The Coast Guard Act, 1978 The Coast Guard Act 1978 states that the preservation and protection of the marine environment and control of marine pollution is the function of the Indian Coast Guard. The ICG has been accordingly nominated in 1986 as the Central Coordinating Authority for oil-spill response in the Maritime Zones of India. Coast Guard officers have been empowered under the Merchant Shipping Act 1958 to take necessary actions against polluters.

Any oil-spill response requires inter-agency coordination. Necessary preparedness measures need to be addressed collectively, and towards that effort, a national level contingency plan that provides all the necessary details and functional responsibilities of various agencies has been prepared. The Government of India approved the National Oil-spill Disaster Contingency Plan (NOSDCP) in 1993 and allocated functional responsibilities to multiple ministries and departments for oil-spill response in the Maritime Zones of India. The ports are responsible for oil-spill clean-up within port limits, and oil-handling agencies are responsible for oil-spill clean-up up to 500 meters around the oil-handling installations. The Coastal States and Union Territories are responsible for shoreline clean-up whenever the oil spill reaches the shore and threatens the shoreline.

The comprehensively revised National Oil Spill Disaster Contingency Plan (NOSDCP) has been prepared for the offshore Oil and gas field that reflect current international norms and best practices, key relevant practices and key relevant national regulations

The Water (Prevention and Control of Pollution) Act, 1974

The "Water Act" has been enacted to prevent and control water pollution and maintain or restore the wholesomeness of water in the country. It further provides for the establishment of Boards for the prevention and control of water pollution with a view to carrying out the aforesaid purposes. The Water Act prohibits the discharge of pollutants into water bodies beyond a given standard and lays down penalties for non-compliance. At the Centre, the Water Act has set up the CPCB, which lays down standards for preventing and controlling water pollution. At the State level, SPCBs function under the direction of the CPCB and the State Government.

The Air (Prevention and Control of Pollution) Act, 1981

The "Air Act" is an act to provide for the prevention, control and abatement of air pollution and the establishment of Boards at the Central and State levels with a view to carrying out the aforesaid purposes. To counter the problems associated with air pollution, ambient air quality standards were established under the Air Act. The Air Act seeks to combat air pollution by prohibiting the use of polluting fuels and substances and regulating appliances that give rise to air pollution. The Air Act empowers the State Government, after consultation with the SPCBs, to declare any area or areas within the State as air pollution control areas or areas. Under the Act, establishing or operating any industrial plant in the pollution control area requires consent from SPCBs. SPCBs are also expected to test air pollution control areas, inspect pollution control equipment and manufacture.

The Environment Protection Act, 1986

The "Environment Act" provides for the protection and improvement of the environment. The Environment Protection Act establishes the framework for studying, planning and implementing long-term requirements of environmental safety and laying down a system of speedy and adequate response to situations threatening the environment. It is an umbrella legislation designed to provide a framework for coordinating central and state authorities established under the Water Act and the Air Act. The term "environment" is understood widely under s 2(a) of the Environment Act. It includes water, air and land, and the interrelationship between water, air and land, and human beings, other living creatures, plants, micro-organisms, and property. Under the Environment Act, the Central Government is empowered to take measures necessary to protect and improve the quality of the environment by setting standards for emissions and discharges of pollution in the atmosphere by any person carrying on an industry or activity; regulating the location of industries; management of hazardous wastes, and protection of public health and welfare. From time to time, the Central Government issues notifications under the Environment Act for the protection of ecologically sensitive areas or issues guidelines for matters under the Environment Act.

The Biological Diversity Act, 2002

The Biological Diversity Act 2002 was born out of India's attempt to realise the objectives enshrined in the United Nations Convention on Biological Diversity (CBD), 1992, which recognises the sovereign rights of states to use their Biological Resources. The Act aims to conserve biological resources and associated knowledge and facilitate access to them in a sustainable manner. The National Biodiversity Authority in Chennai has been established for the purposes of implementing the objects of the Act.

Hazardous Wastes Management Regulations, 2008

Hazardous waste means any waste that, because of its physical, chemical, reactive, toxic, flammable, explosive or corrosive characteristics, causes danger or is likely to cause a threat to health or environment, whether alone or when in contact with other wastes or substances. There are several legislations that directly or indirectly deal with hazardous waste management. The relevant legislations are the Factories Act, 1948, the Public Liability Insurance Act, 1991, the National Environment Tribunal Act, 1995 and rules and notifications under the Environmental Act.

The National Green Tribunal Act, 2010 (No. 19 of 2010)

(NGT Act) has been enacted with the objectives to provide for the establishment of a National Green Tribunal (NGT) for the effective and expeditious disposal of cases relating to environmental protection and conservation of forests and other natural resources, including enforcement of any legal right relating to the environment and giving relief and compensation for damages to persons and property and matters connected therewith or incidental thereto. The Act envisages the establishment of NGT in order to deal with all environmental laws relating to air and water pollution, the Environment Protection Act, the Forest Conservation Act and the Biodiversity Act as having been set out in Schedule I of the NGT Act.

Island Coastal Regulation Zone (ICRZ) Notification, 2019

The notification of the Government of India in the Ministry of Environment, Forest and Climate Change number S.O. 1242(E), dated the 8th March, 2019 [hereinafter referred to as the Island Coastal Regulation Zone (ICRZ) Notification, 2019], the Central Government declared certain coastal stretches as Coastal Regulation Zone and restrictions were imposed on the setting up and expansion of industries, operations and processes in the said zone.

ICRZ clearance for permissible or regulated activities

(i) All permitted or regulated project activities attracting the provisions of this notification shall be required to obtain ICRZ clearance prior to their commencement.

(ii) All development activities or projects in ICRZ-I and ICRZ-IV areas, which are regulated and permissible as per this notification, shall be dealt with by the

Ministry of Environment, Forest and Climate Change for clearance, based on the recommendation of the concerned CZMA.

(iii) For all other permissible and regulated activities as per this Notification, which fall purely in ICRZ–II and ICRZ-III areas, the ICRZ clearance shall be considered by the concerned CZMAs. Such projects in ICRZ –II and III, which also happen to be traversing through ICRZ–I and/or ICRZ-IV areas, ICRZ clearance shall, however be considered only by the Ministry of Environment, Forest and Climate Change, based on recommendations of the CZMA.

(iv) Projects or activities which attract the provisions of this Notification as also the provisions of EIA Notification 2006, shall be dealt with for a composite Environmental and ICRZ clearance under EIA Notification 2006 by the concerned approving Authority, based on recommendations of concerned CZMA, as per delegations i.e., State Environmental Impact Assessment Authority (hereinafter referred to as the SEIAA) for category 'B' projects and by the Ministry of Environment, Forest and Climate Change for category 'A' projects respectively.

(v) In case of building and construction projects with a built-up area less than the threshold limit stipulated for attracting the provisions of the EIA Notification, these shall be approved by the concerned local Union Territory Planning Authorities in accordance with this notification, after obtaining recommendations of the CZMA.

(vi) Only for self-dwelling units up to a total built-up area of 300 sq. meters, approval shall be accorded by the concerned local authority, without the requirement of recommendations of the CZMA. However, such authorities shall examine the proposal from the perspective of this Notification before approval.

2.4 EIA 2006

The Ministry of Environment and Forests (MoEF) uses Environmental Impact Assessment Notification 2006 as a major tool for minimizing the adverse impact of rapid industrialization on the environment and reversing those trends that may lead to climate change in the long run. EIA 2006 was issued on 14th September 2006, in supersession of EIA 1994, except in respect of things done or omitted to be done before such supersession. The Notification is issued under relevant provisions of the Environment (Protection) Act, 1986.

2.4.1 Introduction

Environmental Impact Assessment (EIA) is a process of evaluating the likely environmental impacts of a proposed project or development, taking into account inter-related socio-economic, cultural and human-health impacts, both beneficial and adverse. UNEP defines Environmental Impact Assessment (EIA) as a tool used to identify the environmental, social and economic impacts of a project prior to decision-making. It aims to predict the environmental effects at an early stage in project planning and design, find ways and means to reduce adverse impacts, shape projects to suit the local environment and present the predictions and options to decision-makers. Environment Impact Assessment in India is statutorily backed by **the Environment Protection Act, 1986** , which contains various provisions on EIA methodology and process.

2.4.2 History of EIA in India

- The Indian experience with Environmental Impact Assessment began over 20 years back. It started in 1976-77 when the Planning Commission asked the Department of Science and Technology to examine the river-valley projects from an environmental angle.
- Till 1994, environmental clearance from the Central Government was an administrative decision and lacked legislative support.

- On 27 January 1994, the then Union Ministry of Environment and Forests, under the Environmental (Protection) Act 1986, promulgated an EIA notification making Environmental Clearance (EC) mandatory for expansion or modernisation of any activity or for setting up new projects listed in Schedule 1 of the notification.
- The Ministry of Environment, Forests and Climate Change (MoEF&CC) notified **new EIA legislation in September 2006.**

2.4.3 Importance of EIA

- EIA links environment with development for environmentally safe and sustainable development.
- EIA provides a cost-effective method to eliminate or minimize the adverse impact of developmental projects.
- EIA enables the decision-makers to analyse the effect of developmental activities on the environment well before the developmental project is implemented.
- EIA encourages the adaptation of mitigation strategies in the developmental plan.
- EIA makes sure that the developmental plan is environmentally sound and within the limits of the ecosystem's capacity of assimilation and regeneration.
- The EIA process looks into the following components of the environment.

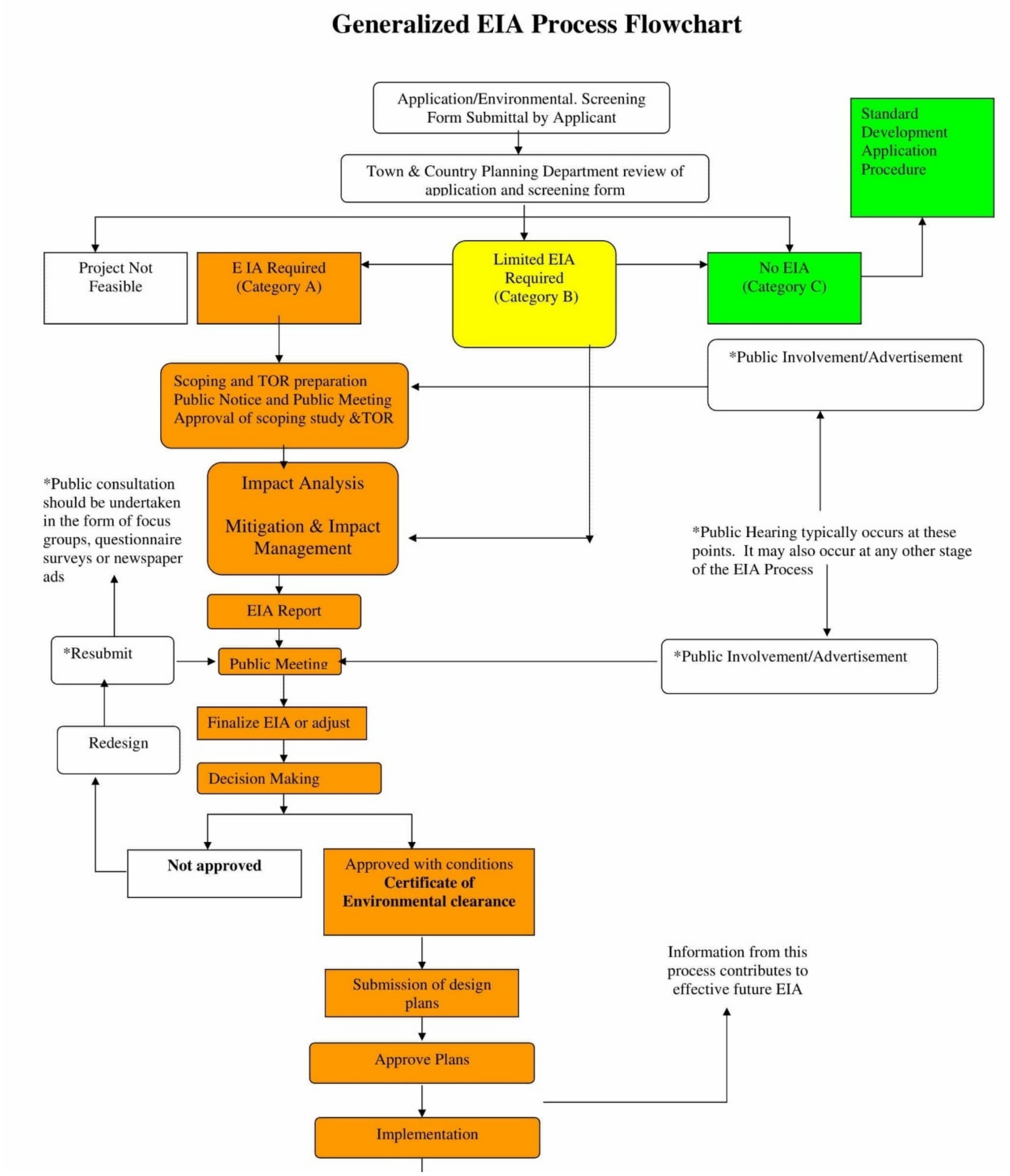

Figure 2. 1 Generalized EIA flow chart

2.4.4 Environmental Components Of EIA

Air environment

- Quality of ambient air present and predicted.
- Meteorological data.
- Quantity of emission likely from the project.
- Impact of the emission on the area.
- Pollution control desires/air quality standards.

Noise

- Levels of noise present and predicted
- Strategies for reducing noise pollution.

Water environment

- Existing water resources, their quality and quantity within the zone.
- Impact of the proposed project on water resources.

Biological environment

- Flora and fauna in the impact zone.
- Potential damage (likely) due to project, due to effluents, emissions and landscaping.
- Biological stress (prediction).

Land environment

- Study of soil characteristics, land use, and the likely adverse impact of the project.
- Impact on historical monuments and heritage sites.

2.4.5 Benefits of EIA

- **EIA** links environment with development **for** environmentally safe and sustainable development**.**
- EIA provides a cost-effective method to eliminate or minimize the adverse impact of developmental projects.
- EIA enables the decision-makers to analyse the effect of developmental activities on the environment well before the developmental project is implemented.
- EIA encourages the adaptation of mitigation strategies in the developmental plan.
- EIA makes sure that the developmental plan is environmentally sound and within limits of the capacity of assimilation and regeneration of the ecosystem.

2.4.6 Salient Features of 2006 Amendment to EIA Notification

- Environment Impact Assessment Notification of 2006 has decentralized the environmental clearance projects by categorizing the developmental projects in two categories, i.e., **Category A (national level appraisal)** and **Category B (state-level appraisal)**.
- 'Category A' projects are appraised at the national level by Impact Assessment Agency (IAA) and the Expert Appraisal Committee (EAC), and Category B projects are appraised at the state level.
- State Level Environment Impact Assessment Authority (SEIAA) and State Level Expert Appraisal Committee (SEAC) are constituted to provide clearance to Category B process.

2.4.7 Environmental Impact Assessment Draft Notification 2020, India:

In India, the adoption of the Draft EIA Notification 2020 by the Ministry of Environment, Forest and Climate Change has triggered several debates over its problematic implications. The Draft EIA Notification normalizes ex post facto clearance, which allows construction or operation of the project without prior environmental clearance. It has significantly curtailed the scope of public consultation and participation by introducing a large number of exemptions for projects. Further, it is silent over the project's transboundary impacts and exempts projects within 100 km of the border areas from public consultation. Seismic surveys, which are part of exploration surveys for offshore and onshore oil and gas, including coal bed methane and shale gas, provided the concession areas have previous conditions of prior-EC or prior-EP for the physical survey.

In the original EIA Notification, 2006, "offshore and onshore oil & gas **exploration**, development and production" has been covered under schedule 1(b) and being category A projects, it requires preparation of an Environment Impact Assessment (EIA) report, the conduct of public hearing and clearance from the Union MoEF&CC. Vide notification **dated 16 January 2020 categorizes onshore and offshore oil and gas exploration activities as B2 category** for seeking prior Environmental Clearance(EC). As exploration activities in the hydrocarbon sector have been moved from Category A to Category B2, they will now require environmental clearance only from the States concerned and will not require preparation of an EIA report or conduct of Public Hearing. However, both on offshore /onshore fields as hydrocarbon blocks, development or production will continue to merit assessment as"category A".

LIST OF PROJECTS REQUIRING PRIOR ENVIRONMENT CLEARANCE OR PRIOR ENVIRONMENT PERMISSION, AS THE CASE MAY BE

Item	Project	Category with threshold limit			Conditions if any
		A	B1	B2	
(1)	(2)	(3)	(4)	(5)	(6)
1	(a) Mining of Minor Minerals	>100 hectare of mining lease area	> 5 hectares and ≤ 100 hectares of mining lease area	≤ 5 hectares of mining lease area	Note: (1) Mining of minor mineral projects with mine lease area more than 2 hectare and up to 5 Ha shall be shall be referred to Distract Level Expert Appraisal Committee (2) Mining lease area includes cluster situation
	(b) Mining of Major Minerals including Coal	>100 hectare of mining lease area	≤ 100 hectares of mining lease area	Dump mining (excavation or handling of dump or overburden or waste material)	
2	Offshore and Onshore Oil & Gas including CBM and Shale Gas				
	a) Exploration	--	--	All projects	
	b) Development and Production (including infrastructure facilities e.g. Gas Collecting or Gathering Station, Early production Systems, pipelines, etc.).	All projects	--	--	

Figure 2. 2 List of projects requiring prior environment clearance or prior environment permission

2.5 Proposed Standard Terms of Reference (ToR) related to Oil and Gas Projects beyond 12 Nautical miles

2.5.1 Proposed Standard Terms of Reference (ToR) for EMP studies related to exploratory projects beyond 12 Nautical miles

ToR for EMP studies in respect of the offshore oil and gas exploration may include, but are not limited to the following:

1. **Executive summary of the project**

2. **The project description should include**

- List of the proposed activity.
- Geographic information of the site.
- Maps showing the drilling area.
- Duration of project activities.
- Information of the proposed drilling rig.
- Details on support infrastructure, vessel etc.
- Details on bathymetry data including sea depth, seawater quality, seafloor relief, navigational information, *etc*.

3. **Environmental Management Plan:**

- Details on solid waste management for drill cuttings, drilling mud and oil sludge, produced sand, radioactive materials, other hazardous materials, etc., including disposal options during the drilling phases.
- Details on wastewater generation, treatment and utilisation/discharge for produced water, cooling waters, other wastewaters, etc.
- Details on oil spill contingency plan.

4. **Environmental Monitoring Program**

- Details on environmental monitoring programs during drilling activities.

2.5.2 ***Proposed Standard Terms of Reference (ToR) for EIA studies related to Development projects beyond 12 Nautical miles***

The proposed development envisages that the produced hydrocarbons will be handled through producing assets. If the project envisaged that the produced hydrocarbons need to be brought to the onshore terminal for further processing and discharge. In that case, the project proponent needs to abide by the EIA notification and its amendment as applicable.

ToR for EIA studies in respect of the offshore oil and gas, development and production projects may include, but are not limited to the following:

1. **Executive summary of the project**
2. **Project description**
   - A complete description of the project includes proposed onshore and offshore facilities.
   - Geographic information of the site
   - Details on support infrastructure, the vessel used for the construction and operation phase of the project.
   - Complete process flow diagram describing each unit, its processes and operations, along with material and energy inputs and outputs (material, water and energy balance).
   - Details on storage of chemicals at the site and measures to prevent hazards.
3. **Description of the environment**
   - Baseline data includes different components of the environment, viz. noise, water and flora & fauna from the study area as mentioned in this manual.
   - The study report details climate and meteorology, including wind patterns, temperature, rainfall, waves, tides, currents, cyclones, earthquakes, etc.
   - Details on establishment of baseline on the water resources of the area affected or potentially impacted by the activities in the various phases of the project. This baseline should include a water quality assessment of available waters sources of the project site and zone of influence. The baseline should potentially include parameters such as Total Nitrate, Salinity, DO, pH, Sulphates, Hardness, Phosphates, Conductivity, Heavy metals (Total metals, mercury, lead, copper *etc.*), TDS, Hydrocarbons and Arsenic.

- Details of the basic physical environment such as tide, currents and waves of the study area.
- Studies on flora and fauna, including the main habitat types with a list of species of flora and fauna and their conservation value, give particular attention to any species protected under law.
- Fisheries study w.r.t. benthos and marine organic material.

4 Anticipated Environmental Impacts & Mitigation Measures

- Details on potential impacts on the sea water quality, sediments, aquatic fauna and flora due to the activities in the various phases of the project.

5 Environmental Management Plan

- Describe mitigation measures, including an EMP to be implemented to reduce or offset the adverse impacts of proposed activities.
- Identify the preferred option(s) for waste management/disposal method based on environmental grounds, including necessary infrastructure. Specify any residual impacts of waste management, their significance, and any mitigation measures to be undertaken.
- Details on wastewater generation, treatment and utilisation/discharge for produced water, cooling waters, other wastewaters, etc.
- Details on oil spill contingency plan.
- Details on occupational health and safety of employees and workers.

6 Analysis of Alternative technologies

- Evaluate alternative options for collecting, treatment, recycling (if appropriate), and disposal of these wastes. Identify any chemicals, planned for use in treating or managing these wastes.

7 Environmental Monitoring Program

- Details on environmental monitoring programs during the construction and operational phase.

8 Risk Assessment

- Details on risk assessment include identification of hazards, proposed measures, disaster management plan, contingency plan, emergency response plan, etc.
- Outline of the overall management structure anticipated for the proposed activities.
- Identify emergency preparation and applicable management measures for the proposed activities dealing with the following eventualities as a minimum:
  - Oil spills
  - Cyclones
  - Fires
  - Blow out
  - H_2S, if any.

Chapter 3: Baseline data of the marine environment by comprehensive analysis of Marine EIA/ monitoring work carried out in the oil fields within the EEZ of India in deep as well as shallow offshore blocks.

3.1 Baseline Data of All Major Sedimentary Basins along with India

3.1.1 Gulf of Kutch

Kutch basin forms the north-western part of the western continental margin of India and is situated at the southern edge of the 17Indus shelf at right angles to the south of the Indus fossil rift. It is bounded by the Nagar- Parkar fault in the North, the Radhanpur-Barmer arch in the east and the North Kathiawar fault towards the south. The basin extends between Latitude 22° 30′ and 24° 30′ N and Longitudes 68° and 72° E covering the entire Kutch district and western part of Banaskantha (Santalpur Taluka) districts of Gujarat state. It is an east-west oriented pericratonic embayment opening and deepening towards the sea in the west towards the Arabian Sea. The basin's total area is about 71,000 sq. km, of which the land area is 43,000 sq. km, and the offshore area is 28,000 sq. km. up to 200 bathymetry. The basin is filled with 1550 to 2500 m of Mesozoic sediments and 550 m of Tertiary sediments in the onland region, and up to 4500m of Tertiary sediments in the offshore region. The sediment fill thickens from less than 500 m in the north to over 4500 m in the south and from 200 m in the east to over 14,000 m in the deep sea region towards the western part of the basin, indicating a palaeo-slope in the south-west. The western continental shelf of India, with an average shelf break at about 200 m depth, is about 300 km wide off Mumbai coast and gradually narrows down to 160 km off Kutch in the north. The prominent features are two coastline indentations, the Gulf of Kutch and the Kori Creek, in the southern and the northern parts of the basin.

The basin is contiguous to the South Indus Basin of Pakistan, where a number of oil and gas fields have already been discovered. Exploratory efforts have led to the discovery of oil and gas in the offshore part of the Kutch Basin. Oil has been struck in well KD-1 in Eocene limestone/siltstone reservoirs, whereas gas has been discovered in wells GK-29A-1 and GK-22C-1 in Paleocene and Cretaceous sandstone reservoirs, respectively.

The Gulf, which occupies an area of 7300 km^2, has a maximum depth that varies from 20 m at the head (Kandla - Navlakhi) to more than 60 m in the outer regions. However, the actual fairway has been disrupted due to the presence of several shoals, as periodic dredging is required in some areas to facilitate navigation to the port of Candela. The tides that follow the axis of the gulf have steep slopes and rough surfaces. Several scraps with a relative elevation of 6 to 32 m occur on the sediment-free bed of the central Gulf.

3.1.1.1 Land Environment

The coastal configuration of the Gulf is very irregular, with numerous islands, creeks, and bays. The coastal area of the Gulf (within 20 km from the shoreline) falls under the Kachchh (6749.77 km^2), Jamnagar (4863.53 km^2), and Rajkot (576.71 km^2) Districts. Cotton is the dominant crop in the Kachchh District, while it is oilseeds in the Jamnagar and Rajkot Districts. Bajra, pulses, wheat, sugarcane, etc., are the other common crops in the region. The general vegetation in the area is sparse and scattered and of tropical dry mixed deciduous scrub and desert thorn type belonging to the xerophytic group.

Due to the extreme unreliability of rainfall in the region, groundwater is a more reliable source of water for domestic as well as agricultural needs. However, uncontrolled and indiscriminate groundwater withdrawal has resulted in a sharp decline in the water table in the coastal belt, causing salinity ingress. The conditions are of considerable concern in Jodia and Okhamandal Talukas of the Jamnagar District and severe in Lakhpat and Anjar Talukas of the Kachchh District.

The coastal region of the Gulf is industrially less developed, and the majority of large-scale industries, including the RIL refinery, are located in the Jamnagar District. Kachchh District is industrially backward, and except for lignite mining, thermal power plant, fertilizer plant, and Mundra and Kandla Ports, there are no major industries in the district. Okha and Bedi are the two important intermediate ports in the Jamnagar District.

3.1.1.2 Meteorological Conditions

The Gulf is a semi-arid region with weak and erratic rainfall confined largely to the June-October period. With a few rainfall days, the climate is hot and humid from April till October and pleasant during brief winter from December to February. Rainfall alone forms the ultimate source of freshwater resource to the region. The average rainfall at Mundra is 414 mm/y on the northern coast and 490 mm/y at Mithapur on the southern coast. The wind records at Okha indicate that (a) the speed varies between 0 and 30 km/h during November-February; the predominant direction being NW - NE, (b) the speed marginally increases during March-April with the change in direction to NW-SW, (c) maximum speeds (40-50 km/h) occur during May with predominant SW-W direction and (d) maximum speeds can reach up to 70 km/h with predominant SW-W direction during depressions in June -

September. Cyclonic disturbances strike North-Gujarat, particularly the Kachchh and Saurashtra regions, periodically. These disturbances generally originate over the Arabian Sea and sometimes the Bay of Bengal. Generally during June, the storms are confined to the area north of 15° N and east of 65° E. In August, they move along the northwest course in the initial stages and show a large latitudinal scatter. West of 80° E, the tracks tend to curve towards the north. During October, the direction of movement of a storm is to the west in the Arabian Sea. However, east of 70° E, some of the storms move north-northwest and later recurve northeast to strike Gujarat-north Mekran coast.

The relative humidity is generally high during June-September (60-85 %) and marginally decreases during the rest of the year (30-80 %). The sky is generally clear or lightly clouded except during the monsoon period. Visibility is good throughout the year. However, average visibility of less than 1 km can be expected for a few days during the winter months.

Table 3. 1 Meteorological/Physical parameters at Gulf of Kutch

Parameter	**Minimum**	**Maximum**	**Average**
Wind speed (m/s)	0.7	12.7	4.9
Surface air pressure (pa)	98529	101630	100187
Air temperature (°C)	18.5	34.2	26.7
Sea surface Temperature (°C)	22.9	31.5	27.3
Sea surface Salinity (psu)	36.1	37.5	36.6
Relative humidity (%) 1000hpa	17.7	96.5	58.3
Net shortwave radiation flux (W/m^2)	17	223	159.5
Net long wave radiation flux (W/m^2)	-106.3	15.6	-56.3
Latent heat net flux (W/m^2)	-7.4	108.9	39.5
Sensible heat net flux (W/m^2)	-6	149	63
Cyclones			
A total of 24 cyclonic/severe cyclonic storms were formed/dissipated over Gulf of Kutch Basin			

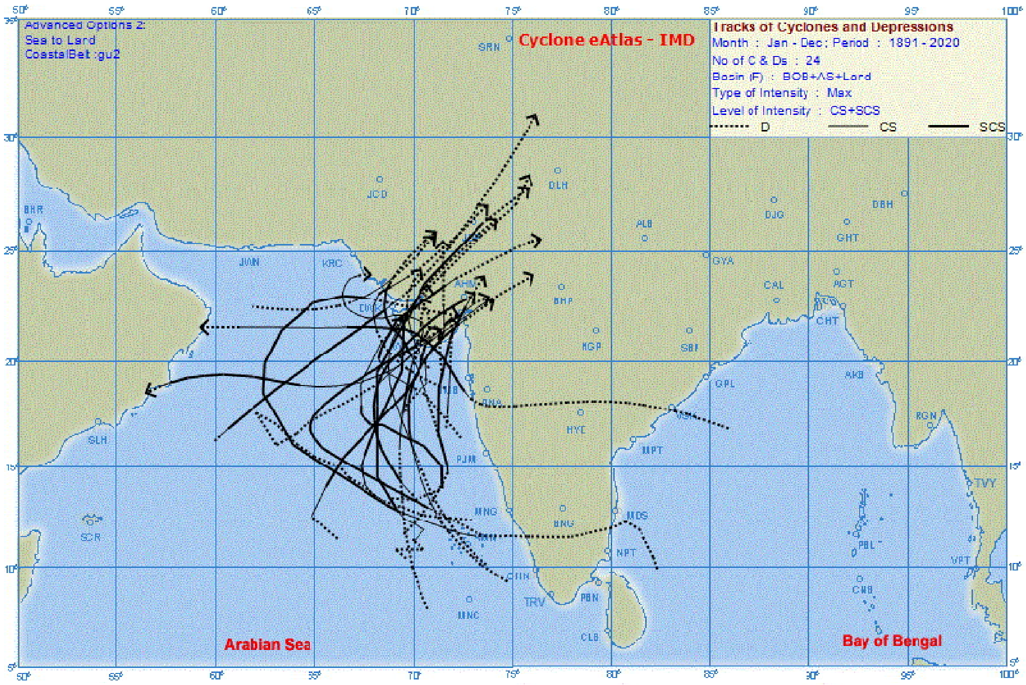

Figure 3. 1 Cyclonic/severe cyclonic storms formed/dissipated over Gulf of Kutch Basin

3.1.1.3 Physical processes

3.1.1.3.1 Tides

Tides in the Gulf are of the mixed, predominantly semidiurnal type with a large diurnal inequality. The tidal front enters the Gulf from the west, and due to shallow inner regions and narrowing cross-section, the tidal amplitude increases considerably upstream of Vadinar. The tidal elevations (m) along the Gulf are as follows:

Table 3. 2 The tidal elevation along Gulf

	MHWS (m)	MHWN (m)	MLWN (m)	MLWS (m)	MSL (m)
Okha	3.47	2.96	1.20	0.41	2.0
Sikka	5.38	4.35	1.74	0.71	3.0
Rozi	5.87	5.40	1.89	1.0	3.6
Kandla	6.66	5.17	1.81	0.78	3.9
Navlakhi	7.21	6.16	2.14	0.78	4.2
Navinal Pt	6.09	5.65	1.81	0.37	3.4

The phase lag between Okha and Kandla is 2 hr to 2 hr 25 min while between Okha and Navlakhi, it is 3 hr to 3 hr 20 min. Due to high tidal ranges in the inner regions, the vast mudflats and coastal lowlands that get submerged during high tide are fully exposed during low tide. Circulation in the Gulf is mainly controlled by tidal flows and bathymetry, though the wind effect also prevails to some extent.

3.1.1.3.2 Currents

The maximum surface currents are moderate (0.7-1.2 m/s) but increase considerably (2.0- 2.5 m/s) in the central portion of the Gulf. The spring currents are 60 to 65 % stronger than the neap currents. The bottom currents are also periodic, with a velocity normally 60-70 % of the surface currents. With a high tidal range, negligible land run-off, and irregular topography, the waters are vertically homogeneous in terms of salinity and temperature.

3.1.1.3.3 Waves

Month wise frequency distribution of maximum wave height showed that In January maximum wave heights were < 0.5 m. In February, the heights varied between 0.1 and 1 m. In May, between 0.5 and 4 m, and in April, between 0.1 and 3.5 m. During the remaining months of the year, maximum wave heights varied between 0.1 and 2.5 m. Month wise per cent frequency distribution of the zero-crossing wave period shows that during June to September, the wave period is mostly between 3 and 7 s. During November, December and February, it varied between 3 and 10 s. In April and May, it varied between 3 and 15 s.

3.1.1.4 Marine environment

Within the Gulf, though water depths of 25 m exist in the broad central portion up to the longitude 70^o E, the actual fairway in the outer Gulf is obstructed by the presence of several shoals. The high tidal influx covers the low-lying areas of about 1500 km^{2,} comprising a network of creeks and alluvial marshy tidal flats in the interior region. The creek system consists of 3 main creeks Nakti, Kandla, and Hansthal, and the Little Gulf of Kachchh interconnecting through many other big and small creeks. Very few rivers drain into the Gulf all along the coast, and they carry only a small quantity of freshwater, except during the brief monsoon. They are broad-valleyed, and their riverbed is mainly composed of coarse sand and gravel. The Gulf is characterized by numerous hydrographic irregularities like pinnacles, as much as 10 m high. The southern shore has numerous islands and islets covered with mangroves and surrounded by coral reefs. The northern shore is predominantly sandy or muddy, confronted by numerous shoals.

3.1.1.4.1 Water quality

The annual variation of water temperature is between 23 and 30^o C though localised higher temperatures up to 35^o C can result in isolated water pools formed in shallow intertidal depressions during low tide. SS is highly variable (5-700 mg/l), spatially as well as temporally, and largely results from the dispersion of fine sediment from the bed and the intertidal mudflats by tidal movements. Evidently, nearshore shallow regions invariably sustain higher SS as compared to the central portions. The region between Okha and Sikka has low Suspended Sediment (SS) varying within a narrow range (10-50 mg/l), whereas the inner Gulf areas contain markedly higher SS, sometimes in excess of 100 mg/l. The average pH of the Gulf water is remarkably constant (8.0-8.3) and is within the range expected for the coastal tropical seas. The evaporation exceeds precipitation leading to salinities markedly higher than that of the typical seawater. This is particularly evident in the inner Gulf, where salinities as high as 40 psu have been reported to commonly occur off Kandla and Navlakhi. Although the salinities decrease considerably for a brief period in some creeks of the Little Gulf of Kachchh under the influence of monsoonal runoff, the impact of this decrease in salinity in the Gulf proper is small, and salinities exceed 36 psu off Sikka and Mundra during normal monsoon periods. The average Dissolved Oxygen (DO) is fairly high (3-5 ml/l), and the Biological Oxygen Demand (BOD) is low (<0.1 – 4.0 mg/l), indicating good oxidizing conditions. Hence, the organic load in the water column is considered to be effectively oxidised. The nutrients (PO_4^{3-}, NO_3^-, NO_2^-, NH_4^+) are more or less uniformly distributed in the OkhaSikka-Mundra segment, and their concentrations indicate healthy natural waters. Their levels, however, are marginally high in the Kandla-Navlakhi segment. The networks of creeks of the Little Gulf of Kachchh sustain high natural concentrations of nutrients, perhaps due to high regeneration rates. As expected for an unpolluted coastal environment, the concentrations of PHC and phenols are low.

Table 3. 3 Minimum, Maximum and Average representation of observed Water quality at Gujarat Basin

Parameter	Minimum	Maximum	Average
Temp (°C)	19.9	31	26
pH	7.9	8.5	8.1
Turbidity (NTU)	4.02	6.8	5.1
SS (mg/l)	7	742	98
Salinity (psu)	32.1	43.7	37.9
DO (ml/l)	2.3	7	4.29
BOD (mg/l)	0.5	4.9	1.8
PO_4^{3-} (µmol/l)	0.3	6.7	1.5
P_{Total} (µmol/l)	1.2	4.2	2.3
NO_3^- (µmol/l)	0.5	31.9	7.2
NO_2^- (µmol/l)	0.1	1.1	0.4
NH_4^+ (µmol/l)	0.1	3.7	0.9
N_{Total} (µmol/l)	6.9	102.7	29.2
PHC (µmol/l)	0.2	14	3.2
Phenols (µmol/l)	2.7	163	36.3

3.1.1.4.2 Sediment quality

The central portion of the Gulf extending from the mouth to upstream of Sikka is rocky, with sediments confined only to the margins. The nearshore sediment that consists of light gray silt and clay and fine sand with patches of coarse sand in-between are poorly sorted with highly variable skewness. The major source of this sediment is considered to be the shore material and the load transported by the Indus River. The portion of sediment derived from the hinterland is considered to be small because of the low run-off. Moreover, the streams discharging in the Gulf (during brief monsoon season) are short, with dams constructed on many of them. The concentrations of heavy metals such as chromium, manganese, cobalt, nickel, copper, zinc, mercury and lead though variable, indicate natural background levels, and there is no evidence of gross sediment contamination. The concentrations of PHC are also low though large quantities of petroleum crude and its products are off-loaded at Vadinar and Kandla, respectively.

Table 3. 4 Minimum, Maximum and Average representation of Sediment quality at Gujarat Basin

Constituents	Minimum	Maximum	Average
Al (%)	0.4	8.7	5
Cr (µg/l)	1.2	176	74
Mn (µg/l)	389	1450	726
Fe (%)	0.5	38	4
Co (µg/g)	5	54	26
Ni (µg/g)	14	70	43
Cu (µg/g)	7	78	34
Zn (µg/g)	15	126	66
Hg (µg/g)	0.009	0.62	0.15
Pb (µg/g)	1.2	20	9.8
C (%)	0.1	1	0.5
P (µg/g)	189	812	602
PHc (µg/g)	0.1	3	0.7

3.1.1.4.3 Flora and fauna

The Gulf abounds in marine wealth and is considered as one of the biologically richest marine habitats along the west coast of India. The marine flora is highly varied, including sand dune vegetation, mangroves, seagrasses, macrophytes, and phytoplankton. The dominant species of sand dune flora are *Euphorbia caudicifolia*, *E.nerifolia*, *Aloevera sp*, *Ephedra foliata*, *Urochodra setulosa*, *Sporobolus maderaspatenus, Eragrostis unioloides,* *Calotropis procera, Fimbristylis sp, Indigofera sp* and *Ipomoea pescaprae*. The common seagrasses found growing on the mudflats are *Halophila ovata*, *H.beccarii* and *Zostrea marina*. The most common marine algal species are *Ulva fasciata, U.reticulata, Enteromorpha intenstinalis, Dictyota sp, Hypnea musciformis, Sargassum tennerimum, S.ilicifolium, Gracilaria corticata, Cystocera sp, Padina tetrastomatica, Corallina sp, Laurencia sp, Caulerpa racemosa, C.peltata, Bryopsis sp, Turbinaria sp, Ectocarpus sp, Acanthophora sp, Chondria sp,* and *Codium sp*. The primary production of the water column as assessed from chlorophyll-a concentration is generally good in the outer Gulf but decreases in the inner regions. The major phytoplankton genera are *Rhizosolenia, Synedra, Chaetoceros, Navicula, Nitzschia, Pleurosigma, Thalassiothrix, Biddulphia, Stauroneis, Coscinodiscus* and *Skeletonema*. The Gulf has a vast intertidal area with rich biota. Sheltered bays, creeks and mudflats provide ideal sites for mangrove vegetation over an estimated area of about 1036 km^2. The formations are of open scrubby type, with isolated and discontinuous distribution from KandlaNavlakhi in the northeast to Jodia, Jamnagar, Sikka, Salaya and Okha in the southwest, as also at Pirotan, Poshitra, Dohlani and Dwarka. Vast stretches of mangroves also exist along the northern shore of the Gulf. The dominant species of mangroves are *Avicennia marina var acutissima, A officinalis, Bruguiera parviflora, B gymnorphiza, Rhizophora mucronata, R apiculata, Ageiceros corniculata* and *Sonneratia apetata* along with the associated species of *Salicornia brachiata, Sueda fruticosa, Artiplex stocksii* and a lichen, *Rosella montana*. The marine fauna of the Gulf is rich, both in variety and abundance. Sponges having an array of colours are seen, both in the intertidal and subtidal biotopes. The common species of sponge is *Adocia sp*, associated with coral reef fauna. In sandy and silty mud shores, *Tetilla dactyloidea* (Carter) is common. The most frequently encountered hydrozoans are *Sertularia sp* and *Plumularia sp*. The giant sea anemone (*Stoichactis gigantum*) is a common sight in the coral ecosystem. Sea anemones, belonging to *Anemonia, Bunodactis, Paracondylactis, Anthopleura* and *Metapeachia*, are widespread. A zoantharian, *Gemmaria sp*, is found forming extensive hexagonal green mats in the coral pools. Another interesting actiniarian is the *Cerianthus sp* found in tubes in the soft mud.

One of the most interesting biotic features of the Gulf is the presence of living corals, thriving as patches, rather than reefs, either on the intertidal sandstones or on the surface of wave-cut, eroded shallow banks along the southern shore of the Gulf. However, the species diversity is poor with the identification of 44 species of Scleractinian and 12 species of soft corals. Several polychaete worms, both *sedentaria* and *errantia*, with the dominant genera of *Eurythoe, Terebella, Polynoe, Iphione* and *Nereis* are rather common. Amongst a variety of sipunculid and echiuroid worms, the dominant species are *Dendrosromum sp, Asphidosiphon sp* and *Ikadella misakiensis* (Ikeda). The intertidal crustacean fauna is very rich and equally diverse, with spider crab (Hyas sp) and furry crab (*Pillumnus sp*), as specialities. Amongst the invertebrate component of the marine fauna of the Gulf, the molluscs have the highest representatives. As many as 92 species of bivalves, 55 species of gastropods, 3 species of cephalopods and 2 species each of scaphopods and amphineurans have been reported. The most notable members of the molluscan fauna are octopus, pearl oyster, and various chanks, including the sacred chank. The echinoderm fauna, represented by four classes and 14 genera, have the commonest genera of *Palmpsis, Astropecten, Asteria, Temnopleura* and *Holothuria*. The subtidal benthic fauna of the Gulf is dominated by polychaetes, crustaceans, echinoderms, gastropods and bivalves, with average biomass of 25 g/m^2. The Gulf has a variety of exploitable species of finfishes and shellfishes. Sciaenids, polynemids, perches, eels, cat-fishes, elasmobranchs and prawns are the commercially important groups with an average catch of 1.4x105 t/y. Fishing grounds for Ghol, Karkara, Khaga, Dhoma, Magra and Musi exist in the Gulf. The Gulf region offers plenty of facilities for feeding, breeding and shelter to a variety of birds. In the mangrove forests lining the islands and along the coast, the birds find a near-perfect environment. In addition, they are well placed to reach their food supply, i.e. the shoals of fish, squids, mud-skippers and other animals, during low tide. All along the creeks and around islands, mangrove trees and mudflats are seen crowded with Grey Herons, Pond Herons, Painted Storks, Large and small Egrets, Reef Heron, Darters, Cormorants, Flamingos, Lesser Flamingos, etc. during the periods of seasonal migration (November-March). Many migratory birds pass through the Gulf and a small population of most species comprising mainly juveniles, and non-breeding adults take shelter in this area during summer. Saltworks spread out along the coast are also important for feeding and breeding of birds. They act as alternate sites for them to roost during high tide. Though a detailed systematic survey of biota is lacking, a number of species have been reported is shown in table 3.5. Because of its high biogeographical importance and rich flora and fauna, several areas along the southern Gulf are notified under the Marine National Park (16289 ha) and the Marine Sanctuary (45798 ha).

Table 3. 5 Flora/Fauna of Gulf

Flora/Fauna	Species (no)
Algae	130
Sponges	70
Corals	37
Fishes	200
Sharks	8
Prawns	27
Crabs	30
Molluscs	200
Sea turtles	3
Sea mammals	3
Birds	200

Table 3. 6 Minimum, Maximum and Average Biological characteristics of Gulf

Phytoplankton			
	Miimum	Maximum	Average
Chlorophyll a (mg/m^3)	0.2	4.3	1.2
Phaeophytin (mg/m^3)	0.2	1.8	0.6
Cell counts ($nox10^3/l$)	6	412	51
Total genera (no)	7	25	12
Zooplankton			
Biomass ($ml/100m^3$)	0.5	53	7
Population ($nox10^3/100m^3$)	0.3	117.3	26.8
Total groups (no)	7	22	13
Macrobenthos			
Biomass (g/m^2, wet wt)	0.1	15.2	3.2
Population (no/m^2)	6.9	5700	907
Total groups (no)	1	17	6

Table 3. 7 Marine fish landings (t x10^3/y) of Gujarat State and districts adjoining the Gulf. Source: Department of Fisheries, Government of Gujarat

Year	State	Jamnagar	Rajkot	Kachchh	Total contribution By districts (%)
1965-66	109.9	4.2	--	2.4	6.0
1966-67	115.2	2.8	--	3.0	5.0
1967-68	124.9	3.8	--	3.3	5.7
1968-69	131.7	2.8	--	2.3	3.8
1969-70	140.0	2.9	--	2.7	4.0
1970-71	151.2	4.7	--	3.9	5.7
1971-72	147.0	5.5	--	4.1	6.5
1972-73	151.2	4.6	--	4.8	6.2
1973-74	177.6	6.8	--	6.9	7.7
1974-75	157.4	3.0	0.3	4.3	4.8
1975-76	208.3	5.1	2.2	3.8	5.3
1976-77	225.4	21.7	1.3	5.4	12.6
1977-78	176.9	14.5	0.4	6.3	12.0
1978-79	230.0	21.8	2.7	6.3	13.4
1979-80	206.7	24.8	0.6	5.7	15.0
1980-81	218.9	32.3	1.7	4.4	17.5
1981-82	220.6	34.2	2.0	6.3	19.3
1982-83	192.7	29.7	0.5	13.8	22.8
1983-84	223.3	27.4	1.3	23.3	17.3
1984-85	290.7	31.5	0.7	34.3	22.9
1985-86	306.6	25.2	1.7	35.4	20.3
1986-87	315.9	28.0	0.5	31.3	18.9
1987-88	327.6	40.2	0.5	29.7	21.5
1988-89	414.1	44.2	2.8	46.9	22.7

Year	State	Jamnagar	Rajkot	Kachchh	Total contribution By districts (%)
1989-90	432.4	45.4	2.5	49.6	22.5
1990-91	500.5	54.3	1.8	65.4	24.3
1991-92	530.0	63.5	2.7	61.8	24.1
1992-93	609.1	66.2	1.1	63.0	21.4
1993-94	619.8	58.9	1.5	63.2	19.9
1994-95	645.3	58.9	1.5	76.8	21.0
1995-96	598.4	68.1	1.0	72.6	23.7
1996-97	660.1	76.2	0.9	76.7	23.3
1997-98	702.4	56.0	0.8	71.8	18.3
1998-99	551.7	28.6	0.2	69.7	17.9
1999-00	671.0	71.7	0.8	75.0	22.0
2000-01	620.5	72.6	1.7	64.7	22.4
2001-02	650.8	83.4	2.1	80.0	25.4
2002-03	743.4	102.8	1.5	80.7	24.9
2003-04	609.1	37.9	1.7	72.0	18.3
2004-05	585.0	45.9	1.9	64.7	19.2
2005-06	663.9	66.5	1.5	62.4	19.6

3.1.2 Saurashtra Basin

3.1.2.1 Land Environment

Saurashtra Basin is located in the northern part of the western continental margin of India, which trends NNW-SSE. The onland part of the basin is also known as Saurashtra Peninsula. This basin lies north of commercially proven Mumbai Offshore and south of the highly prospective Kutch basin. The onland part of the basin borders with the commercially proven Cambay Basin on its eastern flanks. The deeper offshore Saurashtra borders with the Indus fan (to the abyssal plain of the Arabian Sea). Offshore Saurashtra, the shelf extends much less than its average extension on the western offshore (i.e. 160km). The shelf break also occurs at a water depth of 200m itself. The seabed physiography is that of moderately to steeply sloping shelf followed by steep shelf break. Saurashtra consists of Rajkot, Junagadh, Porbandar, Jamnagar, Bhavnagar, Amreli, Dwarka, Somnath, Morbi and Surendranagar. The majority of soils in Saurashtra region are clayey (fine textured). Some scattered parts of the coastal area of the Saurashtra region are saline. The western coastal strip of Saurashtra displays variegated geomorphic features with numerous cliffs rising up to 25 m, islets, extensive tidal flats, deposits of littoral concrete in rocky beaches, sandy beaches, bars, dunes and corals. The peninsular Saurashtra is extensively covered by the Deccan traps, mainly of basalts and dolomites. The topography of the region is gently sloping towards the sea, except for small hillocks of Milliolitic limestone. The Deccan traps, forming the mainland of Saurashtra, is exposed over vast areas, except for a narrow coastal belt along the southwest Saurashtra. Quaternary formations consisted of Milliolitic limestone and alluvium from the narrow coastal strip. The solubility of limestone in water is responsible for creating a coarse topography, where limestone is exposed. The rock surface is pock-marked with various sizes of circular holes, cavities and caverns, and precipitation finds its way to the water table in limestone areas largely through these holes. The coast forms a straight coastline revealing a vivid manifestation of the interaction of marine, aeolian and fluvial processes that have resulted in a number of important geomorphic landforms. The nearshore zone is characterised by the formation of recent alluvium deposits, sand bars, mudflats, mangrove swamps, beach and littoral sands, oyster beds and sand dunes. The inland zone consists of lithophyte beach, beach rocks and Milliolitic limestone of marine and aeolian origin. The white to pale brown limestone strata has a thickness of 30 - 45 m.

3.1.2.2 Meteorological/Physical parameters at Saurashtra basin

The normal wind system in the area is basically seasonal with a reversal of directions. High wind speeds for a greater percentage of time occur during May to July. The predominant direction of these winds is between the west and south-west. The annual rainfall varies from 700 mm at Veraval to 450 mm at Okha, with 80 per cent precipitation occurring during June-August. The tides in the region are mixed semidiurnal types with a large diurnal inequality. The mean high water spring increases from 2.09 m at Veraval to 3.47 m at Okha; the respective increase during neap is from 1.82 m at Veraval to 2.96 m at Okha. The coastal marine belt of the Porbandar district has a relatively high biological potential, encouraging the development of excellent facilities for marine fisheries. The bottom topography with occasional outcrops of rocks. The irregular bathymetry could be due to large scale sediment movement, probably as a side-effect of the breakwater protecting the harbour. Currents are very weak off Porbandar. The current speed responds weakly to the tidal fluctuations, and the spring/neap tides variations are not large. The bottom profiles of the nearshore waters off Porbandar are irregular towards the harbourside, and the submarine obstructions on the southeastern side pose navigational problems. Past studies indicate that the physicochemical parameters of the coastal waters of Porbandar are homogenous vertically as well as laterally. The coastal waters of Porbandar are reported to have good water quality. Phytoplankton pigments and populations indicated wide variations. The biological characteristics of the area are comparable to those normally observed in the nearshore waters of India.

Table 3. 8 Meteorological/Physical parameters at Saurashtra basin

Parameter	Minimum	Maximum	Average
Wind speed (m/s)	1.2	13.5	4.4
Surface air pressure (pa)	98188	101172	100132
Air temperature (^oC)	19.5	29.7	25.8
Sea surface Temperature (^oC)	23.7	30.8	27.6
Sea surface Salinity (psu)	36.2	37.7	36.6
Relative humidity (%) 1000hpa	25	88	72
Net shortwave radiation flux (W/m^2)	30	239	167
Net long wave radiation flux (W/m^2)	-110	13	-53
Latent heat net flux (W/m^2)	-1.3	156.4	55.5
Sensible heat net flux (W/m^2)	-23.9	154.9	58.7
Cyclones			
A total of 6 cyclonic/severe cyclonic storms were formed/dissipated over Saurashtra Basin			

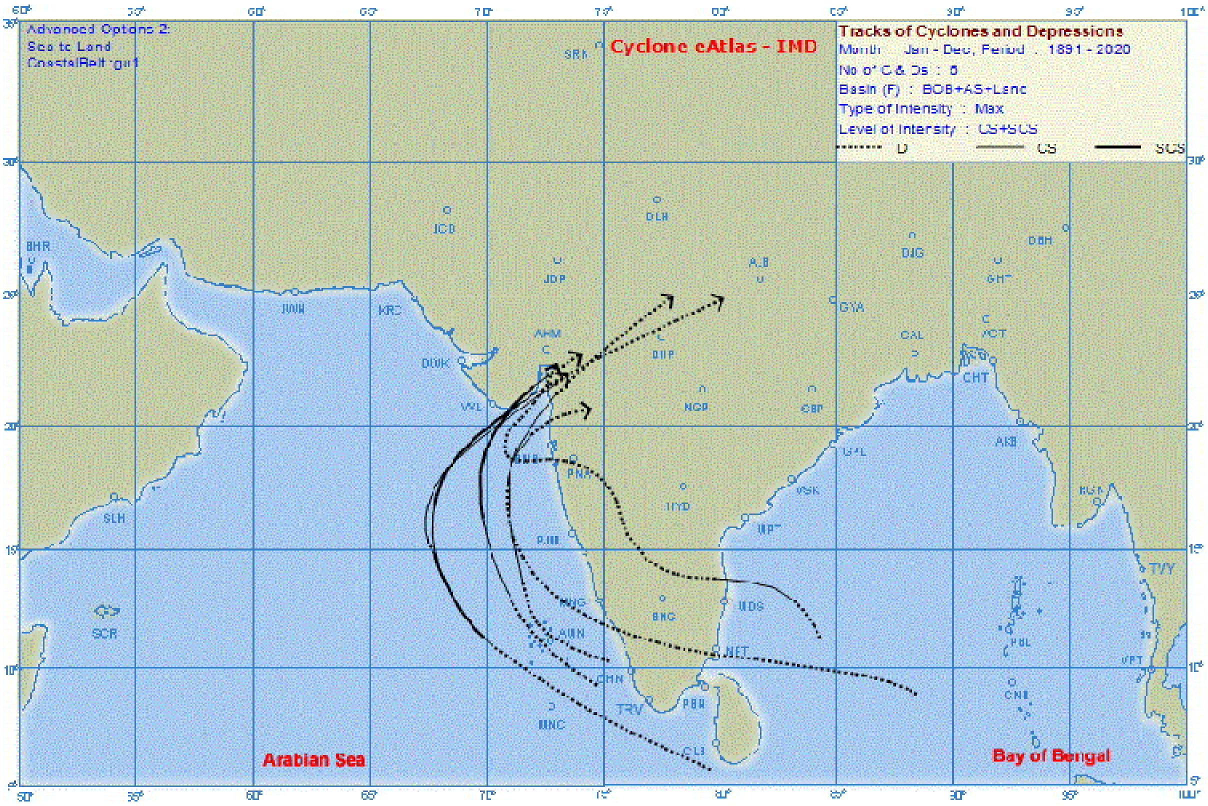

Figure 3. 2 Cyclonic/severe cyclonic storms were formed/dissipated over Saurashtra Basin

3.1.2.3 Physical process

3.1.2.3.1 Tides

The tides along the coast off Porbandar are mixed semi-diurnal, with two unequal high and two unequal low waters occurring in each tidal day. The tidal range decreases considerably from Okha to Porbandar. The maximum observed tide was 2.7 m, and the minimum neap tidal range was 1 m.

Table 3. 9 The tidal elevation along Saurashtra Basin

Level	Okha	Porbandar
MHWS (m)	3.47	2.66
MHWN (m)	2.96	2.38
MSL (m)	2.04	1.82
MLWN (m)	1.20	1.46
MLWS (m)	0.41	0.77

3.1.2.3.2 Currents

Currents recorded during March for a period of 10 days indicated that the maximum current speed observed was 0.2 m/s. The currents varied between 120^o and 340^{o,} indicating that currents run parallel to the coast.

3.1.2.3.3 Wave

Table 3. 10 Wave Characteristics along Saurashtra basin in meters

Sl. no.	Location	Longitude	Latitude	Significant wave height
1	Dahanu	72.72	19.97	2.48
2	Dahej Bandar	72.55	21.73	0.21
3	Dwarka	68.95	22.27	2.89
4	Godia creek	68.60	23.20	2.36
5	Gulf of Kambhat-north	72.55	22.20	0.01
6	Gulf of Kambhat-west	72.20	22.00	0.06
7	Hansthal	70.35	22.93	0.40
8	Jafarabad	71.38	20.87	2.51
9	Kori creek	68.45	23.50	0.36
10	Koteshwar	68.53	23.68	0.36
11	Mandvi	69.35	22.83	1.99
12	Miyani	69.38	21.83	3.00
13	Navinal	69.72	22.73	1.19
14	Navibandar	71.08	20.75	2.51
15	Okha	69.08	22.47	2.04
16	Pipavav	71.57	20.92	1.74
17	Salaya	69.62	22.37	1.04
18	Saurastra coast	69.90	21.35	2.99
19	Sikka	69.82	22.43	1.02
20	Sultanpur	72.23	21.28	1.02
21	Suvali	72.62	21.18	0.72
22	Tapi river (Hazira)	72.67	21.13	0.72
23	Valsad	72.88	20.63	1.79
24	Veraval	70.37	20.90	2.98

3.1.2.4 Marine Environment

3.1.2.4.1 Water quality

Water temperature was in the range of 22.5-31.2 °C. The average pH of the basin was 7.9-8.5 and was in the range of seawater. The average concentration of SS was in the range of 9.3 to 45.3 mg/l. The salinity values were as expected for coastal seawaters (36.0-37.0 psu), with no freshwater influx. The average DO concentration was in the normoxic range (DO value 6.0 mg/l or above), indicating good oxic condition in the region. Low BOD (1.2-3.1 mg/l) values indicated that the area was free from any organic load. Concentrations of nitrogen and phosphorous compounds in the coastal waters of Porbandar were low except for NH4 $_{+}$ $^{-}$N. A comparably high concentration of $NH_4{}^{+}$ -N during ebb indicates its association with effluent. The PHC values (4.1-10.3 µg/l) were in the range generally observed in the nearshore coastal waters. Concentrations of phenols were higher in the nearshore regions in comparison to the offshore, indicating some anthropogenic perturbations. Comparison with previous data indicated that the coastal waters of the Saurashtra basin had good water quality, ammonia and phenols.

Table 3. 11 Minimum, Maximum and Average Water quality of Saurashtra Basin

Parameter	Minimum	Maximum	Average
Water temperature (°C)	22.5	31.2	25.3
pH	7.9	8.5	8.1
Suspended solids (mg/l)	9.3	45.3	22.7
Salinity (psu)	35	36.7	35.9
DO (mg/l)	6.0	7.1	6.6
BOD (mg/l)	1.2	3.1	1.7
PO_4^{3-} (µmol/l)	0.4	1	0.6
NO_3^- (µmol/l)	0.2	14.7	3.9
NO_2^- (µmol/l)	0.1	1.3	0.4
NH_4^+ (µmol/l)	1.2	3	1.9
PHc (µg/l)	4.1	10.3	6.6
Phenols (µg/l)	23.4	122.1	84.2

3.1.2.4.2 Sediment quality

Sediment analyses indicated that the intertidal sediment texture was sandy 93.2 to 97.8% sand, whereas the subtidal sediment texture was clayey-silt with 58.3 to 90.6 % silt. The results also clearly indicated that there was no accumulation of heavy metals, organic carbon, phosphorus and PHC in the study area sediments. The concentration of trace metals in the study region was in the range generally observed in the uncontaminated sediments. Hence, there was no build-up of trace metals in the sediment of the study region. The Saurashtra basin indicated the variation during different sampling events, which is summarized below:

Table 3. 12 Minimum, Maximum and Average Sediment quality of Saurashtra Basin

Parameter	Minimum	Maximum	Average
Al (%)	4	6.3	5.1
Cr (μg/g)	56.5	102	79
Mn (μg/g)	490.7	623	567
Fe (%)	2.3	4.6	3.5
Co (μg/g)	10	39.7	24
Ni (μg/g)	14	66.3	44
Cu (μg/g)	26	60.6	44
Zn (μg/g)	39.5	82.7	62
Ca(μg/g)	22	31.2	25.7
Hg (μg/g)	0.1	0.1	0.1
P (μg/g)	555	1049	856
Corg (%)	0.8	1.4	1
PHC (μg/g)	1.1	7.4	3.3

3.1.2.4.3 Flora and fauna

During both March and November, the distribution of chlorophyll a was patchy, with values fluctuating from 0.4 to 23.8 mg/m3 (av. 4.9 mg/m3) and 0.2 to 5.3 mg/m3 (av 1.9 mg/m3), respectively. A decline in the chlorophyll value as compared to 1981-1982 was observed. High ratios of concentrations of chlorophyll a and phaeophytin in most regions indicated healthy conditions for the growth of phytoplankton. Diurnal observations indicated higher phytopigment concentrations during ebb as compared to flood. Overall, 49 (March) and 38 (November) genera of phytoplankton were identified during recent studies. Overall, the phytoplankton results revealed good productivity in terms of the phytoplankton population with fairly good generic diversity. The intertidal area, being rocky and sandy, was devoid of mangrove vegetation. The present zooplankton biomass was lower as compared to the 1981-82 data. Overall, 18 and 21 groups of zooplankton were observed during March and

November, respectively. Decapod larvae occurred in all zooplankton samples but contributed only about 2.2% and 0.3% during March and November, respectively, to the zooplankton population. Fish eggs were present in low numbers (0.1%) during March, but considerable numbers (2.6%) were present in the zooplankton samples during November. Fish larvae, though at a low percentage, were encountered in most zooplankton collections. The macrobenthic abundances of the intertidal zones near the intake and outfall were comparable during March. The major faunal component in the study area were polychaetes during both seasons. Overall, 11 and 14 faunal groups were recorded in the area during March and November, respectively. Porbandar is one of the major marine fish landing stations in Gujarat, and from January to December, the total landing was $3.0x10^7$ t. September to May is the peak fishing period, while the period from June to August is the lean season.

Table 3. 13 Minimum, Maximum and Average Biological characteristics of Saurashtra Basin

	Phytoplankton		
	Minimum	Maximum	Average
Chlorophyll a (mg/m^3)	0.2	8.5	3.5
Phaeophytin (mg/m^3)	0.5	0.6	0.5
Cell counts (nox10^3 cells/l)	10.3	1092.9	440
Total genera (no)	8	17	12
	Zooplankton		
Biomass (ml/100m^3)	3.3	33.5	12.5
Population (nox10^3/100m^3)	15.2	46.6	29
Total groups (no)	10	14	11
	Macrobenthos		
Biomass (g/m^2, wet wt)	7.9	65.4	34.8
Population (no/m^2)	547	18913	6086
Total groups (no)	2	3	3

Table 3. 14 The year-wise total marine fish landing (t) of Porbandar from 2010-2015.

Year	Total (x10^7 t)
2010-11	8.3
2011-12	9.2
2012-13	10.2
2013-14	10.6
2014-15	10.6

3.1.3 Mumbai offshore

3.1.3.1 Geology of Mumbai Offshore Basin

Mumbai Offshore basin is located on the western continental shelf of India between the Saurashtra basin in NNW and Kerala Konkan in the south. Mumbai offshore is a pericratonic rift basin situated on the western continental margin of India. Towards NNE it continues into the inland Cambay basin. It is bounded in the northwest by the Saurashtra peninsula, north by Diu Arch. East-west trending Vengurla Arch marks its southern limit to the South of Ratnagiri and to the east by Indian craton. Five distinct structural provinces with different tectonic and stratigraphic events can be identified within the basin, viz. Surat Depression (Tapti-Daman Block) in the north, PannaBassein-Heera Block in the east-central part, Ratnagiri in the southern part, Mumbai High-/ Platform-Deep Continental Shelf (DCS) in the mid-western side and Shelf Margin adjoining DCS and the Ratnagiri Shelf. Mumbai offshore basin has been blessed with both clastic and carbonate reservoir facies in almost total Tertiary sections ranging from Paleocene to Middle Miocene.

3.1.3.2 Climate and Meteorology

Mumbai Offshore Basin has a tropical wet and dry climate under the Koppen climate classification. The area/region does not experience distinct seasons, but the climate can broadly be classified into two main seasons—the humid season and the dry season. Usually, the period between October to May is relatively dry. The region gets southwest monsoon rains beginning June to end September, with peak rains occurring in July. Occasionally, northeast monsoon showers occur in October and November. The Mumbai offshore area is in the Arabian Sea off the Northwest coast of India. The Arabian Sea that forms the part of the Indian Ocean north of the equator is separated from the deep-reaching vertical convection areas of the northern hemisphere by the Asian continent. Such an asymmetric configuration leads to a weak circulation and poor renewal at depths in the Arabian Sea.

According to the National Oceanic and Atmospheric Administration (NOAA), the maximum and minimum value of mean sea surface temperature in the Arabian Sea is of the order of 30.8ºC and 26.04 ºC, respectively. As per available data with Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, the maximum and minimum value of mean air temperature in the Arabian Sea is of the order of 30.2ºC and 24.04 ºC, respectively. The average hourly wind speed shows significant seasonal variation over the course of the year. The windier part of the year lasts for 2.9 months, from June 1st to August 30th, with average wind speeds of more than 10.6 miles per hour. The dispersion of pollutants is influenced by the wind speed and wind direction for an area. It is considered as important data for predicting the air quality impacts. The prominent wind direction is from the Northwest (44%). The highest wind speed observed from the northwest direction was more than or equal to 11.10 m/s. As per available data with Physical Sciences Division, Earth System Research Laboratory, NOAA, Boulder, Colorado, the Predominant significant wave height and zero-crossing period are 50 to 70 cm and 8 to 8.5 sec, respectively. The predominant wave periods and wave heights are 5-6 sec and 0.5 to 1.5 m respectively during the fair-weather season (October-May) and 5-9 sec and 1-3 m respectively during the rough weather season (June-September). A wide range of wave heights 0.5-5 m occurs during the rough season. The tides in the offshore area are of the mixed semi-diurnal type with a large diurnal inequality. The gulf water behaves as a homogeneous one-layered structure due to high tidal range, low runoff from land, shallow depth, and irregular bottom topography – all suitable for turbulent flow field. Unpredictable rip currents may show up due to the difference in shelf/depth together with weather patterns. The area is within the monsoon belt, experiencing south-westerly, rain-bearing winds from June to September followed by dry wind spell from October to May. The land segment nearest to the block falls between Diu and

Bhavnagar section on the Saurashtra coast. The climate is semiarid, with an average rainfall of 500 to 600 mm. The west coast is less prone to depressions and cyclones as compared to the east coast of India. The frequency of cyclonic disturbances varies significantly with the season. Generally, cyclonic conditions prevail during May-June and become more frequent in July-November, while the weather is relatively tranquil during February-March.

Table 3. 15 Meteorological/Physical parameters at Mumbai basin

Parameter	**Minimum**	**Maximum**	**Average**
Wind speed (m/s)	0.6	11.4	2.5
Surface air pressure (pa)	98480	101164	100125
Air temperature (^{o}C)	20.5	29.3	26.2
Sea surface Temperature (^{o}C)	25.3	30.4	28.3
Sea surface Salinity (psu)	35.7	36.8	36.1
Relative humidity (%) 1000hpa	45.2	91.1	74.7
Net shortwave radiation flux (W/m^2)	24.6	247.5	168.4
Net long wave radiation flux (W/m^2)	-104	14	-36
Latent heat net flux (W/m^2)	24	252	108
Sensible heat net flux (W/m^2)	-188	165	22.6
Cyclones			
A total of 11 cyclonic/severe cyclonic storms were formed/dissipated over Mumbai Basin			

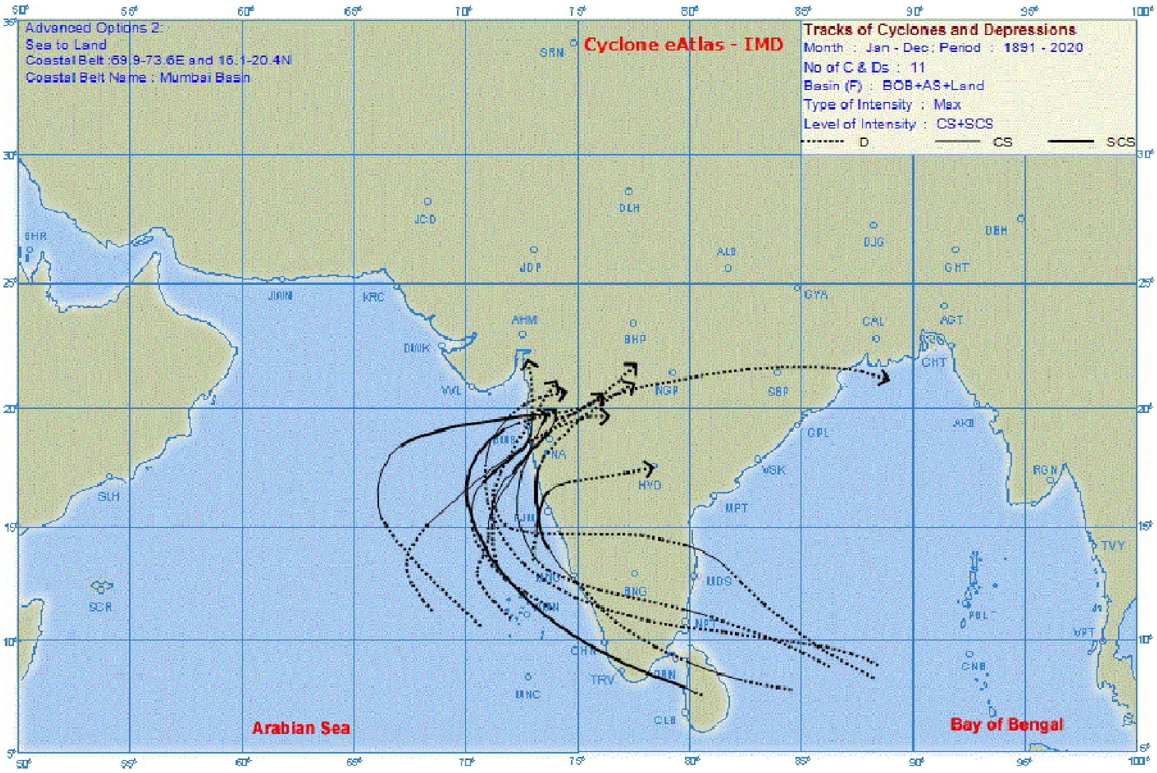

Figure 3. 3 Cyclonic/severe cyclonic storms were formed/dissipated over Mumbai Basin

3.1.3.3 Physical Process

3.1.3.3.1 Tides

Circulation is mainly controlled by tidal flows and bathymetry. The observed large tidal range (up to 3 m during spring tide) at the Mumbai High offshore region located near the continental shelf break, off the central west coast of India. The measured tides were harmonically analysed and the amplitudes and phases of the five major constituents, i.e. M2, S2, K1, O1 and N2 were compared with those observed at the closest coastal station (Apollo Bandar, Mumbai). It was found that the observed tidal range at this offshore location was unusually larger than those found in the open-ocean regions. This large tidal range was found to be associated with the large width of the continental shelf off the central west coast of India.

Table 3. 16 Amplitudes and phases of tidal constituents at Mumbai High. The phases (g) are with respect to Greenwich

Constituent	Amplitude (cm)	Phase (g) in degrees
M_2	73.8	342.5
S_2	28.7	18.9
N_2	17.2	319.2
K_1	45.0	61.5
O_1	18.9	53.7

Table 3. 17 Amplitudes and phases of major tidal constituents at Apollo Bandar (Mumbai). The phases (g) are with respect to Greenwich

Constituent	Amplitude (cm)	Phase (g) in degrees
M_2	123.0	345.0
S_2	48.0	25.0
N_2	29.0	326.0
K_1	42.0	55.0
O_1	20.0	52.0

3.1.3.3.2 Currents

Strong currents normally occur during mid-tide, i.e. 2-3 hr before and after low and high tides. The spring currents are 60-65% stronger than the neap currents. The surface currents are moderate (0.7 to 1.2 m/s) but increases considerably (2.0-2.5 m/s). The bottom currents are periodically strong with bimodal directions generally parallel to the uneven bottom contour. The associated tidal currents are fairly strong and bimodal in nature, having two dominant directions – upstream during flood and downstream during an ebb in all-encompassing oscillatory motions. However, the circulation pattern in the nearshore areas is modified considerably due to the presence of creeks and inlets.

3.1.3.3.3 Waves

The lowest waves are found in January with monthly mean Significant wave height (H)s values of ~ 0.5 m. The waves progressively increase in height from January and reach the highest value (~3.6 m) in June with a monthly average Hs of 1.9 m and then decrease in height and reach the lowest monthly average (~0.4 m) in November. High waves (Hs ~1.5 to 2.5 m) observed during 4-5 December 2017 is due to the tropical cyclone Ockhi which originated in the eastern Andaman Sea on 21 November 2017 and dissipated near the south coast of Gujarat on 6 December 2017. The wave height exhibited greater values than the annual mean (~0.91 m) during the monsoon months (June-September) and smaller values than the annual mean during the rest of the year. During June and July, the Hs is always greater than 1 m. Partitioning the wave spectrum into locally generated waves and remotely generated swells based on partition algorithm indicates that the swell Hs varies from 0.2 to 3.2 m with a mean of 1.2 m during the monsoon and that due to wind-sea are from 0.1 to 2.5 m with a mean of 0.8 m. During the non-monsoon, swell Hs varied from 0.1 to 2.4 m with a mean of 0.3 m and the wind-sea Hs varied from 0.1 to 1.4 m with a mean value of 0.5 m. The annual mean (0.61 m) wind-sea Hs amplitude is generally comparable to that (0.62 m) of the swell Hs. The annual mean Hs for the study area is slightly less than that (~ 1-1.1 m) reported for other locations in the eastern Arabian Sea (Sajiv et al. 2013; Kumar et al. 2014) due to the decrease in the swell Hs. The Hmax varied from 0.3 to 5.7 m with an average value of 1.4 m. Since the waves are measured in the nearshore waters, the crest height is more than the trough height. The crest heights of the individual wave in a 30-minute record vary from 0.56 to 0.86 times the wave height with an average value of 0.6. In the same 30-minutes record, the crest heights more than 3 m is 1.0 to 1.6 times the Hs of the same 30-minutes data.

The variation of the mean wave period over an annual cycle is 2.4 to 8.9 s, with a mean value of 4.6 s. Waves are with a low mean wave period during January to March with average values of 3.8 s and the wave period is relatively high during June. The largest mean wave period (~8.9 s) is during the tropical cyclone Ockhi, whereas the highest value during the monsoon is 8.6 s. A wide range (2 to 22 s) is observed in the peak (most energetic) wave period with a mean value of 10 s, indicating that the wave regime of the study area consists of short to long-period waves. Compared to Hs, the Tp displays a large temporal variability within one month period. The occurrence of these short-term shifts in Tp with negligible variation in Hs is due to the presence of two wave regimes (swells and the wind-sea) and the predominance of one over the other. Lowest Tp occurs during April, with a monthly average value of 7.8 s due to the larger presence of wind seas compared to other seasons. The Highest Tp (monthly average value of 12.1 s) is during October, when long-period swells with relatively small wave heights (Hs < 1 m) are predominant. During the monsoon months, even though strong wind forcing is present, the smaller Tp values do not occur in because of the larger presence of young swells. Long-period waves with Tp more than 15 s are observed during 21, 16, 15, 15% of the time in March, October, May and December, and these waves are with Hs less than 1 m except during 1% of the time in May.

3.1.3.4 Marine Environment

3.1.3.4.1 Water quality

In the Mumbai Basin, the temperature varied from 25.1-28.3 °C. The salinity showed a variation of 35.1-38.77 PSU. pH varied from 6.86-8.16. The turbidity showed a maximum fluctuation of 10-57 NTU. Similarly, suspended solids were also showing fluctuation of 10-139 mg/l. Dissolved oxygen in the Mumbai basin was shown the variation of 3.3-6.8 mg/l. Among the nutrients, Nitrite (NO_2^-) was below detectable; Nitrate (NO_3^-) was varied as 0.07-6.32 µmol/l, Phosphate as 0.07-0.62 µmol/l and silicate was varying as 0.05-2.94 µmol/l , TPH was below detectable**.**

Table 3. 18 Water quality of Mumbai Basin

Parameter	Minimum	Maximum	Average
Temperature^{0}C	25.1	28.3	26.7
Salinity (PSU)	26.5	37.5	32.9
pH	6.86	8.16	7.5
Turbidity (NTU)	10	57	26
Suspended solids mg/l	10	139	68
Dissolved oxygen in mg/l	3.3	6.8	5.2
Nitrite (NO_2^-) in µmol/l	BDL	BDL	BDL
Nitrate (NO_3^-) in µmol/l	0.07	6.32	2.26
Phosphate (PO_4^{3-}) in µmol/l	0.07	0.62	0.26
Silicate (SiO_4^-) in µmol/l	0.05	2.94	0.3
Hydrocarbon TPH in µg/l	BDL	BDL	BDL

3.1.3.4.2 Heavy Metals in Seawater

The concentrations of heavy metals viz., Vanadium, Chromium, Manganese, Iron, Cobalt, Nickel, Copper, Zinc, Arsenic, Cadmium, Barium and Lead in the seawater samples collected from the surface, mid-depth and above bottom have been tabulated in Table 3.19. The average concentrations of various heavy metals lying in different portions of the study domain are given in below. Ranges of certain significant heavy metals that can cause a threat to aqua life in higher concentrations than the usual oceanographic ranges may be considered to have a close watch from a pollution point of view.

The data shows that the distribution of heavy metals in the water column did not reveal any clear pattern either vertically or horizontally. The spatial distribution also did not yield any clear trend of either enrichment or depletion. The heavy metal concentrations observed in the reference stations around Bombay high are slightly lower to the values recorded near the installations; however, all measured concentrations of heavy metals around various installations are well comparable with reference station concentrations and previous year reported values. It is also observed that all measured concentrations are within acceptable limits of the marine environment as prescribed by regulatory agencies. This shows that there is not much enrichment in the heavy metal concentration due to oil field activities. Although the drilling mud discharges and the disposal of produced water are said to have reflected as sources of heavy metals around an oil field installation, the absence of enrichment of any of them indicates their dispersal within short distances from the installations. Though it is observed that values in open oceans are less than those found near the oil installations, almost all analyzed metals concentrations are in permissible limits of heavy metals for coastal marine water. Therefore, it can be safely concluded that the values observed near Bombay High and other fields are very much below the toxicity limits for metals given in the literature.

Table 3. 19 Minimum, maximum and average of Heavy Metal in seawater at Mumbai Basin

Heavy Metal in µg/l	Minimum	Maximum	Average
V	0	2.9	1.8
Cr	0	29.1	0.7
Mn	0	30.7	1.7
Fe	0	2010.7	80.7
Co	0	28.8	0.5
Ni	0	34.5	2.5
Cu	0	29.7	2.4
Zn	0	31.4	2.9
As	0	31.24	1.2
Cd	0	26.6	0.49
Ba	0	27.6	2.4
Pb	0	21.7	0.6

3.1.3.4.3 Sediment Quality

3.1.3.4.3.1 Heavy metals in sediments

The sediments of the present study area were mainly composed of clayey-silt (>95%) with varied proportions of clay and sand. Silt and clay were the dominant textural class at all the deep-sea blocks. The measured concentrations of various heavy metals in sediments have been tabulated in table 3.20. It is observed that the distribution of metal concentrations in the present study area has not followed a particular trend as concentration varied from one station to another, but variation is minimum when are, depth, and other oceanographic parameters are considered.

Table 3. 20 Minimum, maximum and average of Heavy Metal in sediment at Mumbai Basin

Heavy Metal in mg/kg	Minimum	Maximum	Average
V	0.36	261.44	36.42
Cr	0.38	311.48	34.25
Mn	25.19	4142.62	554.85
Fe	2369.35	101302.57	26766.51
Co	0.83	116.52	12.82
Ni	2.65	257.45	24.78
Cu	2.96	330.02	28.57
Zn	1.73	287.78	30.26
As	0	86.3	25.69
Cd	0	0.45	0.10
Ba	0.98	1542.64	375.92
Pb	0.74	22.96	3.70
Hg	0.66	47.38	8.91

3.1.3.4.4 Flora and fauna

The marine environment is known to support the vast population of organisms found distributed in both pelagic and benthic realms. Most of the organisms of the pelagic realm constitute plankton. Phytoplankton and zooplankton together constitute this community and form the primary food source for most marine species. Their response to physio-chemical characteristics of the water column determines their distribution, abundance, and production. The occurrence of marine species, both plants and animals, has largely been controlled by the physio-chemical properties of ocean water. Chlorophyll-a in the Mumbai basin varied from 0.8 – 3.1 mg/m^3. Phytoplankton abundance range is varied from 38-321 units/L with total genera ranging from 10-22. Zooplankton abundance range is varied from 20-150 units/L with total genera ranging from 7-14. Chlorophyll content in the sediment extracted in acetone was below detectable limits. The meiobenthic organism collected along with sediments by using the van-Veen grabs were represented by 2 groups of meiofauna, Nematode worms and Polychaete worms. The total number of macrobenthic organisms varied from 90-510 no/m^2

Table 3. 21 Minimum, Maximum and Average Biological characteristics of Mumbai Basin

Phytoplankton			
	Minimum	Maximum	Average
Chlorophyll a (mg/m^3)	0.8	3.1	1.2
Abundance Range UNITS/L	38	321	149
Total genera (no)	10	22	16
Zooplankton			
Abundance Range UNITS/L	20	150	72
Total groups (no)	7	14	11
Macrobenthos			
Population (no/m^2)	90	510	257
Total groups (no)	2	2	2

3.1.3.4.5 Fisheries

Table 3. 22 Total petroleum hydrocarbons (TPH) from fishes

	Minimum	**Maximum**	**Average**
TPH (µg/g)	**2.18**	**13.11**	**7.27**

Table 3. 23 Heavy metals in Fish

Heavy Metal in mg/kg	Minimum	Maximum	Average
V	0.1	0.93	0.46
Cr	0.11	0.49	0.28
Mn	0.35	2.52	1.27
Fe	7.99	65.25	30.83
Co	0.01	0.05	0.02
Ni	0.01	0.1	0.03
Cu	0.12	0.32	0.23
Zn	2.08	6.98	4.33
As	0.1	0.4	0.2
Cd	0.02	0.46	0.11
Ba	0.08	2.88	0.61
Pb	0.01	0.13	0.02

Table 3. 24 Scientific name and common name of the fishes, crustaceans and other major groups in the Mumbai basin

GROUP	FAMILY & Scientific name	Common name
CEPHALOPODS	FAMILY ; SEPIIDAE	Cuttle Fish
	Sepia pharanis	
	Family: PENAEIDAE *Penaeus indicus* *Penaeus monodon*	Indian White Prawn TigerPrawn
TELEOSTS (Bony fishes)	Family: Bramidae Pampus argenteaus	Silver Pomfret
	Family: Soleidae Cynoglossus lida	Shoulder spot Tongue sole
	Family: Scombridae Thunnus tonggol	Long Tail Tuna
	FamilY;CLUPEIDAE	Sardine
	Sardinella longiceps	
	Family: Congridae	Slender Conger Eel
	Uroconger lepturus	
	FamilY: MURAENESOCIDAE	Common EEL
	Congresox telabonoides	
	Family:HARPADONTIDAE	Bombay Duck
	Hardpodon nehereus	
	Family: SCOMBRIDAE	Indian Mackerel
	Rastrelliger kanagurta	

Table 3. 25 Relative abundance in the fish & shellfish catch during the sample fishing

Sr.No	Common name	Relative abundance	Relative Biomass
		no/Haul	gm/ haul
1	Cuttle Fish	11	7100
2	Indian White Prawn	41	2720
3	Tiger Prawn	52	3960
4	Shoulder spot Tongue sole	5	1130
5	Long Tail Tuna	3	640
6	Sardine	6	1310
7	Common EEL	2	280
8	Bombay Duck	11	1460
9	Indian Mackerel	6	1370
10	Silver Pomfret	7	3140
11	Round tail Alligator Gar/ Spot tail needlefish	4	130
12	Giant Marine Catfish	2	140

3.1.4 Kerala Lakshadweep Konkan Basin

3.1.4.1 Geographic Location of the basin

The Kerala-Konkan basin is located South of 16 °N latitude. Kerala-Konkan offshore basin forms the southern part of the western continental margin of India and extends from Goa in the north to Cape Comorin in the south. Westward, the basin extends to the Arabian Abyssal plain. On the eastern side, it is bounded by the peninsular shield. The basin evolved through an early rift and post-rift phases and contained more than 5 km of Cretaceous to Recent sediments. Post-rift mature sediments with sufficient organic carbon content are present in the basin. Drilling results and adsorbed gas anomalies confirm the generation of hydrocarbons in the basin. This basin covers an area of around 580,000 sq. km. This basin comes under category III. There are 15 exploratory wells drilled so far, but none of them is producing, but wells like Kasargod-1, KK-OS-V1-1 and CSP-1 show faint oil fluorescence.

3.1.4.2 Geologic History

The Kerala-Konkan basin is situated south of the east-west trending Vengurla Arch and extends up to Cape Comorin in the south of the Indian subcontinent in the western offshore basin. The sedimentary sequence is comprised of Mesozoic and Tertiary sediments. India's western continental margin basin evolved through the break-up of eastern Gondwanaland from western Gondwanaland in the Late Triassic/Early Jurassic and the subsequent spreading history of the eastern Indian Ocean. The western margin evolved through an early rift and post-rift phases of divergent margin development. A series of regional and local horsts and grabens resulted in response to rifting along with the dominant basement tectonic trends. The northernmost part of the western continental margin was the first to be subjected to continental rifting and crustal subsidence in the Late Triassic. The process of rifting gradually advanced towards the south, and by Cretaceous time almost all the rift-related horsts and grabens came into existence. The deposition started with the continental environment, changed gradually to paralic and finally to pulsating marine conditions, punctuated by basic lava flows (Deccan Trap) in the terminal stages towards the end of Cretaceous and Early Paleocene. Towards the end of the early rift phase, most of the rift-related grabens and horsts located in the deeper parts were covered up with sediments, and the continental margin became less intricately differentiated. The Deccan Traps

(Cretaceous – Early Paleocene) form the technical basement of the Tertiary Basin. For the most part of the early Tertiary period, Alleppey Plateau and Laccadive ridge were subjected to relative differential rise during the entire Paleogene, thereby creating depressions around them. There were progressive transgressions, accompanied by synsedimentary positive radial movements of low to medium amplitude. Lakshadweep Depression was characterised by rejuvenation of faulting and subsidence of basement, where the continental, deltaic, lagoonal and shallow marine deposition was taking place. The lithological sequence shows gradation upward from continental sand-clay section to sand-shale-coal section and finally terminating in sand-shale-coal limestone (thin) section. The depocenters kept shifting from west to east during Paleocene to Mid-Eocene period. During the late Eocene-early Oligocene period, finer differentiation into second-order horst and graben features became more pronounced. In some cases, the direction of radial movement could have been reversed and resulted in minor changes epochs of alternating transgression and regression; and consequent lateral shifting of the depocenters. Thus, the late Eocene-Early Oligocene period witnessed a relative intensification of the oscillatory/pulsating movements of medium magnitude and dominance of paralic to the shallow marine depositional environment in Lakshadweep Depression. The shelfal horst-graben complex formed the site for the development of shelf depositional systems, whereas the Lakshadweep Depression and Laccadive Ridge lay in the slope and basinal region. The shelf depositional systems comprised deltas, clastic and carbonate tidal flats, strand plains and carbonate ramps, platforms and banks. Lows within the shelf provided a trap for the bulk of the terrigenous clastic sediments, whereas the distal and relatively positive shoal areas favoured the development of thick limestone sequences. Extensive carbonate sequences thus developed over the northern part near Vengurla arch, Alleppy platform, distal parts of paleo-shelves and around Laccadive and Maldive group of islands Regions of favourable buildups. Paleobathymetry over the Laccadive Ridge formed the sites for the development of carbonate. In the basin slope regions, west of the shelfal horst-graben complex, deposition of submarine fans and hemipelagic and pelagic deposits is visualised. Association of shallow and deep marine fauna in limestone bands interbedded with clastics of Early Eocene age in a few drilled wells in the Lakshadweep Depression off Mumbai suggests that submarine canyons traversing platform limestone areas caused intermittent deposition of turbidites composed of allodapic limestone in basin slope transition zone. In the post-Oligocene period, the basin acquired a marked westerly tilt, evidenced by numerous sigmoidal / progradational features observed in the Mio-Pliocene sections. Numerous channels, levees and turbidities observed on the southwesterly slope have accommodated a thick pile of post-Miocene sediments. A significant part of this pile is likely to belong to the Indus River fan in the major part of the Lakshadweep Depression.

3.1.4.3 Coastal Environment

The southwest coast region of India extends from about 8º N to 15º 30' N with a coastline length of 994 km, adjoining three maritime states, Kerala, Karnataka and Goa. The continental shelf area off the southwest coast is 75 400 $km^{2,}$ and 31% of the area is less than 50 m in depth. Wind patterns and water circulation in the Arabian Sea differ drastically from patterns in similar latitudes (Wyrtki 1973). There is a seasonal change in the winds north of the equator. Winds blow over the equatorial ocean between November and March, causing the northeast monsoon. The system reverses from May to September, and the southeast trade winds extend across the equator and blow across the northern Indian Ocean as the southwest monsoon (Tomczak and Godfrey 1994). During the northeast monsoon, there is a north equatorial current, while during the southwest monsoon, the circulation in the northern Indian Ocean largely reverses and the westward north equatorial current is replaced by an eastward southwest monsoon current, flowing with the equatorial countercurrent. Seasonal changes in winds and currents induce an annual cycle of hydrographic events along the southwest coast. During the monsoon, the southerly current spreads over the entire continental shelf. Isolines of water temperature, salinity, dissolved oxygen (DO) and density lift to the surface (upwelling) and occupy the area between the southerly current and the coast. Consequently, dense and cool water with low DO occupies the surface near the coast. There is a strong current with the northerly flow during the post-monsoon period (October - January). On the seaward side of the flow, there exists a southerly flow only in the southern region of the southwest coast. During this period, low saline equatorial waters are advected northwards, causing the sinking of high saline Arabian Sea water between 10º N and 12º N (Devaraj et al. 1997). During the pre-monsoon period (February - May), the northerly current disappears, and the southerly flow constricts to a narrow belt.

Table 3. 26 Meteorological/Physical parameters at Kerala Lakshadweep Konkan basin

Parameter	Minimum	Maximum	Average
Wind speed (m/s)	0.5	12.2	2.1
Surface air pressure (pa)	98752	101226	100231
Air temperature (^oC)	24.3	28.8	26.6
Sea surface Temperature (^oC)	26.8	32.3	29.4
Sea surface Salinity (psu)	14.7	35.5	34.9
Relative humidity (%) 1000hpa	60.4	88.6	78.2
Net shortwave radiation flux (W/m^2)	35.7	248.1	177.2
Net long wave radiation flux (W/m^2)	-100	-2	-34.2
Latent heat net flux (W/m^2)	55	279.5	136.3
Sensible heat net flux (W/m^2)	-145	114	3.5
Cyclones			
A total of 5 cyclonic/severe cyclonic storms were formed/dissipated over Kerala Lakshadweep Konkan Basin			

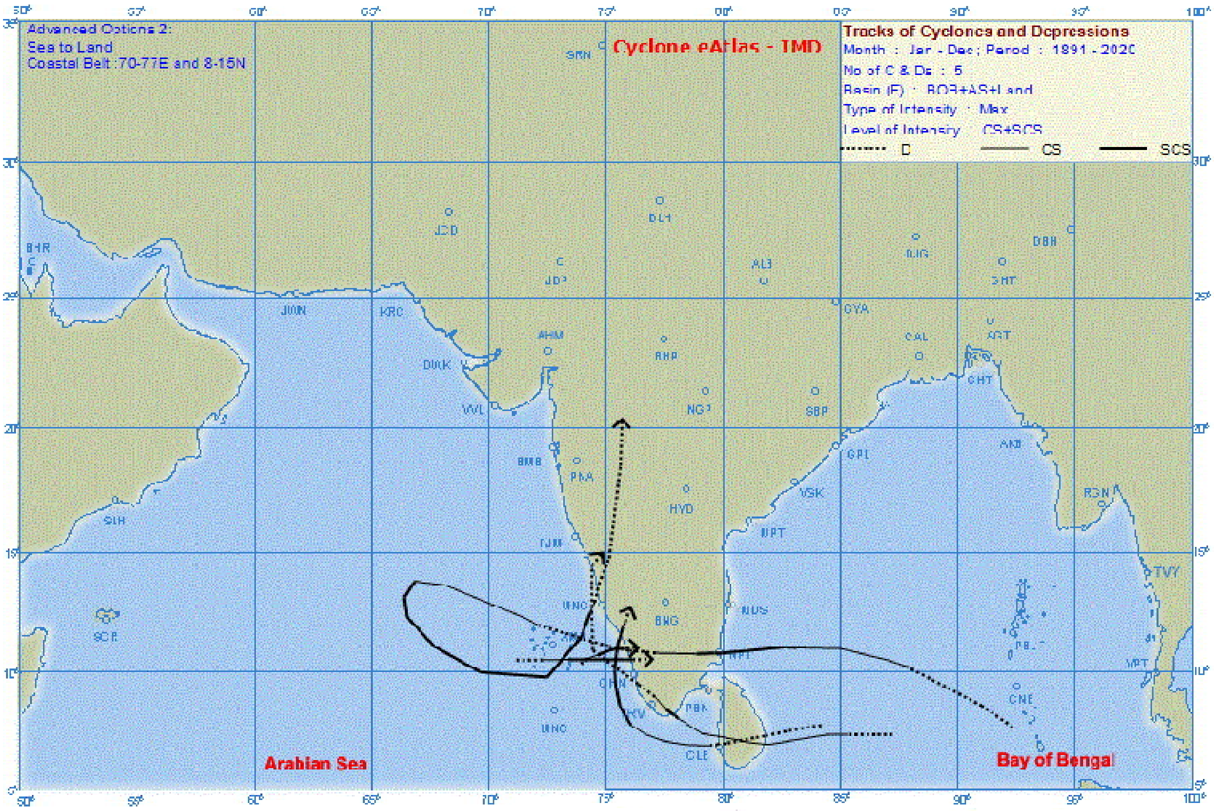

Figure 3. 4 Cyclonic/severe cyclonic storms formed/dissipated over Kerala Konkan Lakshadweep basin

3.1.4.4 Physical Process

3.1.4.4.1 Tide

A comparison of the tide for three places, the Cochin Port, the Beypore and the Mangalore Port, indicate that the tides are 'Mixed and Predominantly Semidiurnal'. Tidal range gradually increased along the coast as one travels from south to north, i.e., from Cochin to Mangalore. The spring tide ranges at Mangalore, Beypore and Cochin are 0.66, 0.92, and 1.10 m, respectively, while the neap tide ranges are 0.57, 0.70, and 0.80 m. The low water level coincides at all three locations, whereas the high water level is amplified as one goes north along the coast, i.e. from Cochin to Mangalore. There is a level difference of high water of about 0.5m between Cochin and Mangalore, which may create a southward flow along the coast irrespective of regular seasonal coastal currents.

3.1.4.4.2 Currents

Currents along the coast are generally influenced by wind, wave, tide and are modulated by bottom topography. The strength and direction of flow velocities measured at the surface, mid-depth and bottom levels observed that the flow is directed north or northwest at all levels during Jan-Feb (pre-monsoon conditions) whereas directed south or southeast during monsoon conditions (June to September). October is the transition stage of the current pattern toward the north. The flow strengths at all levels in general varied between 0.28 and 0.47 m/s in all seasons.

3.1.4.4.3 Waves

The wave spectra were generally multipeaked, and the energy varied seasonally, with maximum values during the southwest monsoon. The energy was low during the fair-weather period. During this period, the peak of the spectra was centred around 0.075–0.085 Hz. A shift of the peak to higher frequencies was observed by the end of May. With the onset of the monsoon, the peak frequency increased and was centred around the range 0.09–0.11 Hz, with a rapid increase in the energy level. The significant wave height (Hs) ranged from 0.29 to 3.79 m, with an average of 1.15 m. During the southwest monsoon season, the full range was observed, but during the fair weather season, the value of Hs ranged from 0.3 m to 1.9 m with an average value of 0.83 m. During the monsoon, waves were generally higher, and 50% of the occurrences were in the range of 1.0–1.6 m. The most commonly occurring Hs were in the range of 1.0–1.2 m, with a frequency of occurrence of 19%. At higher values, the frequency was reduced, and at 3.0 m, it was reduced to nearly 1% of the distribution. During the fair-weather season, the wave intensity was less, and about 65% of the distribution fell in the range of 0.4–0.8 m. About 90% of the waves came in the range of 0.2–1.2 m during this season. During this season, the higher wave heights were caused by occasional depressions that were formed over the Arabian Sea during the pre and post-monsoon periods. During both the monsoon and fair weather season, the wave periods had a wide range because of the coexistence of short-period high waves along with long-period swells. However, the average period was generally lower during the monsoon, with Tz in the range of 6–10 seconds contributing to nearly 87% of the distribution. The predominant values were in the range of 7–8 seconds, contributing to more than 35% of the distribution. During the fair-weather season, the most commonly occurring values were in the range of 8–10 seconds, contributing to more than 45% of the distribution. Tz in the range of 7–11 seconds contributed to more than 81% of the distribution during this period. About 95% of the periods during this season were confined to the range of 6–12 seconds.

3.1.4.5 Marine Environment

3.1.4.5.1 Water quality

The monthly mean seawater temperature varies in space and time along the southwest coast. Off Quilon (9º N, 76º 30' E), for instance, the mean sea surface temperature (SST) is low (27º C) during January - February and June - August, and high (29 to 31ºC) during May (Devaraj et al. 1997). High values are associated with the summer season prior to the onset of the southwest monsoon. Mean water temperature is higher in the northern part of the coast compared to the southern part. For instance, water temperature is 25º C and 17 to 21º C during January - February and June - August, respectively, at 100 m depth off Quilon, while during the same periods it is 29º C and 30º C off Karwar (15º N,74º E) (Devaraj et al. 1997). The lower temperature is recorded in areas where the intensity of upwelling is comparatively higher. The mean depth of the top of the thermocline also varies from season to season. The top of the thermocline is deepest during the winter months of December to February off Quilon (120 m) and during January - February off Karwar (70 to 80 m). The thermocline reaches near the surface in April and October, i.e. prior to and after the southwest monsoon. Mean sea surface salinity has two peaks, one during May - June prior to the onset of the southwest monsoon and another during September - October immediately after the southwest monsoon. Monthly mean surface salinity varies between 32.5 and 36.1 psu. The maxima occur comparatively late in the southern areas and are associated with advection of highly saline Arabian Seawater, and the presence of highly saline bottom water brought upward to surface levels in areas of upwelling. The minima are associated with monsoon rains and river runoff, and also the incursion of low salinity equatorial surface waters. The minima occur first in the southern region and progressively move northward following the trend in monsoon rainfall (Devaraj et al. 1997). The salinity maximum occurs at depths of 100 to 150 m during the northeast monsoon and between 30 and 50 m during the southwest monsoon. The salinity maximum associated with the main thermocline probably represents an intrusion of high saline waters below the less saline surface layers (Pillai 1983).

The shelf waters are generally well-aerated during most of the year except during the southwest monsoon and the associated upwelling season. A good correlation between the depth of the top of the thermocline and oxycline has been observed. By May, oxygen-deficient waters start penetrating the shelf. By June/July, the oxygen-deficient waters penetrate below the thermocline and cover the entire bottom of the shelf. In August, the oxycline becomes very shallow, and in the areas of upwelling, the low oxygen intermediate water reaches near the surface. Oxygen deficient water remains on the shelf until October, especially in areas where upwelling is intense. By December, the shelf waters are well-aerated again. Mean monthly sea surface DO values range between 6.0 mg/l and 1.5 mg/l. Oxygen deficient waters remain in the continental shelf of the northern region (off Karwar: 6 months) for a longer duration than in the southern region (off Quilon: 2 months) (Pillai 1983).

The surface water temperature ranged from 26.3°C to 31.4°C. The variation in surface water temperature in the basin is highly correlated to a variable intensity of solar radiation, evaporation and water column turbidity, and the upwelling phenomena during monsoon season. There was a significant fluctuation in salinity among the coastal basin waters as well as offshore waters. The maximum salinity of 35.64 was recorded offshore during the upwelling, and the minimum 14.7 was recorded at the Cochin nearshore. Among the basin, all coastal waters recorded low salinity compared to offshore. This could be attributed to a large quantity of freshwater discharge (from backwaters) which is one of the prime factors influencing the abundance and distribution of the fauna and flora in the coastal and offshore waters. There was not much variation in DO concentration and which varies from 4.29 to 5.18 mg/l. pH values remained alkaline throughout the study period at all the stations, varying from 6.21 to 8.2. Turbidity of water is generally caused by the presence of suspended matter such as clay, silt, finely divided organic and inorganic matter and other microscopic organisms. It has been reported that wave action increases during the pre-monsoon season, resulting in turbulence in the coastal waters favouring the resuspension of the bottom sediment due to stirring action that causes low water transparency. The high turbidity of water during the monsoon period could be due to the influx of heavily silt-laden freshwater. The turbidity of water samples varied from 0.5 to 20.55 NTU.

Table 3. 27 Water quality of Kerala Konkan Lakshadweep basin

Parameter	Minimum	Maximum	Average
Temp ^{0}C	26.3	31.4	29.1
Salinity (PSU)	14.7	35.64	34.93
pH	6.21	8.2	7.66
Turbidity (NTU)	0.5	20.55	4.2
Suspended solids mg/l	2.16	12.56	4.24
Dissolved oxygen in mg/l	4.29	5.18	4.83
Nitrite (NO_2^-) in µmol/l	0.04	9.61	0.82
Nitrate (NO_3^-) in µmol/l	0.05	16.35	1.95
Phosphate (PO_4^{3-}) in mg/l	1.36	2.78	2.08
Silicate (SiO_4^-) in µmol/l	1.73	11.86	6.27
Hydrocarbon TPH in µg/l			

3.1.4.5.2 Heavy metals in seawater

The magnitude of different heavy metals followed the hierarchy, Zn>Mn>Pb>Cu> Cd>Hg. In this study, dissolved Hg, Cd, Cu, Pb, Mn and Zn concentrations ranged from 0.007 to 0.065 µg/ l, 0.10 to 0.23 µg/ l, 0.18 to 6.2 µg/ l, 1.6 to 1.99 µg/ l, 0.68 to 13.48 µg/ l and 0.89 to 17.18 µg/ l, respectively.

Table 3. 28 Heavy metals in seawater of Kerala Konkan Lakshadweep basin

Heavy Metal in µg/l	Minimum	Maximum	Average
V	--	--	--
Cr	--	--	--
Mn	0.68	13.48	4.21
Fe	--	--	--
Co	--	--	--
Ni	--	--	--
Cu	0.18	6.2	1.28
Zn	0.89	17.18	9.45
As	--	--	--
Cd	0.1	0.23	0.7
Ba	--	--	--
Pb	1.6	1.99	1.86
Hg	0.007	0.065	0.03

3.1.4.5.3 Heavy metals in Sediment

The sediments were generally rich in organic carbon and predominant in sandy-silt fraction. The nearshore was characterized by a high sand fraction. The textural analysis of the sediment showed a higher sand percentage (77%), followed by silt (23%). The distribution of organic carbon availability in the soil was irregular, with comparatively lower concentrations. The nearshore sediment was recorded low in organic carbon, with a low percentage of clay, silt and a high percentage of sand. The hierarchy of sediment heavy metals in the basin was as follows, Fe>Zn > Cr > Ni > Cu > Pb >Mn> Cd>Al > Hg>As.

Table 3. 29 Heavy metal in the sediment of Kerala Konkan Lakshadweep basin

Heavy Metal	Minimum	Maximum	Average
V	--	--	--
Cr (µg/g)	41.7	212	118
Mn (µg/g)	0.12	4.2	1.75
Fe (µg/g)	5.05	248.62	78.36
Co	--	--	--
Ni (µg/g)	26.4	97	53.3
Cu (µg/g)	21	66.5	35.2
Zn (µg/g)	44.8	219	10.04
As (µg/g)	0.006	0.17	0.02
Cd (µg/g)	0.11	2.3	0.7
Ba	--	--	--
Pb (µg/g)	11	33	19.7
Hg (µg/g)	0.04	0.65	0.2
Al (µg/g)	0.43	11.12	4.12
Sand (%)	20.77	87.10	77.26
Silt (%)	14.88	41.43	24.04
Clay (%)	7.89	37.12	13.25

3.1.4.5.4 Flora and Fauna

Chlorophyll-*a* concentration positively correlated with plankton density and nutrient concentration. The chlorophyll concentration ranged from 0.85 to 3.83 $mg.m^{-3}$. The distribution and succession of phytoplankton are influenced by physical parameters, seasonal variations in rainfall and its subsequent effect on the spatial distribution of salinity. Phytoplankton abundance in the basin ranged from 330 to 5928 cells/L with an average of 4260 cells/L. The zooplankton population density in the basin ranged from 117 to 1218 No. L-1 with an average of 544 No. L-1. *Copepoda* was the most important group both in terms of species number and abundance. Along the basin, macrobenthic biomass varied between 0.05 g m^{-2} and 13.8 g $m^{-2,}$ with an average of 4.93 g m^{-2}. The abundance ranged from 105 ind. m^{-2} to 6400 Ind. m^{-2} with an average of 1539 ind. m^{-2}. Major groups that contributed to the biomass and abundance were polychaetes and crustaceans.

Table 3. 30 Minimum, Maximum and Average Biological characteristics of Kerala Konkan Lakshadweep Basin

	Phytoplankton		
	Minimum	Maximum	Average
Chlorophyll a (mg/m^3)	0.85	3.83	2.7
Abundance Range cells/L	330	5928	4260
Total genera (no)	21	29	25
Phytoplankton production (mg C·m-2·day-1)	1.1	49.9	11.2
	Zooplankton		
Population No/L	117	1218	544
Total groups (no)	15	19	17
Zooplankton production (mg C·m-2·day-1)	6.4	27.5	9.3
	Macrobenthos		
Biomass (g/m^2)	0.05	13.8	4.93
Abundance (Ind.m^2)	105	6400	1539

3.1.4.5.5 Fishery Resources and Potentials

Due to high productivity, the southwest coast is one of India's most important areas in terms of marine fish production. While the length of the southwest coast is only about 16% of the Indian coastline, it contributes 31.7% (0.74 million t) annually to national marine fish production. Landings are higher around the southwest monsoon (July to September: 28.6%) and post-monsoon (October to December: 34.6%) seasons. Using stratified multistage random sampling, the Central Marine Fisheries Research Institute (CMFRI) has collected data on marine fish landings along the southwest coast. Information on the fishery resources provided here is based on statistical and periodic publications of CMFRI.

Table 3. 31 Marine fish landings along the Kerala Lakshadweep Konkan Basin

State	Jan. - Mar.	Apr. - June.	July - Sept.	Oct. - Dec.
Kerala	18.6	18.1	33.7	29.6
Karnataka	26.9	11.9	19.2	42.0
Goa	23.6	9.5	18.7	48.2
SW coast	21.1	15.7	28.6	34.6

Table 3. 32 Estimates of the potential yield of fish resources along the Kerala Lakshadweep Konkan Basin

Depth zone	Potential yield ($x10^3$ t)	Source
0 - 200 m (oceanic)	1 422	George et al. (1977)
0 to 200 m (only demersals)	438	Joseph (1980)
0 to 500 m (oceanic)	853	Joseph et al. (1976)
0 to 200 m	900	Alagaraja (1989)
0 to 200 m (only demersals)	332	Sudarsan et al. (1989)
0 to 50 m (only demersals)	361	Anon. (1991)
0 to 50 m (only pelagics)	589	Anon. (1991)
51 to 100 m	63	Anon. (1991)
101 to 200 m	29	Anon. (1991)
201 to 500 m (only oceanic tunas)	265	Anon. (1991)
0 to 500 m	1 307	Anon. (1991)

3.1.5 Cauvery Basin

The Cauvery Basin Extends along the East Coast of India, bounded by 08º – 12º 5' North Latitude, 78º – 80º East Longitude has been under hydrocarbon exploration since the late nineteen fifties. The first deep well for exploration was drilled in 1964. The Cauvery Basin covers an area of 1.5 lakh sq. km, comprising onland (25,000 sq. km) and shallow offshore areas (30,000 sq km). In addition, there is about 95,000 sq km of deep-water offshore areas in the Cauvery Basin. The basin is the Result of Gondwanaland fragmentation during drifting of India- Sri Lanka landmass system away from Antarctica/ Australia plate in Late Jurassic/ Early Cretaceous. The basin is endowed with five to six kilometres of sediments ranging in age from Late Jurassic to Recent (mainly thick shale, sandstone & minor limestone). Prognosticated resources is 700 MMT (430 MMT: onland areas and 270 MMT: offshore)

3.1.5.1 Land Environment

The Cauvery basin extends over states of Tamil Nadu, Karnataka, Kerala and Union Territory of Puducherry, draining an area of 85,626.23 Sq.km, which is nearly 2.7% of the total geographical area of the country with a maximum length and width of about 560 km and 245 km, respectively. Out of this, 42% area lies in Karnataka, 54% area in Tamil Nadu & Karaikkal region of Puducherry and 4% in Kerala. It falls in peninsular India and lies between 75°27'E to 79°54'E and 10°9'N to 13°30'N. The Western Ghats bounds it on the west, the Eastern Ghats on the east and south, and the ridges separate it from the Krishna and Pennar basin on the north. The three main physiographic divisions of the basin are the Western Ghats, the plateau of Mysore and the Delta. The Western Ghats region is mountainous and covered with thick vegetation. The utilizable surface water resource for the basin is 19 BCM. The Average Annual Runoff and Average Annual Water Potential in the basin are the same as 21.36 BCM. The major part of the basin is covered with agricultural land accounting to 66.21% of the total area, and 20.50 % of the basin is covered by forest area

3.1.5.2 Meteorological Conditions

In the Cauvery basin, four distinct seasons occur. They are Winter, Summer, South-West Monsoon, and North-East Monsoon. The climate at the basin level generally remains dry except in monsoon months. There is a considerable variation in the mean daily maximum and minimum temperatures across the basin. in the cold season, the Western Ghat is cooler than the rest of the basin, and the climate is generally pleasant. The Central, Northern and Eastern regions are hotter than the Westernmost parts in the hot weather season. The South-

West monsoon sets by the middle of June and ends by the middle of September. During this season, the basin receives a major part of its total annual rainfall. The North-East monsoon is from October to December and is important, particularly for the Eastern part of the basin. However, around 44 blocks of 10 districts falling in the basin are drought-prone. The rainfall in the basin varies from region to region. The highest rainfall in the Cauvery basin usually occurs in July or early August, and the mean annual rainfall is around 1075.23 mm. In the coastal areas, the highest rainfall months are October, November and December, while further inland, the peak monthly rainfall is early October. This rainfall pattern is conducive to a fairly high flow during the irrigation season from June to January, except for a short period of about six weeks when there is a break in the monsoon.

Table 3. 33 Meteorological / Physical parameters in Cauvery basin

Parameter	Minimum	Maximum	Average
Wind speed(m/s)	0.7	12.9	4.2
Surface Pressure (Pa)	99504.8	101448	100597
Air temperature(°C)	23.9	28.8	26.5
Sea surface Temperature(°C)	27.2	31.8	29.4
Sea Surface Salinity (SSS)	32.9	34.2	33.7
Relative Humidity (%)	63.5	89	78.6
Net Shortwave radiation(w/m^2)	28.2	229.2	172.5
Net longwave radiation(w/m^2)	-84.9	-1.12	-45.3
Latent heat net flux (w/m^2)	20.2	159.2	63.3
Sensible heat net flux (w/m^2)	-59.1	129.8	63.8

3.1.5.3 Cyclones and Tsunami

The geographical setting of the basin makes the coastal regions vulnerable to natural disasters such as cyclones, floods and earthquake-induced tsunami. About 8% of the basin is affected by five to six cyclones every year, of which two to three are severe. Cyclonic activities on the east coast are more severe than on the west coast and occur mainly between April-May and October-November. This basin is also prone to very severe damaging earthquakes. Its people feel much more vulnerable to earthquake-induced tsunamis since the 2004 Indian Ocean tsunami, which affected the coastal regions and destroyed much of the marine biology and severely damaged the ecosystem.

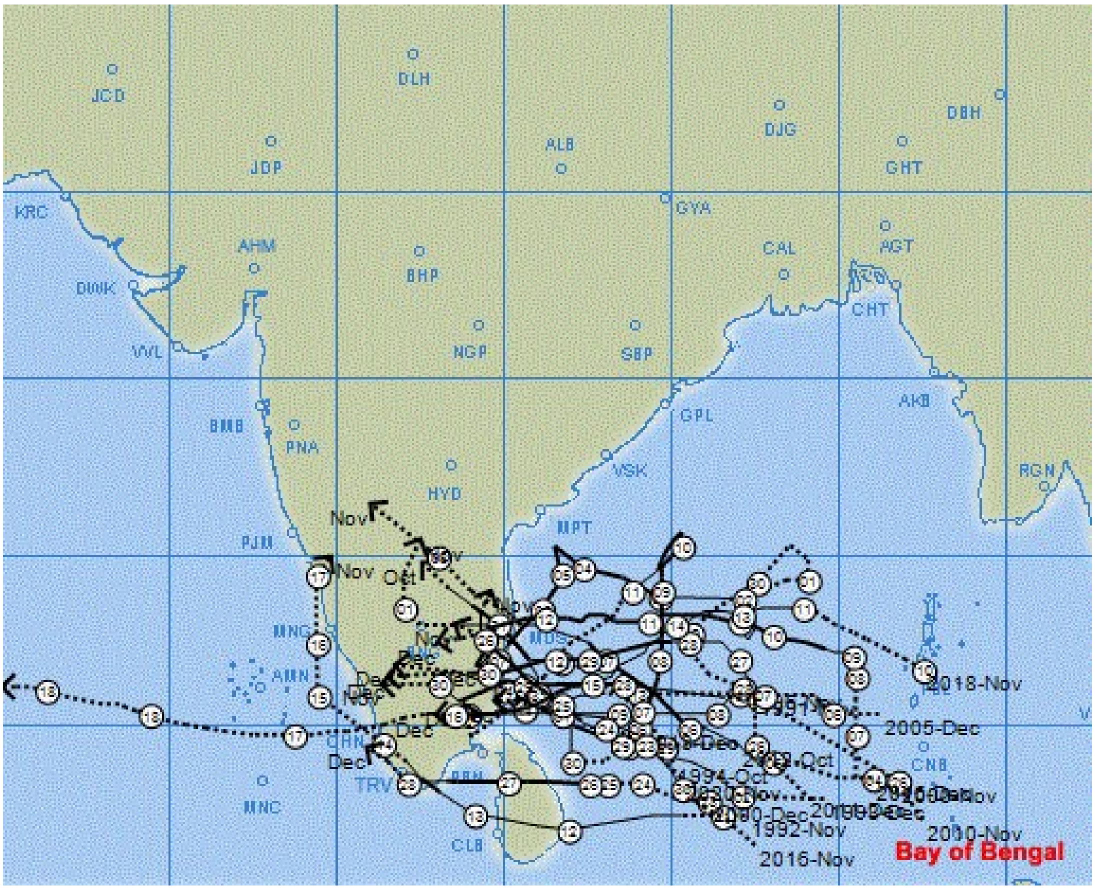

Figure 3. 5 shows Past Cyclonic events in Cauvery Basin

3.1.5.4 Water Quality

Water temperature was recorded as more or less similar and differed during seasons. Water temperature varied from 23.4 ºC to 29.4 ºC. The maximum temperature was observed during summer (May), and the minimum was recorded during monsoon (October). Water salinity varied between 24 psu and 32.7 psu. The maximum salinity was recorded during the month of May (summer), and the minimum was observed during the month of October (monsoon). pH values varied in the range 8.05 - 8.29. The changes influence the seawater pH in the pCO_2 levels. Photosynthetic activity increases pH, whereas respiration tends to lower the pH. Thus, the pH is greatly influenced by biological activity and carbon cycling. The relatively high pH of oceanic surface waters keeps pCO_2 at moderately low levels. Although the biological pump operates in all areas, the rate at which it removes CO_2 from surface waters may vary due to biological productivity differences. Dissolved oxygen is an important parameter influencing the biogeochemical processes in the sea. The dissolved oxygen distribution in the sea is mainly regulated by air-sea interaction, photosynthesis, and respiration. The other processes that affect the oxygen saturation in the sea are surface circulation, upwelling, coastal input, nitrification, and sediment-water exchange. Generally, a saturated water column indicates the oxidizing capacity of that region, while an under-saturation is caused by increased respiration or chemical oxidation. An increased supply of organic matter may considerably reduce the dissolved oxygen concentration in seawater. DO in the surface waters ranged from 4.80 to 6.23 mg/l (mean 5.67 mg/). The nitrite (NO_2^-) concentrations in the study region ranged from 0.02 to 0.53 µmol/l with a mean value of 0.12 µmol/l. Nitrate (NO_3^-) is the primary nutrient species in the sea. The surface nitrate concentrations were 0.22 to 15.61 µmol/l, (mean 3.22 µmol/l). The silicate concentrations ranged from 5.11 to 16.3 µmol/l. The Cauvery Basin generally showed less contamination due to PHC in water, which ranged from 0.3 to 0.58 µg/l. Moderate contamination due to PHC is possible in this region due to port activities and mechanized fishing vessels since it is an active fishing zone.

Table 3. 34 Water quality parameters in the Cauvery basin

Parameter	Minimum	Maximum	Average
Water Temperature(°C)	23.4	29.4	26.01
Salinity(psu)	24	32.7	28.82
pH	8.05	8.29	8.15
DO (µmol/l)	187.36	242.63	221.47
NO_3^- (µmol/l)	0.22	15.61	3.22
PO_4^{3-} (µmol/l)	0.24	1.04	0.66
NO_2^-	0.02	0.53	0.12
SiO_4^- (µmol/l)	3.11	15.77	8.36
PHC (µg/l)	0.3	0.58	0.08

3.1.5.5 Heavy metal Concentrations

Coastal regions form rapid growth in urbanization and industrialisation, which leads to the inflow of heavy metals into marine ecosystems. It has now become a major threat to the aquatic ecosystem. Coastal ecosystems are highly affected by pollutants, such as heavy metals, pesticides and antifoulants entering into the water column and sediments. The investigation of heavy metals in the marine environment is more important because their consumption is highly harmful and results in poisoning. Table 3.35 shows water/sediment concentrations of different metals in the Cauvery basin.

Table 3. 35 Heavy metal concentrations in the water and surface sediments of the Cauvery basin

Element(µg/l)	Concentration values		
	minimum	Maximum	Average
Water			
Cd	0.02	0.45	0.23
Cu	0.01	0.54	0.27
Pb	0.08	1.55	0.67
Hg	0.05	2.01	0.75
Zn	0.33	1.27	0.54
Element(µg/g)	**Concentration values**		
	minimum	Maximum	Average
Sediment			
Cd	0.12	2.26	1.06
Cu	0.38	3.87	2.07
Pb	0.43	5.63	3.15
Hg	0.06	1.12	0.31
Zn	0.2	1.28	0.87

3.1.5.6 Sediment Quality

The sediments during the present study were mainly comprised of sand, calcareous organisms, seagrass, and shells. Organic carbon in the sediment from the area ranged from 0.35-3.59% (mean 1.34). These values are comparable to the reported values from the region (Mazumdar et al., 2007; Ramana et al., 2009). In the region, sediment TN varied from 0.025-0.081 %. The sediment TN content was low on the shelf compared to the offshore. Sediment TP in the area ranged from 0.021 to 0.083 %. The distribution of heavy metals in the marine environment is complicated since it is regulated by geochemical and biogeochemical processes like sedimentation, precipitation, and flocculation. The distribution of trace metals spatially varied in the coastal and offshore regions.

Table 3. 36 Visual identification of sediment (colour, smell, and presence of fauna) in the Cauvery basin

Colour	Munsell Notation	Smell	Texture	Presence of Conspicuous Fauna
Dark Grey	4/1	Nil	Sandy	Calcareous shells
Very dark grey	3/1	Nil	Sandy	Calcareous shells
Reddish Brown	5/3	Nil	Sandy	Calcareous shells
Brown	5/4	Nil	Sandy	Nil
Very Dark Grey	3/1	Nil	Sandy	Calcareous shells
Grey	6/1	H_2S	Sandy	Sea grass
Reddish brown	5/6	Nil	Sandy	Calcareous shells
Reddish grey	5/2	Nil	Sandy	Nil
Reddish brown	4/4	Nil	Sandy	Large Calcareous shells
Yellow	7/6	Nil	Sandy	Nil

Table 3. 37 Shows Sediment Parameters in Cauvery basin

Parameter	Minimum	Maximum	Average
PHC (μg/g)	0.19	0.82	0.60
TP (%)	0.021	0.083	0.05
OC (%)	0.35	3.59	1.34
TN (%)	0.025	0.081	0.04

3.1.5.7 Biological parameters

The phytoplankton are mainly classified as diatoms and dinoflagellates, and the benthic organisms are grouped as macro-benthos and meiobenthos. Phytoplankton is microscopic plants living in the ocean surface layer, especially in the euphotic water column, and they are mainly composed of diatoms, dinoflagellates, and cyanobacteria. Usually, in marine environments, diatoms usually outnumber dinoflagellates, especially in nutrient-enriched waters, where the BOB basin has been considered a region of low biological productivity. However, high plankton production is evident along the coastline in the inshore waters associated with river influx and several mesoscale coastal processes. In fact, this region shows more productivity than a general trend found in the Bay of Bengal as a whole. Surface water chlorophyll was found maximum value of 3.12 μg/L, and the lowest was0.21 μg/L. Among zooplankton groups, Copepod dominated in the basin. Apart from copepod, Gastropod larvae, Decapod larvae, Bivalve larvae, Fish egg, Lucifer and Appendicularia contribute more to the abundance, whereas the groups Cladocera, Fish larvae and siphonophores contribute least to the abundance. The macrobenthic biomass was the highest at 21.01 gm-2. The average meiobenthic density value is 1933.81 No. m-2.

Table 3. 38 Shows Biological Parameters in the Cauvery basin

Parameter	Minimum	Maximum	Average
Phytoplankton			
Chl a (µg/l)	0.21	3.12	1.36
Abundance (No/l)	379	2305	1298.3
Diatom abundance (No/l)	281	1589	906
Dinoflagellate abundance (No/l)	98	716	392
Zooplankton			
Biomass (ml/m^3)	0.23	1.5	0.69
Density (No/m^3)	838.75	5587.92	2156.75
Macro-benthos			
Sediment chlorophyll (µg/g)	0.34	3.61	1.21
Biomass (g/m^2)	1.0725	21.01	7.02
Density (no./m^2)	150	5700	1736.45
Meio-benthos			
Biomass (g/m^2)	0.002	0.045	0.0165
Density (no./m^2)	416	3376	1933.81

3.1.5.8 Experimental Fishing

The abundance and diversity of fish is a good indicator of the biological productivity of a marine area. This would also help to understand how an altered marine environment could impact higher trophic level organisms. Experimental fishing was conducted in <100m depth) using trawler in basin region. Details are shown below.

Table 3. 39 Shows Experimental Fishing in Cauvery basin

Composition	Total Quantity (Kg)
Shrimp	12.2
Leognathid	6.9
Crab	7.2
Cat fish	5.9
Carangids	6.6
Flat fish	3.2
Cephalopods	4.9
Upenoids	4.4
Sciaenids	1.6
Seer fish	6.1
Elasmobranch	6.1
Clupeoid	4.7
Indian drift fish	3.7
Silver belly	5.9
Ribbon fish	2.7
Nemipterids	3.8
Priacanthid	0.7
Others	2.2

3.1.6 Krishna Godavari Basin

The Krishna Godavari Basin is a proven petroliferous basin of continental margin located on the east coast of India. Its onland part covers an area of 15000 sq. km, and the offshore part covers an area of 25,000 sq. km up to 1000 m isobath. The basin contains about 5 km thick sediments with several cycles of deposition, ranging in age from Late Carboniferous to Pleistocene. The major geomorphologic units of the Krishna Godavari basin are Upland plains, Coastal plains, Recent Flood and Delta Plains. The climate is hot and humid, with the temperature reaching up to 42 °C during summer. The mean day temperature varies between 35 °C and 40 °C during summer and 25 °C and 30 °C during winter. The Krishna Godavari Basin is an established hydrocarbon province with a resource base of 1130 MMT, of which 555 MMT are assessed for the offshore region (up to 200 m isobath. Several oil and gas fields are located both in onland and offshore parts of the basin. The entrapments are to be expected from Permo-Triassic to Pliocene sediments. The Tertiary hydrocarbon entrapments are so far observed only in the offshore part of the basin, while Paleogene to Permo-Triassic entrapments is discovered in East Godavari and West Godavari sub-basins in the onland part. In offshore, so far, more than 84 prospects have been probed by 182 exploratory wells. Hydrocarbon accumulations have been proved in 33 of these prospects (11 oil & gas and 22 gas prospects).

3.1.6.1 Land Environment

The Godavari is the second largest basin and accounts for nearly 9.5% of the country's total geographical area. It extends over states of Maharashtra (48.7%), Andhra Pradesh (23.7%), Chhattisgarh (12.4%) and Odisha (5.7%) in addition to smaller parts in Madhya Pradesh (7.8%), Karnataka (1.4%) and Union Territory of Puducherry (0.01%). The basin falls under division-All drainage flowing into the Bay of Bengal and Region-Rivers draining in the Bay of Bengal, delineated primarily based upon drainage of rivers to the outlet. The basin falls in the Deccan Plateau, lying between 73°24' to 83°4' east longitudes and 16°19' to 22°34' north latitudes. The basin is bounded on the north by the Mahadeo Hills, the Satmala Hills, on the northwest by the Ajanta Range, on the west by the North Sahyadri range of the Western Ghats, on the east and southeast by the Eastern Ghats and on the south by the Balaghat Range. The Godavari basin receives a major part of its rainfall during the southwest monsoon season. The delta of the Godavari is gradually extending into the sea

3.1.6.2 Meteorological Conditions

It is found that the average temperature varies from 20 oC to 29 oC in winters and 29 oC to 40 oC in summers. The study region experiences higher temperatures than other parts of India; the highest maximum temperature recorded up to 47.8 oC in May. May is the hottest month of the year, and the temperature falls up to 20 °C during January. Humidity affects the nature and characteristics of pollutants in the atmosphere as it is the measure of the amount of moisture in the atmosphere. Humidity helps suspended particulate matter coalesce and grow in size to settle under the gaseous pollutants by providing an aqueous medium. Humidity ranges from 65.11% to 87.77%, with a maximum of 78.5%. The southwest monsoon sets in by July and ends by September, receiving the maximum part of its annual rainfall during it. The monsoon entering through the west and south-west coast of the basin meets the Sahyadri Range sweeps across the interior of the peninsula. The annual rainfall of the basin varies from 755 mm to 1531 mm. The average annual rainfall in the basin is 1096.92 mm. It is found that the rainfall varies temporally and spatially across the basin. In the Godavari, the high rainfall zone in the Western Ghats, the annual rainfall varies from 1000 to 3000 mm in this reach. There is a belt some distance east of the Western Ghats experiencing less than 600 mm annual rainfall. After this area, the rainfall again gradually increases to about 900 mm towards the East coast. January and February are the driest months in the basin, with the annual rainfall ranging from less than 0.5 mm to 55 mm. During the next three months, it varies from less than 1 mm to 50 mm until the end of May. The maximum rainfall recorded was 1531 mm in 1990, and the minimum was 755 mm.

Table 3. 40 Meteorological / Physical parameters in KG basin

Parameter	Minimum	Maximum	Average
Wind speed(m/s)	0.1	1.4	4.1
Surface Pressure (Pa)	99451.3	101863.5	100786
Air temperature(°C)	22.8	47.8	29.3
Sea surface Temperature(°C)	27.1	31.5	29.1
Sea Surface Salinity (SSS)	31.6	34.5	33.1
Relative Humidity (%)	65.11	87.77	78.5
Net Shortwave radiation(w/m^2)	23.3	229.2	163.1
Net longwave radiation(w/m^2)	-88.2	-5.03	-44.5
Latent heat net flux (w/m^2)	3.3	203.8	77.6
Sensible heat net flux (w/m^2)	-76.7	154.1	41.1

3.1.6.3 Physical parameters

3.1.6.3.1 Tides

The tides in the region are semidiurnal. The tidal range was 0.7 m during the spring tide and 0.3 m during the neap tides. The details are given below.

Table 3. 41 Shows Tidal data in the KG basin

Tide	Level (m)
Mean High Water Spring (MHWS)	(+) 1.2
Mean High Water Neap (MHWN)	(+) 1.0
Mean Sea Level (MSL)	*(+) 0.8*
Mean Low Water Neap (MLWN)	(+) 0.7
Mean Low Water Spring (MLWS)	(+) 0.5

3.1.6.3.2 Currents

It is observed that the significant wave height is between 0.5 to 1 m during January, March to May, August to October and 0.5 to 1.5 m during June, July, November and December. Similarly, the significant wave height is less than 1 m in February. The zero-crossing wave periods vary from 3 to 5 seconds in January and September, from 3 to 4 seconds in February to May, from 4 to 5 seconds in June, July, October, November and December and from 4 to 6 seconds in August. The predominant wave direction prevails from 67.5° to 112.5° in January and December from 90° to 135° in February, from 112.5° to 157° in March to May, from 112.5° to 135° in June to October, and from 67.5° to 90° in November. The month-wise predominant wave characteristics are given below.

Table 3. 42 Month wise predominant wave characteristics

Months	Significant Wave Height, Hs (m)	Zero – crossing Wave Period, Tz (s)	Wave Direction
January	0.5 - 1.0	3 – 5	67.5° - 112.5°
February	<1	3 – 4	90.0° - 135.0°
March	0.5 - 1.0	3 – 4	112.5° - 157.0°
April	0.5 - 1.0	3 – 4	112.5° - 157.0°
May	0.5 - 1.0	3 – 4	112.5° - 157.0°
June	0.5 - 1.5	4 – 5	112.5° - 135.0°
July	0.5 - 1.5	4 – 5	112.5° - 135.0°
August	0.5 - 1.0	4 – 6	112.5° - 135.0°
September	0.5 - 1.0	3 – 5	112.5° - 135.0°
October	0.5 - 1.0	4 – 5	112.5° - 135.0°
November	0.5 - 1.5	4 – 5	67.5° - 90.0°
December	0.5 - 1.5	4 – 5	67.5° - 112.5°

3.1.6.3.3 Cyclones and Tsunami

The coastal region of the basin is highly vulnerable to cyclones with varying intensities. Past experience shows that certain parts of the coastal regions are vulnerable to loss of life and property due to cyclone and storm surges and associated flooding as well as high wind speeds. More than 103 cyclones have been affected in this region.

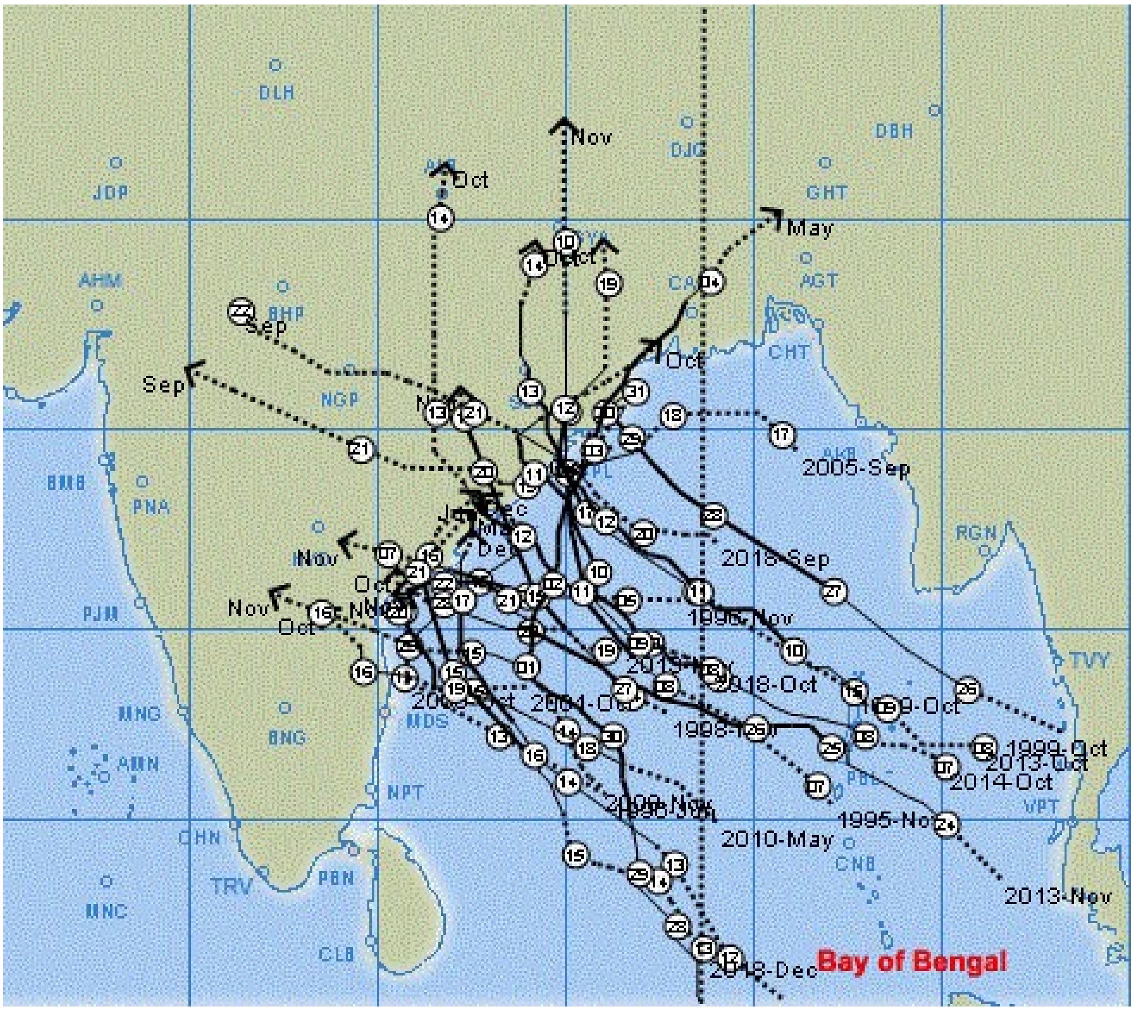

Figure 3. 6 shows Past Cyclonic events in KG Basin

Tsunami: Though the occurrence of Tsunami is a rare phenomenon particularly along the basin, still it is exposed to a threat against the submarine tectonic movement of Indonesian and Indian plates. The occurrence of a Tsunami on 26th December 2004 along the east coast of India had an impact of about 0.5 m run-up between Visakhapatnam and Kakinada. However, any kind of worst scenario can be expected over a period of 100 to 500 years in the project region as it is critically exposed to the movement against the Indonesian tectonic plate and Andaman tectonic plate. In case of such eventuality, the Tsunami that runs up along the coastal region can rise up to 2.5 m, causing severe devastation to the coastal land.

3.1.6.4 Water Quality

The temperature range varied from 27.0°C to 28.8°C with an average of 27.88 °C. The temperature variation across the water column was insignificant and followed a normal pattern indicating the absence of any significant stratification. Salinity is an important parameter that governs the spatial distribution of marine organisms. Normally, the salinity of seawater is about 35 PSU among world oceans. Seawater salinity values varied between 31.6 and 34.5 PSU, with an average was 33.82 PSU. Identifying pH for acidic or alkaline disturbances may help locate zones of pollution and other qualifying seawater conditions. pH ranged from 8.20 to 8.32 with an average of 8.27. There was no conspicuous variation in average pH values with the station as well as between surface and bottom. The higher pH might be due to the influence of seawater penetration and high biological activity and due to the occurrence of high photosynthetic activity. The amount of oxygen dissolved in the water column at a given time is the balance between consumption and replenishment. These two processes should be at equilibrium in an ideal ecosystem to keep the water column saturated with DO. DO level below 2 mg/l will cause respiratory impacts on marine fauna. The DO concentration varied from 5.1 to 6.1 mg/l, with an average was 5.59 mg/l. DO concentration in this coastal water was largely dependent on the freshwater influx. The rate of aerobic utilization of oxygen is a useful tool to evaluate the intensity of deterioration in an aquatic medium. The oxygen taken up for the breakup of organic matter leads to a reducing environment, or in the event of a release of excess nutrients, it may cause eutrophication. The BOD values varied from 1.2 to 1.9 mg/l, with an average was 1.48 mg/l. The low BOD values indicate that the oxidisable organic matter brought to the nearshore water is effectively assimilated in coastal waters. The range of variation in BOD values indicates that the water column is well mixed. Turbidity is the measure to understand the suspended particulate matter which controls the photosynthesis in the water column. The mean value was 5.95 NTU with varied between 4.1 to 9.0 NTU. The bottom water was showing higher turbidity than the surface resulting in a turbulent condition in the coastal waters favouring the resuspension of the bottom sediment due to stirring action that causes low water transparency. Total Suspended Solids (TSS): Total Suspended Solids in seawater originate either from autochthonous (biological life) or allochthonous (derived from the terrestrial matter) sources. The TSS value varied from 14.0 to 34.0 mg/l, with an average was 22.31 mg/l.

Nutrients determine the potential fertility of an ecosystem, and hence it is important to know their distribution and behaviour in different geographical locations and seasons. The fishery potential of an area is dependent on the availability of primary nutrients like nitrogen and phosphorus. Enrichment of these nutrients by anthropogenic inputs in the coastal waters may result in eutrophication. Unpolluted waters are generally devoid of ammonia and nitrite. However, coastal input by sewage and other nitrogenous organic matter and fertilizers can increase these nutrients to higher levels. In addition, ammonia in seawater can also come from various organisms as an excretory product due to the metabolic activity and the decomposition of organic matter by micro-organisms. The concentration of Ammonia varied from 0.26 to 0.35 µmol/l with an average of 0.30 µmol/l. Nitrite (NO_2^-) is an important element, which occurs in seawater as an intermediate compound in the microbial reduction of nitrate or ammonia's oxidation. In addition, nitrite is excreted by phytoplankton, especially during plankton bloom. The Nitrite concentration ranged from 0.03 to 0.31 µmol/l with an average was 0.21 µmol/l. There was no significant variation among the stations. Nitrate (NO_3^-) values are in general higher as compared to nitrite values. Nitrate is the final oxidation product of nitrogen compounds in seawater and is considered to be the only thermodynamically stable oxidation level of nitrogen in seawater. Nitrate is considered to be the micronutrient, which controls primary production in the euphotic surface layer. The concentration of nitrate is governed by several factors, of which microbial oxidation of NH_3 and uptake by primary producers may be important. Nitrate concentration varied from 1.21 to 3.59 µmol/l with an average was 2.18 µmol/l. The total nitrogen concentration varied from 8.21 to 13.43 µmol/l with an average was 10.92 µmol/l. The station-wise average value showed that there existed a significant difference between the coastal and open seas waters. Inorganic Phosphate (PO_4^{3-}) is also an important nutrient like nitrogen compound in the primary production of the sea. The concentration of phosphate, especially in the coastal waters, is influenced by the river runoff and anthropogenic activity. The phosphate concentration varied from 0.12 to 0.56 µmol/l with an average was 0.30 µmol/l. The mean value of Total phosphorous was 1.28 µmol/l with ranged from 1.05 to 1.28 µmol/l.

Table 3. 43 Water quality parameters in the KG basin

Parameter	Minimum	Maximum	Average
Water Temperature(°C)	27	28.8	27.88
Salinity(psu)	31.6	34.5	33.82
pH	8.20	8.32	8.27
Turbidity (NTU)	4.1	9	5.95
Total Suspended Solid((mg/l))	14	34	22.31
DO (mg/l)	5.1	6.1	5.59
BOD (mg/l)	1.2	1.9	1.48
NO_3^- (µmol/l)	1.21	3.59	2.18
PO_4^{3-} (µmol/l)	0	1.04	0.66
NO_2^- (µmol/l)	0.03	0.31	0.21
SiO_4^- (µmol/l)	3.36	15.96	9.08
PHC (µg/l)	0.3	0.58	0.08

3.1.6.5 Heavy Metal Concentrations

Coastal marine sediments are a major repository of trace metals as well as a major potential source of trace metals. Of the pollutants in sediments, heavy metals are classified as the most persistent since they are relatively stable and cannot be degraded in natural conditions. Fine-grained sediments are often used as a good indicator of trace metal contamination due to their large adsorption capabilities for metals.

Table 3. 44 Heavy metal concentrations in the water and surface sediments of the KG basin

Element(ppm)	Water			Sediment		
	minimum	Maximum	Average	minimum	Maximum	Average
^{51} V	23.41	47.46	37.58	2.67	53.9	12.58
^{52} Cr	0.96	6.97	1.6	2.33	78.54	16.51
^{55} Mn	0.05	1.84	0.57	15.73	703.61	156.61
^{56} Fe	2.52	79.66	27.56	2336.58	28865.05	12518.32
^{59} Co	0.63	0.88	0.78	0.45	17.53	4.12
^{60} Ni	0.25	3.2	1.35	1.21	38.85	8.6
^{63} Cu	33.94	65.89	54.17	1.66	41.91	9.36
^{66} Zn	0.56	10.51	1.99	2.07	34.57	8.68
^{75} As	42.03	70.35	58.57	2.47	5.85	4.27
^{111} Cd	0	0.17	0.07	0	0.3	0.08
^{138} Ba	3.86	6.09	4.86	6.19	371.5	89.39
^{208} Pb	0	0.6	0.14	0.3	9.38	1.99

3.1.6.6 Sediment quality

The organic matter in sediments expressed as total organic carbon (TOC) and total nitrogen (TN), represents an important reservoir for the global carbon cycle. It plays an important role in ocean chemistry.

Total Organic Carbon: Since most marine organic carbon comes from photosynthetic fixation of CO2 by phytoplankton, the nutrients excess from human activities represent an issue for many water bodies. In eutrophic environments, the amount of organic matter deposited exceeds the assimilative capacity of the sediments. Total organic carbon content ranged from 0.14% to 0.59%, with a mean value of 0.33%.

Total Nitrogen: TN plays an important role as a source of nutrients, decreasing with depth due to the remineralization of organic matter and non-biological oxidation. Total nitrogen concentration varied from 117 to 284 μg/g with a mean value of 185 μg/g.

Total Phosphorus: Sediments may play an important role in the regeneration of phosphate. Much of the regeneration takes place in shallow environments (lakes, estuaries, and continental shelves). In the aquatic environment, dissolved phosphate is consumed during the growth of phytoplankton and is regenerated during the bacterial decomposition of organic matter.

Total phosphorus concentration ranged from 15.5 to 39.80 µg/g with a mean value of 23.86 µg/g.

Calcium Carbonate (CC): Virtually all calcium carbonate deposits in the oceans are formed by organisms. The calcareous organisms are primarily foraminifera, coccoliths, corals, molluscs, and algae in shallow and open ocean water. When the planktonic organisms die their calcareous shells fall to the ocean bottom. The calcium carbonate content in the sediments varied from 6.9% to 11.0%, with a mean value of 8.54%.

Table 3. 45 Shows Sediment Parameters in KG basin

Parameter	Minimum	Maximum	Average
OC (%)	0.35	3.59	1.34
TN (%)	0.025	0.081	0.04
TP (µg/g)	15.5	39.80	23.86
CC (%)	6.9	11	8.54

3.1.6.7 Biological Parameters

Phytoplankton are microscopic plants living in the ocean surface layer, especially in the euphotic water column, and they are mainly composed of diatoms, dinoflagellates, and cyanobacteria. Usually, in marine environments, diatoms outnumber dinoflagellates, especially in nutrient-enriched waters, where they contribute most of the chlorophyll-a concentration. Zooplankton are drifting small animals that can be microscopic or visible to the naked eye. They are considered to be the secondary producers in the marine ecosystems and formed of most complex components consisting of about 15 to 21 taxonomic groups. Usually, copepods contribute to a significant proportion of the zooplankton community in the marine environment by their high number and biomass to the total. Benthos are organisms living in or on the seafloor, which can be grouped into categories based on their body size:

macrobenthos (>0.5mm) and meiobenthos (<0.5mm). Biomass in the present study was calculated based on the wet weight of the organism. Gastropods, bivalves, polychaetes, foraminifera, and crustaceans contributed to the macro-benthos community whereas, nematodes, smaller polychaetes, and foraminiferans contributed to the meiobenthos community. The disturbance in the bottom substratum due to natural and anthropogenic activities is usually reflected in the abundance, biomass, and diversity of benthos. Benthos are one of the most essential organisms in the continental shelf region, which can be used as important indicators of water pollution, as they respond quickly to minor environmental changes. The distribution of benthic animals in marine ecosystems depends on the sediment quality, organic matter, and bottom dissolved oxygen concentration. A detailed summary of biological parameters in the KG basin is shown in table 3.46

Table 3. 46 Shows Biological Parameters in the KG basin

Parameter	Minimum	Maximum	Average
Phytoplankton			
Chl a (µg/L)	0.07	0.59	0.36
Abundance (No/L)	228	679	457
Diatom abundance (No/L)	145	514	332.5
Dinoflagellate abundance (No/L)	69	254	167
Zooplankton			
Biomass (ml/m3)	0.13	1.18	0.65
Density (No/m3)	23.06	4906.52	2464.79
Macro-benthos			
Sediment chlorophyll (µg/g)	0.21	0.97	0.61
Biomass (g/m2)	0.09	1.48	0.78
Density (no./m2)	50	1675	862.67
Meio-benthos			
Biomass (g/m2)	0.008	0.089	0.0195
Density (no./m2)	356	3486	1873.81

3.1.6.8 Marine Fisheries

Marine fishery resources are renewable and limited, therefore management of the harvest of marine fishery resources is necessary for sustained production from the sea. Towards this, it is essential to have a reliable and updated knowledge base on the status of marine fishery resources. The basin has a coastline of about 968 km and has good fishery resources. The continental shelf area covers 39,109 km2 extending up to 32 - 43 km. The dominant commercially important fishes in the region are elasmobranchs, Clupeids, Perches, Flat fishes, Pomfrets, Carangids, Mackerels, Seer fishes, neritic Tunas, other pelagic fishes, Milkfish, Mullets, marine shrimp, lobsters, Cephalopods and miscellaneous species Penaeus monodon, P. semisulcatus, Scylla serrata and Scylla tranquebarica (Mud crab) are common crustaceans in this region.

3.1.7 Mahanadi Basin

The Mahanadi basin originates from the rifting and breakup of Gondwana Land, situated on the east coast of India, covering an area of 14,000 km2 in the shallow offshore area. The on-land part is restricted to the northwest and west through Pre-Cambrian outcrops, which belong to the Indian Crystalline aegis. The Onshore Mahanadi basin is situated in the Orissa, but the shallow offshore portion lies off in the Andhra Pradesh coast and Orissa. The basin lies between 80◦30 to 86◦50 east longitude and 19◦21 to 23◦35 north latitude. It covers the area in Madhya Pradesh, Orissa, Bihar, and Maharashtra states. The generalized Litho-Stratigraphic column of the Mahanadi shallow offshore basin consists of sands, clays, and silts. The temperature gradient in the onshore and offshore basins is found to be >2.5/100 m. The presence of organic matter and stratigraphic and structural traps in the basin indicate the hydrocarbon potential of the basin. The presence of coarse-grained sandstones confirmed the potential of sediments to host the hydrocarbons. The Mahanadi basin has the potential for the formation of gas hydrates due to the enormous volume of coarse-grained sediment and organic-rich sediments from the Brahmani and Mahanadi Rivers. Mahanadi-NEC area is so greatly influenced by Bengal deltaic sedimentation system that its north-eastern boundary with Bengal Basin becomes obscure. To date, four wells in the onshore part (MNO-1 to 4) and seven wells in Mahanadi shallow offshore (MND-1 to 7) have been drilled, some of which indicated significant hydrocarbon shows during drilling. In NEC area, two wells viz. BB-A-1R and BB-B-1 were drilled by Carlsberg, four wells viz. NEC 1,2,3, and 4 were drilled by OIL, and in more recent times, another Company drilled 6 wells. Some of the wells gave very encouraging results.

3.1.7.1 Meteorological Conditions

The Mahanadi basin falls under the sub-tropical zone, and the geographical location of the catchment mainly influences the climate with respect to the Bay of Bengal. Also, The Mahanadi basin experiences four distinct seasons, namely the cold weather, the hot weather, the south-west monsoon and the post-monsoon. The winds are generally light in the cold weather and blow either from the north or the northeast. The hot season commences in March lasts till the middle of June till the south-west monsoon. The mean maximum and minimum temperatures were observed to be 35.96°C and 13.30°C, respectively. Thunderstorms are quite frequent in the hot season, bringing some rainfall comparatively higher in hilly regions. The highest relative humidity in the basin varies between 68% and 87% and occurs during July/August. The lowest relative humidity occurs during April/May and varies between 9% and 45%. The average highest relative humidity in the basin is 82%, and the average lowest relative humidity is 31.6%. The basin receives an average annual rainfall of 1291 mm, of which about 90 per cent is received from the southwest monsoon, i.e., from June to October. However, the delta region receives less rainfall (60-70 per cent annual average rainfall), but more rainfall during the northeast monsoon (10-22 per cent annual average rainfall).

Table 3. 47 Meteorological / Physical parameters in Mahanadi basin

Parameter	Minimum	Maximum	Average
Wind speed(m/s)	0.45	12.6	4.9
Surface Pressure (Pa)	99450.4	101282.4	100450.4
Air temperature(°C)	23.9	31.3	26.4
Sea surface Temperature(°C)	27.4	31.5	29.3
Sea Surface Salinity (SSS)	32.755	33.77	33.295
Relative Humidity (%)	65.29	88	79.21
Net Shortwave radiation(w/m^2)	43.05	252.17	183.68
Net longwave radiation(w/m^2)	-89.425	-8.795	-44.55
Latent heat net flux (w/m^2)	5.52	282.135	76.37
Sensible heat net flux (w/m^2)	-90.78	293.195	57.92

3.1.7.2 Physical Parameters

a) Tides

Tides in the basin are characterized by a “mixed type”, predominantly— semidiurnal, with the Highest High-Water Level (HHWL) of+ 3.50 m and Lowest Low Water Level (LLWL) of + 0.40 m from the Mean Sea Level (MSL) of+1.70 m with respect to Chart Datum (CD). The flood and ebb currents are of the order of 0.6 knots (0.3 m/s) and 0.45 knots (0.23 m/s) during spring tides and neap tides

b) Currents

Play a major role in coastal climate and ocean temperature. The Currents measured in the coastal waters of the basin indicate that the flow is towards the south with speeds varying from 14- 29 cm s-1 in the water column.

c) Waves

The mean significant wave height ranges between 1.25 and 1.40 m, mostly plunging from June to December and surging from January to May. However, during the southwest monsoon, winds generate high waves of 3m or more which strike the shore obliquely and induce littoral/longshore drift of 1.5 million cubic meters of sand annually from southwest to the northeast nearshore regime.

d) Cyclones and Tsunami

Cyclones are low-pressure systems that form over oceans and have inward spiralled, moist rising air. The Mahanadi basin coastal region is vulnerable to multiple disasters. Due to its sub-tropical littoral location, the state is prone to tropical cyclones and storm surges. This basin is also prone to very severe damaging earthquakes. Its people feel much more vulnerable to earthquake-induced tsunamis since the 2004 Indian Ocean tsunami, which affected the coastal regions and destroyed much of the marine biology and severely damaged the ecosystem.

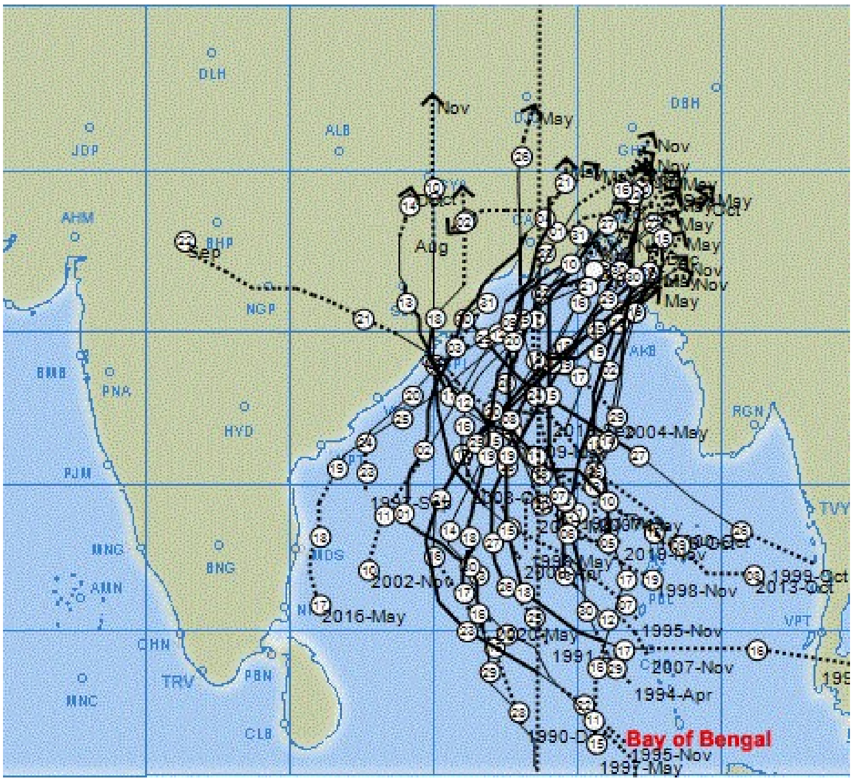

Figure 3. 7 shows Past Cyclonic events in Mahanadi Basin

3.1.7.3 Water Quality

The basin's chemical characteristics of coastal water in the basin ranged between pH: 7.8-8.06, temperature: 25.1-31.6 ^{o}C and turbidity: 1-158 NTU. The total suspended solids vary from 26-288 mg/l. Salinity values have been found to vary between 28.3-32.9. Dissolved oxygen available in water at any given time results from the amount consumed by aquatic organisms and replenishment through natural processes. Dissolved oxygen was found in the range of 2.5 to 4.9 mg/l. Biochemical oxygen demand (BOD) is widely used to determine the quantitative load of biochemically oxidizable organic matter and the degree of organic pollution. The BOD values were less than 10 mg/l. Nutrients determine the primary production potential of the waterbody, and therefore, it is important to know their distribution and behaviour in different geographical locations and seasons. Nitrogen and phosphorus compounds from a major source of nutrients for the growth of phytoplankton. Nitrate is an essential nutrient for the growth of many photosynthetic autotrophs and has been identified as a growth-limiting nutrient. Nitrate as NO_3^- levels in the region was found in the range of 0.38 to 0.42 mg/l. and Total Phosphates were in the range of 0.4-0.6 mg/l

Table 3. 48 Summary of Marine water Quality in Mahanadi basin

Parameters	Units	Minimum	Maximum	Average
pH at 25°C	--	7.8	8.06	7.9
Temperature	°C	25.1	31.6	27.5
Turbidity	NTU	1	159	25.6
Salinity	psu	28.3	32.9	29.9
Total Suspended Solids	mg/l	28	36	32
Silica as SiO_2	mg/l	33.8	34.5	34.06
Phosphate as PO_4^{3-}	mg/l	0.4	0.6	0.5
Nitrite (NO_2^-)	mg/l	0.38	0.42	0.40
Nitrate (NO_3^-)	mg/l	41.6	42.1	41.86
Calcium as Ca	mg/l	516	536	524
Sodium as Na	mg/l	7159.6	7477.5	7281
Potassium as K	mg/l	5.2	5.6	5.4
Dissolved Oxygen	mg/l	2.4	4.9	2.4
Chemical Oxygen Demand	mg/l	20	30	24.6
Biochemical Oxygen Demand (5 days @ 20°C)	mg/l	7	10	8.3
Ammonia as NH_3-N		0.68	0.89	0.8
Phenol	mg/l	<0.001	<0.001	<0.001
Oil & Grease	mg/l	0.1	0.1	0.1
Total Plate Count	CFU/100ml	32	40	36
Feacal coliform	CFU/100ml	4	7	5.6

3.1.7.4 Heavy metals in Sea water

Inorganic elements such as metals, even at trace levels, invite attention due to their persistence in waterbodies. Some of the heavy metals, viz. arsenic, cadmium, chromium, copper and lead, are toxic at very low concentrations and can affect the prey and predator equilibrium in the waterbody. Heavy metals were found to be as Arsenic: 0.001-0.006 mg/l, Chromium: 0.008-0.021 mg/l, Iron: 0.422-3.486 mg/l, Molybdenum: 0.015-0.021 mg/l, Nickel: 0.001-0.009, Lead: 0.015-0.022 mg/l, Selenium: 0.001-0.003 mg/l and Vanadium: 1.272-1.428 mg/l;

Table 3. 49 Heavy metal concentrations Seawater at Mahanadi basin

Element(µg/L)	Concentration values		
	Minimum	Maximum	Average
As	0.001	0.006	0.003
Cr	0.008	0.021	0.014
Fe	0.422	3.486	1.95
Mo	0.015	0.21	0.11
Ni	0.001	0.009	0.005
Pb	0.015	0.022	0.018
Se	0.001	0.01	0.005
V	1.273	1.428	1.35

3.1.7.5 Biological Parameters

Phytoplankton in the study area comprised of 41 genera belonging to class Cyanophyceae, Chlorophyceae, Bacillariophyceae and Dinophyceae. The density of phytoplankton varied from 1.17 X 104 No. L-1 to 2.53 X 105 No. L-1. Bacillariophyceae dominated the phytoplankton group in all the surface water by almost three-fold, comprising 66.67-100 % of the total Phytoplankton class, followed by Cyanophyceae, Chlorophyceae, and Dinophyceae. Phytoplankton genera belonging to class Chlorophyceae and Dinophyceae were comparatively less, comprising 0.0-33.3% and 0.0-29.41% of the total Phytoplankton composition, respectively. Zooplankton species composition comprised of 25 genera belonging to Class Granuloreticulosea, Oligotrichea, Hydrozoa, Scyphozoa, Polychaete, Hexanauplia, Malacostraca, Ostracoda, Sagittoidae, eggs and larvae, and zoea and Nauplius Eggs and larvae of chordates, polychaetes, arthropods; and initial developmental stages of decapod crustaceans in the form of zoea and Nauplius were also identified. The zooplankton density varied from 1120 to 12640 No. m-3 Hexanauplia (Copepoda) dominated the zooplankton class at all the sampling locations with a species composition of 36.84-85.71%. Zooplankton genera belonging to class Granuloreticulosea, Oligotrichea, Hydrozoa, Scyphozoa, Polychaete, Malacostraca, Ostracoda, and Sagittoidae were comparatively less;

thereby, comprising of 0.0-4.35%, 0.0-5.06%, 0.0-4.35%, 0.0-13.04%, 0.0-10.34%, 0.0-3.8%, 0.0-1.92% and 0.0-12.82% of the total Zooplankton composition, respectively. Benthic organisms in the study area comprised of fifty-three genera belonging to Ninteen groups. Macrobenthos comprised of Coelenterata, Annelida, Decapoda, Macrura, Gastopoda, Pelecypoda and Cirripedia; while Protozoa, Aschelminthes, Nemertina, Polychaete, Rotifera, Copepoda, Cladocera, Amphipoda, Mysida, Ostracoda, Foraminifera and Trematoda constituted the Meiobenthos The density of Macrobenthos varied from 47 No./ m3 to 2570 No./ m3.

Table 3. 50 Shows Biological Parameters in Mahanadi basin

Parameter	Minimum	Maximum	Average
Phytoplankton			
Chl a (µg/L)	0.29	3.78	1.67
Abundance (No/L)	398	2513	1328.3
Diatom abundance (No/L)	296	1498	898
Dinoflagellate abundance (No/L)	91	705	378
Zooplankton			
Biomass (ml/m3)	0.29	1.57	0.63
Density (No/m3)	829.84	5592.87	2156.75
Macro-benthos			
Sediment chlorophyll (µg/g)	0.43	3.16	1.12
Biomass (g/m2)	1.0527	21.1	7.2
Density (no./m2)	105	5500	1637.54
Meio-benthos			
Biomass (g/m2)	0.002	0.045	0.0165
Density (no./m2)	416	3376	1933.81

3.1.7.6 Marine Fisheries

The basin's proximity to the rich shrimp grounds in the northern Bay of Bengal as well as the existence of a broad continental shelf (in the north zone), is characterised by a high proportion of commercially important species like hilsa, pomfrets, shrimp, lobster, squids and cuttlefish. Among the finfishes, croakers constituted 13.22%, followed by Mackerel (10.36%), Trichuridae (10.32%) and Clupeids (7.85%). Cephalopods comprising of Squids and cuttlefish constituted 7.39% of the average annual landing; while, crabs and lobsters constituted 4.89% and 0.17%, respectively. Moreover, the fish catch also constitutes of Bombay duck, Silver Bar, Polynemids, Carangids, Mullets, Eels, Catfishes, and Flatfishes.

3.1.8 Andaman Basin

The Andaman Islands and Basin lie between North Sumatra and Myanmar. The Basin extends 1200 km from Myanmar to Sumatra and 650 km from the Malay Peninsula to the Andaman & Nicobar Islands. The bathymetry varies between 200 m and 2000 m (Mohan et al., 2006). The Basin is associated with converging plate boundaries and is part of a large geotectonic unit which, from West to East, includes the fore-deep (Java Trench), fore-arc, volcanic arc and back-arc. The main Basin is in the back-arc portion and is more than 5000 m of thick sediments ranging from late Cretaceous to Recent (Dangwal et al., 2008). From a petroleum exploration viewpoint, the Basin is frontier in nature, with the 14 wells drilled so far targeting the shallow water fore-arc part. Well X-1 has been reported to have produced gas (Dangwal et al., 2008), as has well AN-1-1 (from Middle Miocene limestone); with gas also shows in well AN-32-1 (from Lower Miocene vitric ash beds) and in Cretaceous sandstones in well AN-1-1 (DGH website www.dghindia.org, 2009). However, major discoveries within other Sumatra-Andaman-Myanmar belts indicate that the Andaman Basin could hold substantial gas reserves (Mohan et al. 2006). For example, it has been reported by Jha et al., 2008 that in the adjacent North Sumatran Basin, which is a proven and mature petroliferous basin, with large fields such as Arun, Kuala Langsa and NSO, there have been discoveries of around 28 TCF of gas, 2300 mmbl of oil and 900 mmbl of condensate. In addition to this, further north in Myanmar waters on the margin of the Basin, a number of gas fields have been discovered and are being developed – these include Yadana (5 TCF in Miocene carbonates) and Yetagun (3 TCF in Miocene clastic)

3.1.8.1 Meteorological Conditions

Andaman & Nicobar Islands climate is a warm tropical climate, with the presence of irregular rainfall during the southwest monsoon. According to the climate data of IMD (1960 – 1991), the humidity of Port Blair was found to vary between 65% and 85%. The maximum and minimum temperature does not present many variations in the year. April was found to be the hottest month with a temperature of 32.5°C, while 29.5°C was the lowest daily maximum temperature recorded during January. The annual rainfall is about 3000 mm, where June, July and August receive the maximum rainfall. The average wind speed at Port Blair was measured to be a little under 11 kmph (3 m/s), while the wind was found to be a high as 19.5 kmph during monsoon months. During May to August, S, SW and W is the predominant sector, months of April, September and October are transient months while N, NE and E are prominent direction for the months between November to March.

Table 3. 51 Hazards and Risk

Risk	**Hazards**
Seismicity	Earthquake's shock (An understanding of the tectonic setting of the region is important in tsunami generation)
Tsunami triggered by earthquake or volcanism	Catastrophic wave and associated Inundation to inshore region collapse vessel and its operation that anchorage in the port premises
Meteorology	Heavy downpours during the rainy season (avg. Rainfall 3000 mm) and possible flooding may hinder the operations.
Currents	Tidal currents of up to 1m/sec are reported in the Andaman-Nicobar Islands can change ship movement
Cyclone	4 to 5 cyclones are likely to occur in the study area per year on average. High wind and wave associated with this activity adversely affect ship movement and operation at the port

Table 3. 52 Meteorological / Physical parameters in Andaman basin

Parameter	Minimum	Maximum	Average
Wind speed(m/s)	0.2	12.3	5.64
Surface Pressure (Pa)	99396	101117	100304
Air temperature(°C)	23.9	27.9	26.3
Sea surface Temperature(°C)	27.7	31.3	29.2
Sea Surface Salinity (SSS)	32.61	33.34	32.89
Relative Humidity (%)	67.08	87	79.82
Net Shortwave radiation(w/m^2)	57.81	275.14	194.86
Net longwave radiation(w/m^2)	-93.95	-16.47	-43.8
Latent heat net flux (w/m^2)	-9.16	405.07	89.44
Sensible heat net flux (w/m^2)	-122.5	456.59	52.04

Temperature–The A & N island had a humid tropical climate because of its location in the equatorial zone surrounded by the Andaman Sea. Winter is virtually absent, and the islands have only two seasons, viz. rainy Season and summer Season. The temperature in Andaman & Nicobar Island remains similar and ranges between 23.9^{0}C (minimum) to 27.9.

Relative Humidity–Being a humid tropical climate, high humidity is observed in all the months. The relative humidity in the region ranges between 67.08-87%. The maximum humidity during the rainy season is 87%.

Rainfall– The annual total rainfall is 2968.1 mm. Over 95% of the total annual rainfall is received from May to December month.

Cloud Cover – Most of the year, clouds were observed in the sky. The maximum of rain is received in the region from April to December.

Wind Speed– The mean wind speed ranges from 4.5 to 8.6 m/s during the summer and 9.6 to 14.1 m/s during monsoon seasons. High wind speed was observed during monsoon season and normal winds from November to April.

Wind Direction– The predominant wind direction at Port Blair is from North- East and East in November to April months. During the monsoon period, the predominant wind direction is from South-West and West**.**

Special Weather Phenomena- The occurrence of the thunderstorm is 64.8 days per year, mostly spread across the months of April to July. Annual Dust Storm is only 0.2 days during September month. Annually 0.5 days have visibility less than 1 km, 10.4 days has visibility in the range of 1 - 4 km, 95.4 days have visibility in the range of 4 -10 km, 219.4 days between 10 - 20 km and 39.3 days have visibility above 20 km.

3.1.8.2 Physical Parameters

The Andaman waters (surrounding the Andaman and Nicobar Islands) occupy the area between 6°–14°N and 91°–95°E in the eastern part of the North Indian Ocean. The northern part of the islands has a wide continental shelf (170–200 km). The continental slope along the eastern part of the islands is steeper than the western part (Murthy et al., 1981) and has erratic bottom topography. Sills are observed on the eastern side due to the sediment accumulation of the Ayeyarwady River system (Ramaswamy et al., 2004). The abyssal plain (3000– 4180 m) with an even floor is situated along the west coast of the Andaman and Nicobar Islands. Prepares Channel (between Cape Negrais and North Andaman) in the north (200 m, 285 km wide), Ten Degree Channel (150 km wide) between Andaman and Nicobar Islands (1800 m), and Great Channel between Great Nicobar Island and Sumatra (> 1800 m and 189 km wide) connect the sea with Bay of Bengal (Sengupta et al. 1981; Kamesh Raju et al. 2004). The sea is also linked with the South China Sea and the Pacific Ocean through Malacca Strait at the southeast. The primary sources of freshwater to the northeast of Andaman and Nicobar Islands are Ayeyarwady (13.6 × 103 m3/s), Salween rivers (6.69 × 103 m3/s), and minor contributions from Sittang (1.59 × 103 m3/s) and Tavoy rivers (Robinson et al. 2007). The other minor rivers in the Islands are Kalpong in North Andaman and Alexandra, Dagmar and Galatheariver in Great Nicobar.

The Andaman waters experience the seasonally reversing Asian monsoons (Wyrtki 1973), summer monsoon during May–September, and winter monsoon during November–February. During the northeast monsoon, the low saline water spread over the eastern side of the islands originates from the river discharge at the north and the intrusion of low saline water from the South China Sea through the Malacca Strait at the south (Ibrahim and Yanagi

2006). In addition, during the season, the region experiences strong evaporation of surface water due to cold, dry continental air from the north. Thus, the area In addition to this, internal wave and tidal induced elevated vertical mixing are likely to influence the regional stratification and circulation pattern. The region is one of the sites where extraordinary large solitons have been observed (Osborne 1990; Hyder et al. 2005). Internal waves of the extraordinary amplitude of 60 m, wavelength of 6–15 km, and speed > 2 m/s were noticed in this region (Alpers et al. 1997). This, together with a longer period of internal oscillation in the Northern Andaman Sea, produced the downward perturbation of the pycnocline. This also endorsed the eastward-propagating Kelvin wave parallel to the continental slope. Such waves helped the mixing processes in the Andaman Sea (Hyder et al., 2005). This area is experienced with cold, dry continental air from the northeast, and the oceanic region is experienced with evaporative cooling with significant spatial variation (Wang et al. 2006). Immediate response due to atmospheric forcing will be best reflected in the sea surface temperature (SST) pattern and is thus is a spot of deep air-sea interaction and associated convective activities and is marked as cyclone-prone area (Varkey et al. 1996). The presence of rivers and monsoonal winds influences the regional hydrography and circulation considered the most important parameter in the air-sea interaction processes (Manikiam 1988). The maximum sea surface temperature is observed as above 31.3°C in the southern end of the Andaman Sea, and it's extended over the region, and the temperature changed from 28.4 to 30.4 °C. The sea surface salinity (SSS) is low and falls in the range of 31.8–33.4. Temperature-salinity (TS) profiles characterize two water types in the northeastern section as warm (27.5–29.0 °C) less saline (32.5–33.5) and less dense (20.2–21.5 kg/m3) for the upper (5–55 m) and below this level, uniform waters occupied up to 1000 m. A similar trend exists for the southeast also with warm (24.5–29.3 °C), saline (32.3–34), and less dense water (20.5–23.4 kg/m3) for the upper (5–80 m) column, but the source of water occupying the upper layer is found to be different. The northeast is due to heavy runoff from the Ayeyarwady-Salween river system, while intrusion of Malacca Strait water (Riley and Chester 1971) in the south defines the water mass (Rama Raju et al. 1981; Tan et al. 2006). The intrusion of low saline water through the Malacca Strait during the active winter. The western side of the island chain exhibits a more or less similar pattern, and the area is shown to be occupied by Bay of Bengal waters with temperature 25.0–29.2 °C, salinity 32.1–34.0, σt20.3–22.0 kg/m3 in the upper column (5–75 m) and below with 5.0–24.9 °C, 34.0–34.9, and 22.1–27.3 kg/m3 respectively up to 1000 m depth during December and January. The tidal levels observed at the South Bay (Galatea, Close of Port Blair on North) with respect to Chart Datum of admiralty chart were observed to vary between 0.2 m to 1.6 m with a tidal range of 1.4 m.

Table 3. 53 Tidal data in Andaman basin

Tidal Levels	Height
Mean Highest Water Spring	+ 1.6 m
Mean Highest Water Neap	+ 1.1 m
Mean Sea Level	+ 0.9 m
MLWN	+ 0.7 m
MLWS	+ 0.2 m

3.1.8.2.1 Cyclones and Tsunami

The Andaman Sea is known for the genesis of many severe cyclones that traverse the Bay of Bengal. The Andaman Islands face the surge disaster threat as their north-south orientation comes across the eastward path of severe cyclones moving from the Andaman Sea and the western Pacific Ocean.). 4 to 5 cyclones are likely to occur in the Andaman Sea per year on average. In general terms, it can be seen that the risk from tropical storms is moderate in the Andaman Sea. Studies indicate that there is an increasing trend in the frequency of intense tropical cyclones over the north Indian Ocean. The Andaman basin lies on the Indian Plate and the Eurasian Plate. However, the Eurasian Plate is divided into several platelets, and it comprises the Burma Plate and the Sunda Plate. As per the seismic map, the region falls in Zone V, which falls in high damage risk. 208. Tsunami is long-wavelength, long-period sea waves generated by an abrupt movement of large volumes of water, generally caused by vertical displacement of the seabed along fault lines by earthquakes with Magnitude 7 or above, by a volcanic eruption, volcanic collapse or submarine landslides. Tsunami wave heights at sea are usually less than 1m, and the waves are frequently not noticed by people in ships. As tsunami waves approach the shallow water of the coast, their heights increase and sometimes exceed 20m. Run-up height is highly influenced by offshore bathymetry and on-shore topography, and as a result, the level of destruction varies widely.

The destructive power of the wave correlates with water depth and the square of velocity. Water has a thousand-fold greater density than air, and this attribute, together with enhanced drag coefficients due to partial inundation, more than compensate for lower fluid velocities.

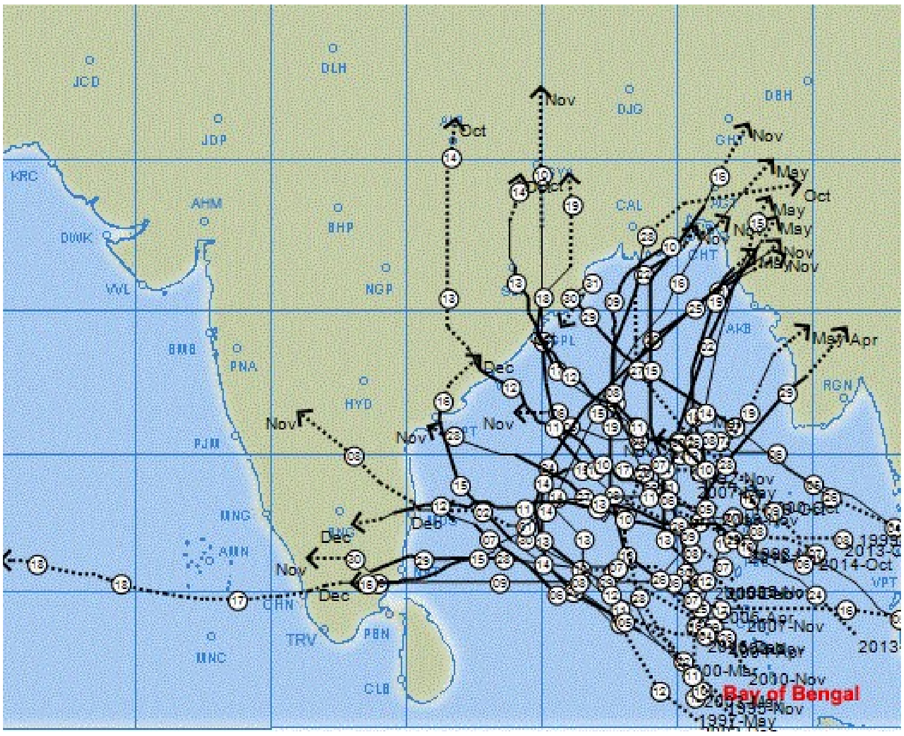

Figure 3. 8 shows Past Cyclonic events in Andaman Basin

As per NDMA, coastal areas of Andaman and Nicobar Islands are prone to cyclones and tsunami and have a very high damage risk.

3.1.8.3 Water Quality

The analysis helps to conclude that the pH of all the samples was found to vary between 7.12 and 7.30. It should be noted that the values obtained were within the desirable limit for pH as prescribed by CPCB. The total hardness was observed to be ranging between 198-210 mg/l. The concentration of Total Dissolved Solids was estimated in the range of 334mg/l to 385 mg/l. The Chemical Oxygen Demand (COD) & Biochemical Oxygen Demand (BOD) values were calculated to be in the range of 11.3 mg/l to 16.6 mg/l & 5.2 mg/l to 6.5 mg/l, respectively

Table 3. 54 the water quality of the Andaman basin waters

Parameters	Value		
	Min	Max	Average
pH Value	7.12	7.3	7.21
Temperature (^oC)	24.6	24.8	24.7
Conductivity, (mhos/cm)	514	592	553
Turbidity (NTU)	<1	<1	<1
Total Dissolved Solids (mg/l)	334	385	359.5
Total Suspended Solids (mg/l)	<2	<2	
Total Hardness	198	210	204
Chloride as Cl (mg/l)	44	52	48
Total Alkalinity (mg/l)	180	238	209
Sulphates as SO_4 (mg/l)	18	22	20
Nitrates as NO_3^- (mg/l)	0.88	0.98	0.93
Fluoride as F (mg/l)	0.56	0.62	0.59
Iron as Fe (mg/l)	0.62	0.84	0.73
Zinc as Zn (mg/l)	<0.01	<0.01	<0.01
Calcium as Ca (mg/l)	67.2	72.8	70
Magnesium as Mg (mg/l)	7.3	6.8	7.05
Sodium as Na (mg/l)	11	13	12
Potassium as K (mg/l)	2.3	3.2	2.75
Cadmium as Cd (mg/l)	<0.01	<0.01	<0.01
Copper as Cu (mg/l)	<0.01	<0.01	<0.01
Nickel as Ni (mg/l)	<0.01	<0.01	<0.01
Lead as Pb (mg/l)	0.025	0.046	0.0355
Mercury as Hg (mg/l)	<0.001	<0.001	<0.001
Chromium (Total as Cr) (mg/l)	<0.05	<0.05	<0.05
Arsenic as As (mg/l)	<0.01	<0.01	<0.01
Phenolic compound (mg/l)	<0.001	<0.001	<0.001

Table 3. 55 Heavy Metals concentration in sediments

Element(µg/g)	Concentration values		
	Minimum	Maximum	Average
Sediment			
Cd	0.29	2.1	1.19
Cu	0.55	3.71	2.13
Pb	0.6	5.47	3.03
Hg	0.23	0.96	0.59
Zn	0.37	1.12	0.74

3.1.8.4 Biological Parameters

The phytoplankton species recorded were belonging to families Asterolampraceae, Bacillariaceae, Biddulphieae, Ceratiaceae, Chaetocereae, Coscinodisceae, Cyanophyceae, Fragilaroideae, Hemiaulineae, Naviculoideae, Oxytoxaceae, Peridiniaceae, Prorocentriaceae and Soleniae. A total of 105 species were recorded from seven different stations. The phytoplankton density (Nos./L) recorded during the period of study ranged from 613.64 to 19825.24 Nos./L. A total of 96 species of zooplankton belonging to 19 groups and 74 genera were recorded, and Copepods were the dominant group, and their composition of occurrence ranged from 30.39% to 44.30%. Foraminiferans were the subdominant group in the region. Their composition varied from 6.90% to 14.70; besides that, chaetognaths, Appendicularians, Crustacean larvae and Molluscs occurred in considerable composition at quite a number of stations. The number of species recorded for individual groups ranged from 1 to 37.

Table 3. 56 Shows Biological Parameters in the Andaman basin

Parameter	Minimum	Maximum	Average
Phytoplankton Density (Nos./L)	613.64	19825.24	4251.766
Zooplankton			
Fresh weight(mg/100m^3)	2540	4580	3364.286
Dry weight (mg/100m^3)	718	1240	956.1429
Volume (ml/100m^3)	4.7	12.7	9.028571
Numerical density (No/100m^3)	17300	31620	26321.43
Groups			
Amphipods	1.32	1.71	1.4725
Annelid larvae	1.37	4.7	3.392
Appendicularians	3.92	10.27	6.977143
Chaetognaths	5.13	11.76	7.818571
Cladocerans	1.96	5.23	3.39
Copepods	30.39	44.3	37.75143
Crustacean larvae	4.79	12.5	7.735714
Doliolids	1.31	2.14	1.803333
Echinoderm larvae	1.71	3.36	2.5325
Foraminiferans	6.90	14.7	11.18714
Isopods	2.61	2.61	2.61
Leptomedusae	1.34	3.43	1.898
Molluscs	2.61	7.69	5.122857

3.1.8.5 Biological Environment

The Andaman and Nicobar Islands are very rich in biodiversity, harbouring unique endemic life forms. The islands have both rich terrestrial as well as marine ecosystems, such as mangroves, coral reefs and seagrass beds. The marine biodiversity includes marine mammals such as whales, dolphins, dugong; marine turtles; estuarine or saltwater crocodile; fishes; prawns and lobsters; corals; seashells, including rare and endangered Trochus species and Giant Clam Shells and numerous other marine life forms, including coelenterates and echinoderms etc. The sandy beaches on some islands provide nesting places for four species of marine turtles. The nearshore waters are rich in finfish, shellfish and other economically important species such as seashells, sea cucumbers, crabs, lobsters etc. At the same time, seas around these islands are also rich in pelagic fishes such as Tunas, Indian Mackerel, Seer fish, Sharks.

Table 3. 57 Marine biodiversity and endemism

Animal group	No. of species/ sub	No. of endemics	Percentage of endemism
Mammalia (mammals)	7	–	–
Reptilia (reptiles)	12	–	–
Pisces (fishes)	1,200	2	0.2
Echinodermata (star fishes, etc.)	350	4	0.4
Mollusca (squids, octopus, etc.)	1,000	18	1.9
Crustacea (crabs, lobsters etc.)	600	6	1.0
Polychaeta (marine worms)	184	4	2.2
Anthozoa (sea anemones and corals)	326	2	0.6
Porifera (sea sponges)	72	–	–
Meiofauna (small invertebrate sea creatures)	490	102	21.0
TOTAL	4,241	138	0.11

Source: State Action Plan on Climate Change Andaman and Nicobar Islands (2013)

3.1.8.5.1 Coral Reefs and Marine Biodiversity

ANI is fringed with one of the most spectacular and extensive reefs in the world. Andaman reefs consist of about 83% of coral diversity found anywhere in the world and is at par with the „Coral Triangle" of Indonesia. ANI has the last pristine reefs in the Indian Ocean region and is one of the world's most important coral reef sites. Coral reefs are intimately connected to other marine communities such as mangrove forests, seagrass beds, and the open seas as water currents transport larvae, plants, animals, nutrients, and organic materials. They play a significant role in the development of other ecosystems such as mangroves and wetlands and protect coastlines from wave and storm damage and erosion. Life-saving medicines, such as anticoagulants, and anticancer agents, such as prostaglandins, come from coral reefs. Around 180 species of corals have been recorded. At least two species appear to be endemic to Andaman waters. They are Deltocyathus andamanicus (Alcock) and Polycyathus andamanensis (Alcock), both belonging to family Caryophyllifae. Two more species, namely, Pocillopora ankeli (Scheer and Pillai) and Pavona xarifae (Scheer and Pillai) have been described as new species from Nicobar waters. By far the highest number of coral species have been recorded from Andaman and Nicobar coral reefs in comparison to reefs occurring along the Indian mainland coast.

3.1.8.6 Marine Fishery

More than 1150 fish species under 507 genera of 151 families have been recorded from the sea around Andaman and Nicobar Island. These species occur in freshwater, brackish water, coastal waters and offshore. The interesting groups are, chimaerids (Chimaeridae), pelagic sharks (Carchaehinidae), deep sea sharks (Squalidae), skates (Rhinobatidae) sting rays (Rajidae), herrings, moray eels (Muraenidae), sardines (Clupeidae), Milkfish, catfish, (Ariidae), lizard fish (Synodontidae), flying fish (Exocoetidae), halfbeaks (Hemirhamphidae), alligator gar (Belo-nidae) , soldier fish (Holocentridae), pipefish (Syngnathidae), groupers (Serranidae), grunters (Teraponidae), flag tails (Kuhlidae),Bulls eye (Priacanthidae), cardinal fishes (Apogonidae), whitings (Sillaginidae), sucker fish (Echeneididae), travellys (Carangidae), silver belly (Leiognathidae), snappers (Lutjanidae), fusiliers (Caesionidae), silver biddys (Gerridae), grunters (Haemulidae), sweetlips (Haemulidae), breams (Sparidae, Lethrindae), threadfins (Nemipterdae), jaw fish (Sciaendae), goat fish (Mullidae), bat fish (Ephippididae), butterfly fish (Chaetodontidae), angel fish (Pomacanthide), Tilapia (Cichlidae), demoiselles (Pomacentridae), anemone fish (Pomacentridae), mullets (Mugilidae), barracuda (Sphyraenidae), tassel fish (Polynemidae), wrasses (Labridae), Parrot fishes (Scaridae), blennids (Blennidae), dragonets (Callionymides), gudgeons (Eleotrididae), gudgeons (Eleotrididae), goby (Gobidae), sword fish (Istiophoridae), mackerel (Scombridae), tunas (Scombi-dae), flounders (Pleuro-nectidae), soles (Cynoglassidae, sollidae), file fish (Balitidae), tiger fish (Balistidae), Box fish (Ostra-cidae), Blow fish (Tetrodontidae), and porcupine fishes (Diodontidae). Sharks, sardines, mackerels, travellys, cat fish, mullets, ribbon fish, barracudas, groupers, snappers, seer fish and tunas are from important fish groups in the commercial fishery.

3.1.9 Sources of the baseline data collected for different sedimentary basins

Baseline data of the marine environment prepared by comprehensive analysis of Marine EIA/ monitoring work carried out in the oil fields within the EEZ of India in shallow and deep offshore blocks, we have compiled most of the available reports related to the oil field along with the western and eastern offshore blocks, books, journal papers, thesis and other documents. For each basin, Meteorological parameters (wind speed, relative humidity barometric pressure, air temperature, solar radiation), physical parameters (currents, wave, temperature, salinity, density, turbidity/TSM), chemical parameters (Dissolved oxygen (DO), Nutrients (nitrate- NO_3^-, silicate - SiO_4^- and phosphate – PO_4^{3-}), Dissolved petroleum hydrocarbon, Dissolved heavy metals), sediment parameters, heavy metals, phytoplankton, zooplankton, benthos, the abundance of fish etc. were prepared through the compilation of the documents. Apart from that, we have referred and verified meteorological and physical datasets from several websites, such as NCEP, ECMWF, GIOVANNI, APDRC and NIO web database, for supporting the baseline data collected from available reports. For each basin, we have tabulated the minimum, maximum, and average values. For all basin Cyclone data were taken from India Meteorological Department (IMD). The following sections detail the sources of baseline data collection.

a. Gujarat Basin

Meteorological parameters and physical parameters:

Marine Environmental Impact Assessment for Discharge Channel of 4000 MW Ultra Mega Power Project Near Mundra, Gulf of Kachchh SPONSORED BY Coastal Gujarat Power Limited, New Delhi FEBRUARY 2009

Gujarat State Action Plan On Climate Change Government Of Gujarat Climate Change Department Supported By The Energy And Resources Institute New Delhi & Giz 2014

Patel, D., Nagababu, G., Radadia, N., Parsana, S., Sheth, M. and Sheth, N., 2018, May. GIS-based approach for the evaluation of offshore wind power potential for Gujarat. In IOP Conference Series: Earth and Environmental Science (Vol. 154, No. 1, p. 012001). IOP Publishing.

Kumar, V.S. and Kumar, K.A., 2010. Waves and currents in tide-dominated location off Dahej, Gulf of Khambhat, India. Marine Geodesy, 33(2-3), pp.218-231.

Nayak, R.K. and Shetye, S.R., 2003. Tides in the Gulf of Khambhat, west coast of India. Estuarine, coastal and shelf science, 57(1-2), pp.249-254.

Nayak, R.K. and Shetye, S.R., 2003. Tides in the Gulf of Khambhat, west coast of India. Estuarine, coastal and shelf science, 57(1-2), pp.249-254.

Subeesh, M.P., Unnikrishnan, A.S., Fernando, V., Agarwadekar, Y., Khalap, S.T., Satelkar, N.P. and Shenoi, S.S.C., 2013. Observed tidal currents on the continental shelf off the west coast of India. Continental Shelf Research, 69, pp.123-140.

Mitra, A., Kumar, V.S. and Naidu, V.S., 2020. Circulation in the Gulf of Khambhat—A Lagrangian Perspective. Journal of Marine Science and Engineering, 8(1), p.25.

Water quality

Marine Environmental Impact Assessment for Discharge Channel of 4000 MW Ultra Mega Power Project Near Mundra, Gulf of Kachchh SPONSORED BY Coastal Gujarat Power Limited, New Delhi FEBRUARY 2009

Pandit, P.R. and Fulekar, M.H., 2017. Quality characterization of coastal water in Gujarat Coast, India. Journal of Biotechnology and Biochemistry, 3(4), pp.8-15.

Patel, R., Salvi, H., Bhagat, R., Vankar, J., Christian, L. and Kamboj, R.D., 2018. Assessment of spatial and temporal variations in coastal water quality of Gulf of Kachchh, Gujarat using GIS application.

Salvi, H., Patel, R., Thakur, B., Shah, K. and Parmar, D., 2014. Assessment of Coastal Water Quality Parameters of Selected Areas of Marine National Park & Sanctuary (Okha, Sikka & Khijadiya). Available at SSRN 2456093.

Bhadja, P. and Kundu, R., 2012. Status of the seawater quality at few industrially important coasts of Gujarat (India) off Arabian Sea.

Heavy metals:

Government of India MINISTRY OF OCEAN DEVELOPMENT ANNUAL REPORT 2005-06

Marine Environmental Impact Assessment for Discharge Channel of 4000 MW Ultra Mega Power Project Near Mundra, Gulf of Kachchh SPONSORED BY Coastal Gujarat Power Limited, New Delhi FEBRUARY 2009

Panseriya, H.Z., Gosai, H.B., Sankhwal, A.O., Sachaniya, B.K., Gavali, D.J. and Dave, B.P., 2020. Distribution, speciation and risk assessment of heavy metals: geochemical exploration of Gulf of Kachchh, Gujarat, India. Environmental Earth Sciences, 79(213), p.213.

Devi, V., Karthikeyan, K., Lekameera, R., Nandhagopal, G., Mehta, P.N. and Thivakaran, G.A., 2014. Water and sediment quality characteristics near an industrial vicinity, Vadinar, Gulf of Kachchh, Gujarat, India. International Journal of Plant, Animal and Environmental Sciences, 4(3), pp.219-226.

Pandit, P.R. and Fulekar, M.H., 2017. Quality characterization of coastal water in Gujarat Coast, India. Journal of Biotechnology and Biochemistry, 3(4), pp.8-15.

ENVIRONMENT MONITORING REPORT OF DEENDAYAL PORT TRUST (Annual Report) (March 2020 to February 2021) (Report No - DCPL/DPT(19-22)/AMR/20-21/01)

Sediment quality and Heavy metals:

Deshraj, T., Mani Christy, R., Koravangatt, D., Devender, K., Ilya, B., Nagesh R, I. and Rajesh R, N., 2012. Sediment characteristics of tidal deposits at Mandvi, Gulf of Kuchchh, Gujarat, India: geophysical, textural and mineralogical attributes. International Journal of Geosciences, 2012.

R. R. Nair, N. H. Hashimi and V. P Rao, “On the Possibility of High Velocity Tidal Streams as Dynamic Barriers to Long Shore Sediment Transport: Evidence from the Continental Shelf of the Gulf of Kuchchh,” Indian Marine geology, Vol. 47, 1982, pp. 77-86.

Y. Pradhan, A. S. Rajawat and S. R. Nayak, “Application of IRS-P4 OCM Data to Study the Impact of Tidal Propagation on Sediment Dynamics in the Gulf of Kachchh,” Indian Journal of Marine Sciences, Vol. 34, No. 2, 2004, pp. 157-163.

P. D. Kunte, B. G. Wagle and Y. Sugimori, "Sediment Transport and Depth Variation Study of the Gulf of Kutch Using Remote Sensing," International Journal of Remote Sensing, Vol. 24, No. 11, 2003, pp. 2253-2263.

Flaura and fauna

Government of India MINISTRY OF OCEAN DEVELOPMENT ANNUAL REPORT 2005-06

Marine Environmental Impact Assessment for Discharge Channel of 4000 MW Ultra Mega Power Project Near Mundra, Gulf of Kachchh SPONSORED BY Coastal Gujarat Power Limited, New Delhi FEBRUARY 2009

Marine Environmental Impact Assessment for Rerouting the 42" Sour Gas Pipeline Segment of ONGC in the Nearshore and Intertidal Areas of Umbhrat, Navsari District SPONSORED BY OIL AND NATURAL GAS COMMISSION, JANUARY 2015

Thakur, B., Chavda, C. and Salvi, H., 2015. Phytoplankton diversity at some selected sites of the Gulf of Kachchh, Gujarat, India. Bulletin of Environmental and Scientific Research, 4(4), pp.7-12.

Patel, R., Salvi, H., Bhagat, R. and Kamboj, R.D., 2017. Zooplankton Diversity at important Coral and Mangrove areas of Gulf of Kachchh, Gujarat, India. Bulletin of Environmental and Scientific Research, 6(3-4), pp.1-7.

Raghunathan, C., Tewari, A., Joshi, H.V., Kumar, V.G., Trivedi, R.H. and Khambhaty, Y., 2003. mpact of turbidity on intertidal macrofauna at Gopnath, Mahuva and Veraval coasts (west coast of India).

b. Saurashtra Basin

Meteorological parameters and physical parameters:

Marine EIA Study For Replacement of Existing Seawater Intake Pipeline and Enhancement in Seawater Intake of Saurashtra Chemicals, Division of Nirma Ltd. SPONSORED BY Saurashtra Chemicals Division of Nirma Ltd, Porbandar June 2017.

Rao, A.D., 2010. Variability of coastal ocean processes along the west coast of India.

Mitra, A., Kumar, V.S. and Naidu, V.S., 2020. Circulation in the Gulf of Khambhat—A Lagrangian Perspective. Journal of Marine Science and Engineering, 8(1), p.25.

Murthy, C.R., Sinha, P.C. and Rao, Y.R. eds., 2008. Modelling and monitoring of coastal marine processes. Springer.

Kumar, V.S. and Kumar, K.A., 2010. Waves and currents in tide-dominated location off Dahej, Gulf of Khambhat, India. Marine Geodesy, 33(2-3), pp.218-231.

Bhatt, N., Murari, M.K., Ukey, V., Prizomwala, S.P. and Singhvi, A.K., 2016. Geological evidences of extreme waves along the Gujarat coast of western India. Natural Hazards, 84(3), pp.1685-1704.

GOVERNMENT OF INDIA CENTRAL WATER COMMISSION COASTAL MANAGEMENT DIRECTORATE Guidelines for “Protection and Control of Coastal Erosion in India”

Water quality

Marine EIA Study For Replacement of Existing Seawater Intake Pipeline and Enhancement in Seawater Intake of Saurashtra Chemicals, Division of Nirma Ltd. SPONSORED BY Saurashtra Chemicals Division of Nirma Ltd, Porbandar June 2017.

Patel, R., Salvi, H., Bhagat, R., Vankar, J., Christian, L. and Kamboj, R.D., 2018. Assessment of spatial and temporal variations in coastal water quality of Gulf of Kachchh, Gujarat using GIS application.

Bhadja, P. and Kundu, R., 2012. Status of the seawater quality at few industrially important coasts of Gujarat (India) off Arabian Sea.

Sediment quality and Heavy metals:

Rao, C.; Indusekhar, V. (1986) Manganese, Zinc, Copper, Nickel and Cobalt Contents in Sea Water and Seaweeds from Saurashtra Coast. Mahasagar – Bull. Natl. Inst. Oceanography, 19, 129–136

Marine EIA Study For Replacement of Existing Seawater Intake Pipeline and Enhancement in Seawater Intake of Saurashtra Chemicals, Division of Nirma Ltd. SPONSORED BY Saurashtra Chemicals Division of Nirma Ltd, Porbandar June 2017.

Gohel, N.A., Mehta, S.K., Vyas, S.J., Talekar, S.D., Pawar, U.S. and Joshi, A.J., International Journal Of Scientific Research And Education.

Flaura and fauna

Marine EIA Study For Replacement of Existing Seawater Intake Pipeline and Enhancement in Seawater Intake of Saurashtra Chemicals, Division of Nirma Ltd. SPONSORED BY Saurashtra Chemicals Division of Nirma Ltd, Porbandar June 2017.

Desai, I. and Nair, A., DIVERSITY AND ECOL DIVERSITY AND ECOLOGY OF AQUATIC OGY OF AQUATIC MICROFAUNA ALONG THE COAST OF SAURASHTRA.

Raghunathan, C., Gupta, R.S., Wangikar, U. and Lakhmapurkar, J., 2004. A record of live corals along the Saurashtra coast of Gujarat, Arabian Sea. Current Science, pp.1131-1138.

Gideon, P.W., Menon, P.K.B., Rao, S.R.V. and Jose, K.V., 1957. On the marine fauna of the Gulf of Kutch: A preliminary survey.

Buragohain, D. and Ghosh, A., 2021. Seasonal Distribution Trends of Benthic Foraminiferal Assemblages from the Saurashtra Coast, Western India. Journal of the Geological Society of India, 97(1), pp.61-69.

Sukumaran, S., Vijapure, T., Mulik, J. and Ridha, H., 2021. Marine macrobenthos of NorthWest India-Reviewing the known and unknown. Frontiers in Marine Science, p.954.

c. Mumbai offshore

Meteorological parameters and physical parameters:

Environmental Monitoring Around ONGC Installations in the Western Offshore Region for IPSEHM - Oil and Natural Gas Corporation Limited 2019-2020

EIA Report - Offshore Oil & Gas Development and Production from Discovered Small Field of B-9 Cluster Offshore Fields at Mumbai Offshore Basin.

Joseph, A., Vijaykumar, K., Mehra, P., Unnikrishnan, A.S., Sundar, D. and Desai, R.G.P., 2009. Observed tides at Mumbai High offshore region near the continental shelf break in the eastern Arabian Sea.

Kumar, V.S., George, J., Dora, U. and Naseef, M., 2019. Surface wave dynamics off Mumbai coast, north-eastern Arabian Sea. Ocean Dynamics, 69(1), pp.29-42.

Shankar, D., 2000. Seasonal cycle of sea level and currents along the coast of India. Current Science, 78(3), pp.279-288.

Subeesh, M.P., Unnikrishnan, A.S., Fernando, V., Agarwadekar, Y., Khalap, S.T., Satelkar, N.P. and Shenoi, S.S.C., 2013. Observed tidal currents on the continental shelf off the west coast of India. Continental Shelf Research, 69, pp.123-140.

Aboobacker, V.M., Vethamony, P., Samiksha, S.V., Rashmi, R. and Jyoti, K., 2013. Wave transformation and attenuation along the west coast of India: Measurements and numerical simulations. Coastal Engineering Journal, 55(1), pp.1350001-1.

Water quality

Environmental Monitoring Around ONGC Installations in the Western Offshore Region for IPSEHM - Oil and Natural Gas Corporation Limited 2019-2020

EIA Report - Offshore Oil & Gas Development and Production from Discovered Small Field of B-9 Cluster Offshore Fields at Mumbai Offshore Basin.

Gupta, I., Dhage, S. and Kumar, R., 2009. Study of variations in water quality of Mumbai coast through multivariate analysis techniques.

Kamble, S.R. and Vijay, R., 2011. Assessment of water quality using cluster analysis in coastal region of Mumbai, India. Environmental monitoring and assessment, 178(1), pp.321-332.

Dhage, S.S., Chandorkar, A.A., Kumar, R., Srivastava, A. and Gupta, I., 2006. Marine water quality assessment at Mumbai West Coast. Environment international, 32(2), pp.149-158.

Sediment quality and Heavy metals:

Environmental Monitoring Around ONGC Installations in the Western Offshore Region for IPSEHM - Oil and Natural Gas Corporation Limited 2019-2020

EIA Report - Offshore Oil & Gas Development and Production from Discovered Small Field of B-9 Cluster Offshore Fields at Mumbai Offshore Basin.

Raju M. Patil , Sagar T. Sankpal and Pratap V. Naikwade ,“ DISTRIBUTION OF HEAVY METALS IN WATER AND SEDIMENT OF RATNAGIRI COAST, MAHARASHTRA.” Indian Streams Research Journal | Volume 4 | Issue 6 | July 2014 | Online & Prin

Kumar, P., Das, G.L. and Garg, A., 2021. Heavy metal accumulation in marine sediments-An assessment in ONGC's platforms in Mumbai High Region, Arabian Sea. World Journal of Advanced Engineering Technology and Sciences, 2(1), pp.060-068.

Flaura and fauna

Environmental Monitoring Around ONGC Installations in the Western Offshore Region for IPSEHM - Oil and Natural Gas Corporation Limited 2019-2020

EIA Report - Offshore Oil & Gas Development and Production from Discovered Small Field of B-9 Cluster Offshore Fields at Mumbai Offshore Basin.

Shahi, N., Godhe, A., Mallik, S.K., Härnström, K. and Nayak, B.B., 2015. The relationship between variation of phytoplankton species composition and physico-chemical parameters in northern coastal waters of Mumbai, India.

JiyalalRam, M.J., Ram, A., Rokade, M.A., Karangutkar, S.H., Yengal, B., Dalvi, S., Acharya, D., Sharma, S. and Gajbhiye, S.N., 2013. Phytoplankton dynamic responses to oil spill in Mumbai Harbour.

Diversity of Zooplankton in Coastal Waters of Mumbai (West Coast of India) November 2020 Publisher: LAMBERT PUBLICATIONISBN: ISBN-13: 978-620-3-02450-0, ISBN-10: 6203024503, EAN: 9786203024500

Gaonkar, C.A., Krishnamurthy, V. and Anil, A.C., 2010. Changes in the abundance and composition of zooplankton from the ports of Mumbai, India. Environmental monitoring and assessment, 168(1), pp.179-194.

Joydas, T.V. and Damodaran, R., 2002. Macrobenthos of the shelf waters of the west coast of India (Doctoral dissertation, School of Marine Sciences).

Ingole, B.S., Gaonkar, U.V., Deshmukh, A., Mukherjee, I., Sivadas, S.K. and Gophane, A., 2014. Macrobenthic community structure of coastal Arabian Sea during the fall intermonsoon.

d. Kerala Lakshadweep Konkan Basin

Meteorological parameters and physical parameters:

Philip, A.S., Babu, C.A. and Hareeshkumar, P.V., 2013. Meteorological aspects of mud bank formation along south west coast of India. Continental Shelf Research, 65, pp.45-51.

Sharma, G.S., 1978. Upwelling off the southwest coast of India. Indian Journal of Marine Sciences, 7(4), pp.209-218.

Uma, G. and Sannasiraj, S.A., 2021. Swell and sea characteristics along the south-west coast of India during the monsoon. Ocean Engineering, 237, p.109572.

Rao, V.R., Ramu, K., Dash, S.K., Patra, S., Vishnuvardhan, K., Rao, V.D. and Mohan, R., 2015. A Study on Hydrodynamic Behaviour of SW Coast of India–Implication to Ecosystem Model. Procedia engineering, 116, pp.746-754.

Status Report on Coastal Protection & Development in India by Central Water Commision, 2016

Shetye, S.R., 1998. West India coastal current and Lakshadweep high/low. Sadhana, 23(5), pp.637-651.

Shahul Hameed, T.S., Kurian, N.P., Thomas, K.V., Rajith, K. and Prakash, T.N., 2007. Wave and current regime off the southwest coast of India. Journal of Coastal Research, 23(5), pp.1167-1174.

Kumar, V.S., Dora, G.U., Philip, C.S., Pednekar, P. and Singh, J., 2012. Nearshore currents along the Karnataka coast, west coast of India. The International Journal of Ocean and Climate Systems, 3(1), pp.71-84.

Shetye, S.R., Gouveia, A.D., Shenoi, S.S.C., Michael, G.S., Sundar, D., Almeida, A.M. and Santanam, K., 1991. The coastal current off western India during the northeast monsoon. Deep Sea Research Part A. Oceanographic Research Papers, 38(12), pp.1517-1529.

Coastal Zones of India (Sponsored by Ministry of Environment & Forests, Govt. of India)

Subeesh, M.P., Unnikrishnan, A.S., Fernando, V., Agarwadekar, Y., Khalap, S.T., Satelkar, N.P. and Shenoi, S.S.C., 2013. Observed tidal currents on the continental shelf off the west coast of India. Continental Shelf Research, 69, pp.123-140.

Water quality

Jose, D.M., Mandla, V.R., Subbarao, S.S., Rao, N.S. and Moses, S.A., 2018. Assessment of coastal water quality along south west coast of India using multile regression analysis on satellite data. Journal of Rural Development, 37(2), pp.269-284.

Report On Status Of Ground Water Quality In Coastal Aquifers Of India, 2014

Jaison, C.A. and Sivanandan, A.V., 2012. Assessment of Water Quality along the Coastal Areas of Kerala: A Study of the Tsunami Impact on Groundwater (Doctoral dissertation, Cochin University of Science and Technology).

Maya, K., Das, P., Sreelash, K. and Babu, K.N., 2018. The Coastal Springs of Southern Kerala, SW India–Hydrology and Water Quality Assessment. Journal of the Geological Society of India, 92(5), pp.616-625.

Sediment quality and Heavy metals:

Manjunatha, B.R., Yeats, P.A., Smith, J.N., Shankar, R., Narayana, A.C. and Prakash, T.N., 1999. Accumulation of heavy metals in sediments of marine environments along the southwest coast of India.

Vineethkumar, V., Sayooj, V.V., Shimod, K.P. and Prakash, V., 2020. Estimation of pollution indices and hazard evaluation from trace elements concentration in coastal sediments of Kerala, Southwest Coast of India. Bulletin of the National Research Centre, 44(1), pp.1-16.

Balasubramanian, T., 2012. Heavy metal contamination and risk assessment in the marine environment of Arabian Sea, along the southwest coast of India. Am. J. Chem, 2, pp.191-208.

Nair, M., Balachandran, K.K., Sankaranarayanan, V.N. and Joseph, T., 1997. Heavy metals in fishes from coastal waters of Cochin, Southwest Coast of India.

Flaura and fauna

Joydas, T.V. and Damodaran, R., 2009. Infaunal macrobenthos along the shelf waters of the west coast of India, Arabian Sea.

Dineshbabu, A.P., 2013. Trawl fishery of eastern Arabian Sea. In APFIC Regional Expert Workshop on Tropical Trawl Fishery Management, Thailand (Vol. 34).

Krishnankutty, S., Joseph, C.A., Vincent, P.D., Jabir, T., Vishnu, P.S., Saramma, A.V. and Hatha, A.A., 2019. Hydrographic, seasonal diversity, distribution and abundance of phytoplankton in coastal waters off Cochin-south-eastern Arabian Sea.

Vivekanandan, E., Srinath, M., Pillai, V.N., Immanuel, S. and Kurup, K.N., 2003. Marine fisheries along the southwest coast of India. WorldFish.

Nutrients And Its Influence On Biological Productivity Along Kerala Coast, India Robin, R.S, Pradipta, R . Muduli, Vishnu Vardhan, K., Raj Kumar, J.S.I., Prasun Goswami4 and

Balasubramanian, T, International Journal of Current Research Vol. 10, pp.038-045, November, 2010

Anandavelu, I., Robin, R.S., Purvaja, R., Ganguly, D., Hariharan, G., Raghuraman, R., Prasad, M.H.K. and Ramesh, R., 2020. Spatial heterogeneity of mesozooplankton along the tropical coastal waters. Continental Shelf Research, 206, p.104193.

e. Cauvery Basin

Meteorological and physio-Chemical parameters:

Eastern Offshore Environmental Monitoring of Palk bay, Cauvery basin, Bay of Bengal, 2019

Satpathy, K.K., 1996. Seasonal distribution of nutrients in the coastal waters of Kalpakkam, East Coast of India.

Sampathkumar, P. and Kannan, L., 1998. Seasonal variations in physico-chemical characteristics in the Tranquebar-Nagapattinam Region, South-East coast of India. Pollution Research, 17, pp.397-402.

Dash, S.K., Shekhar, M.S. and Singh, G.P., 2006. Simulation of Indian summer monsoon circulation and rainfall using RegCM3. Theoretical and applied climatology, 86(1), pp.161-172.

Annamalai, H., Prasanna, V., Hafner, J., Nagothu, U. and Kitterod, N.O., 2011. Modeling the current and future climate over the Cauvery river basin. Sustainable Rice Production in a Warmer Planet, pp.59-81.

Anandakumar, S., Subramani, T. and Elango, L., 2008. Spatial variation and seasonal behaviour of rainfall pattern in Lower Bhavani River basin, Tamil Nadu, India. The Ecoscan, 2(1), pp.17-24.

Jayaram, K.C., 2000. Kaveri riverine system: An environmental study. The Madras Science Foundation, Chennai, pp.1-6.

Venkatachalapathy, R. and Karthikeyan, P., 2013. Physical, chemical and environmental studies on Cauvery River in parts of Tamil Nadu (Mettur and Bhavani). Universal Journal of Environmental Research and Technology, 3(3), pp.415-422.

Water quality

Tiwari, T.N. and Mishra, M.A., 1985. A preliminary assignment of water quality index of major Indian rivers. Indian J Environ Prot, 5(4), pp.276-279.

Jameel, A.A. and Hussain, A.Z., 2005. Water quality index of Ujjakondan channel of river Cauvery at Tiruchirappalli. Indian Journal of Environmental Protection, 25(10), p.941.

Kalavathy, S., Sharma, T.R. and Sureshkumar, P., 2011. Water quality index of river Cauvery in Tiruchirappalli district, Tamilnadu. Arch Environ Sci, 5, pp.55-61.

Begum, A., 2008. Study on the quality of water in some streams of Cauvery River. E-Journal of chemistry, 5(2), pp.377-384.

Lata, K.S., Jesu, A. and Dheenadayalan, M.S., 2015. SEASONAL VARIATION OF CAUVERY RIVER DUE TO DISCHARGED INDUSTRIAL EFFLUENTS AT PALLIPALAYAM IN NAMAKKAL. Rasāyan Journal of Chemistry, 8(3), pp.380-388.

World Health Organization (WHO, 1993) Guidelines for drinking water quality. World Health Organization, Geneva, Switzerland.

Sediment quality and Heavy metals

Vybhav, K., Narasimha, P., Mujumdar, P.P., Nagendra, R. and Gobalakrishnan, N., 2018. Geochemical Characterization and Provenance Study of Ilmenites from Fluvial Sediments of River Cauvery in Parts of Tamil Nadu, Southern India. International Journal of Economic and Environmental Geology, 9(4), pp.45-48.

Sharma, A.N.U.P.A.M. and Rajamani, V., 2001. Weathering of charnockites and sediment production in the catchment area of the Cauvery River, southern India. Sedimentary geology, 143(1-2), pp.169-184.

Vaithiyanathan, P., Ramanathan, A.L. and Subramanian, V., 1992. Sediment transport in the Cauvery River basin: sediment characteristics and controlling factors. Journal of Hydrology, 139(1-4), pp.197-210.

Flaura and fauna

Perumal, N.V., Rajkumar, M., Perumal, P. and Rajasekar, K.T., 2009. Seasonal variations of plankton diversity in the Kaduviyar estuary, Nagapattinam, southeast coast of India. J. Environ. Biol, 30(6), pp.1035-1046.

Hays, G.C., Richardson, A.J. and Robinson, C., 2005. Climate change and marine plankton. Trends in ecology & evolution, 20(6), pp.337-344.

Jyothibabu, R., Karnan, C., Jagadeesan, L., Arunpandi, N., Pandiarajan, R.S., Muraleedharan, K.R. and Balachandran, K.K., 2017. Trichodesmium blooms and warm-core ocean surface features in the Arabian Sea and the Bay of Bengal. Marine pollution bulletin, 121(1-2), pp.201-215.

Kasturirangan, L.R., 1963. A Key for the Identification of the More Common Planktonic Copepoda: Of Indian Coastal Waters (No. 2). Council of Scientific & Industrial Research.

Farhadian, O. and Pouladi, M., 2014. Seasonal changes in the abundance and biomass of zooplankton from shallow mudflat river-estuarine system in Persian Gulf. Brazilian Journal of Aquatic Science and Technology, 18(2), pp.19-29.

Brodeur, R.D., Sugisaki, H. and Hunt Jr, G.L., 2002. Increases in jellyfish biomass in the Bering Sea: implications for the ecosystem. Marine Ecology Progress Series, 233, pp.89-103.

UNESCO, 1994. JGOFS Protocols.

Verardo, D.J., Froelich, P.N. and McIntyre, A., 1990. Determination of organic carbon and nitrogen in marine sediments using the Carlo Erba NA-1500 Analyzer. Deep Sea Research Part A. Oceanographic Research Papers, 37(1), pp.157-165.

f. KG Basin

Meteorological and physio-Chemical parameters:

Eastern Offshore Environmental Monitoring of KG-PG Basin, Bay of Bengal (2019 -20)

Saisastry, A.G.R. and Chandramohan, P., 1990. Physicochemical characteristics of Vasishta Godavari estuary, east coast of India: Pre-pollution status.

Guhathakurta, P., Sreejith, O.P. and Menon, P.A., 2011. Impact of climate change on extreme rainfall events and flood risk in India. Journal of earth system science, 120(3), pp.359-373.

Guhathakurta, P. and Revadekar, J., 2017. Observed variability and long-term trends of rainfall over India. In Observed climate variability and change over the Indian region (pp. 1-15). Springer, Singapore.

Kumar, K.N., Rajeevan, M., Pai, D.S., Srivastava, A.K. and Preethi, B., 2013. On the observed variability of monsoon droughts over India. Weather and Climate Extremes, 1, pp.42-50.

Nelson, G., Cai, Z., Hassan, R., Godfray, C., Santos, M. and Swaminathan, H., 2012. Food security and climate change: A report by the high level panel of experts on food security and nutrition.

Water quality

Grasshoff, K., Kremling, K. and Ehrhardt, M. eds., 2009. Methods of seawater analysis. John Wiley & Sons

Murphy, J.A.M.E.S. and Riley, J.P., 1962. A modified single solution method for the determination of phosphate in natural waters. Analytica chimica acta, 27, pp.31-36.

Bendschneider, K. and Robinson, R.J., 1952. A new spectrophotometric method for the determination of nitrite in sea water.

Rasheed, M.A., Lakshmi, M., Rao, P.L.S., Kalpana, M.S., Dayal, A.M. and Patil, D.J., 2013. Geochemical evidences of trace metal anomalies for finding hydrocarbon microseepage in the petroliferous regions of the Tatipaka and Pasarlapudi areas of Krishna Godavari Basin, India. Petroleum Science, 10(1), pp.19-29.

Sediment quality and Heavy metals:

Biksham, G. and Subramanian, V., 1988. Sediment transport of the Godavari River basin and its controlling factors. Journal of Hydrology, 101(1-4), pp.275-290.

Biksham, G. and Subramanian, V., 1988. Elemental composition of Godavari sediments (central and southern Indian subcontinent). Chemical Geology, 70(3), pp.275-286.

Biksham, G., Subramanian, V., Ramanathan, A.L. and Van Grieken, R., 1991. Heavy metal distribution in the Godavari river basin. Environmental Geology and Water Sciences, 17(2), pp.117-126.

Biswas, S.K., 1992. Tectonic frame-work and evolution of graben basins of India.

Murty, K.V.S. and Ramakrishna, M., 1980. Structure and tectonics of Godavari–Krishna coastal sedimentary basins. Bulletin of Oil and Natural Gas Corporation, 17(1), pp.147-158.

Rao, G.N., 2001. Sedimentation, stratigraphy, and petroleum potential of Krishna-Godavari basin, East Coast of India. AAPG bulletin, 85(9), pp.1623-1643.

Flaura and fauna

Ganesh, T. and Raman, A.V., 2007. Macrobenthic community structure of the northeast Indian shelf, Bay of Bengal. Marine Ecology Progress Series, 341, pp.59-73.

Ganesh, T. and Raman, A.V., 2007. Macrobenthic community structure of the northeast Indian shelf, Bay of Bengal. Marine Ecology Progress Series, 341, pp.59-73.

Ghani, S.A.A., 2015. Trace metals in seawater, sediments and some fish species from Marsa Matrouh Beaches in north-western Mediterranean coast, Egypt. The Egyptian Journal of Aquatic Research, 41(2), pp.145-154.

Giangrande, A., Licciano, M. and Musco, L., 2005. Polychaetes as environmental indicators revisited. Marine Pollution Bulletin, 50(11), pp.1153-1162.

Gopal, A., Abdul Jaleel, K.U., Parameswaran, U.V., Sanjeevan, V.N., Saramma, A.V., Vijayan, A., Saravanane, N., Gupta, G.V.M. and Sudhakar, M., 2020. Distinctive community patterns with exceptional diversity of polychaetes around a tectonically active archipelago in the tropical Indian Ocean. Frontiers in Marine Science, 7, p.710.

Gordon, J., Gillespie, D., Potter, J., Frantzis, A., Simmonds, M.P., Swift, R. and Thompson, D., 2003. A review of the effects of seismic surveys on marine mammals. Marine Technology Society Journal, 37(4), pp.16-34.

g. Mahanadhi Basin

Meteorological and physio-Chemical parameters:

Upadhyay, S., 1988. Physico-chemical characteristics of the Mahanadi estuarine ecosystem, east coast of India.

Das, J., Das, S.N. and Sahoo, R.K., 1997. Semidiurnal variation of some physico-chemical parameters in the Mahanadi estuary, east coast of India.

Panigrahy, P.K., Das, J., Das, S.N. and Sahoo, R.K., 1999. Evaluation of the influence of various physico-chemical parameters on coastal water quality, around Orissa, by factor analysis.

Nayak, B.B., Das, J., Panda, U.C. and Acharya, B.C., 2001. Industrial effluents and municipal sewage contamination of Mahanadi estuarine water, Orissa. In Proceedings (pp. 77-86).

Radhakrishna, I., 2001. Saline fresh water interface structure in Mahanadi delta region, Orissa, India. Environmental Geology, 40(3), pp.369-380.

Sundaray, S.K., Pand, U.C., Nayak, B.B. and Bhatta, D., 2005. Behaviour and distribution pattern of nutrients in river-estuarine waters of Mahanadi, Orissa, India. Asian Journal of Water, Environment and Pollution, 2(1), pp.77-84.

Konhauser, K.O., Powell, M.A., Fyfe, W.S., Longstaffe, F.J. and Tripathy, S., 1997. Trace element geochemistry of river sediment, Orissa State, India. Journal of Hydrology, 193(1-4), pp.258-269.

Panda, U.C., Sundaray, S.K., Rath, P., Nayak, B.B. and Bhatta, D., 2006. Application of factor and cluster analysis for characterization of river and estuarine water systems–a case study: Mahanadi River (India). Journal of hydrology, 331(3-4), pp.434-445.

Water quality

Samuel, A., Joy, K.J. and Bhagat, S., 2017. Integrated Water Management of the Mahanadi Basin.

Hussain, J., Dubey, A., Hussain, I., Arif, M. and Shankar, A., 2020. Surface water quality assessment with reference to trace metals in River Mahanadi and its tributaries, India. Applied Water Science, 10(8), pp.1-12.

Centre for Environmental Studies (2014). Water quality of Mahanadi River. ENVIS Newsletter, Vol.38, July-September 2014. CES, Department of Environment, Forest and Climate Change, Government of India.

Water Quality Monitoring and Its Assessment on Mahanadi Basin, 2019

Government of India (1956). The Interstate River Dispute Act 1956 (modified in 2002), Retrieved May, 2017, from Ministry of Law, Justice and Company Affairs

Government of India (2012) National Water Policy, Retrieved from, Ministry of Water Resources, GoI:

Government of India (2016). Guidelines for Integrated Water Resources Development and Management. Ministry of Water Resources.

Sediment quality and Heavy metals:

Chakrapani, G.J. and Subramanian, V., 1993. Rates of erosion and sedimentation in the Mahanadi River basin, India. Journal of hydrology, 149(1-4), pp.39-48.

Chakrapani, G.J. and Subramanian, V., 1993. Heavy metals distribution and fractionation in sediments of the Mahanadi River basin, India. Environmental Geology, 22(1), pp.80-87.

Chakrapani, G.J. and Subramanian, V., 1993. Rates of erosion and sedimentation in the Mahanadi River basin, India. Journal of hydrology, 149(1-4), pp.39-48.

Chakrapani, G.J. and Subramanian, V., 1990. Preliminary studies on the geochemistry of the Mahanadi river basin, India. Chemical Geology, 81(3), pp.241-253.

Flaura and fauna

Naik, S., Mahapatro, D., Behera, D.P., Kumar, M., Panda, C.R. and Mishra, R.K., 2013. Spatio-temporal Study of Zooplankton Community in Mahanadi Estuary, Bay of Bengal. Int J Ecosyst, 3(6), pp.185-195.

Gouda, R. and Panigrahy, R.C., 1996. Ecology of phytoplankton in coastal waters off Gopalpur, east coast of India.

Mishra, R.K., Shaw, B.P., Sahu, B.K., Mishra, S. and Senga, Y., 2009. Seasonal appearance of Chlorophyceae phytoplankton bloom by river discharge off Paradeep at Orissa Coast in the Bay of Bengal. Environmental monitoring and assessment, 149(1), pp.261-273.

h. Andaman Basin

Meteorological and physio-Chemical parameters:

Guhathakurta, P., Sreejith, O.P. and Menon, P.A., 2011. Impact of climate change on extreme rainfall events and flood risk in India. Journal of earth system science, 120(3), pp.359-373.

Nelson, G., Cai, Z., Hassan, R., Godfray, C., Santos, M. and Swaminathan, H., 2012. Food security and climate change: A report by the high-level panel of experts on food security and nutrition.

Thornes, J.E., 2002. IPCC, 2001: Climate change 2001: impacts, adaptation and vulnerability, Contribution of Working Group II to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by JJ McCarthy, OF Canziani, NA Leary, DJ Dokken and

KS White (eds). Cambridge University Press, Cambridge, UK, and New York, USA, 2001. No. of pages: 1032.

Jarvis, A., Lau, C., Cook, S., Wollenberg, E., Hansen, J., Bonilla, O. and Challinor, A., 2011. An integrated adaptation and mitigation framework for developing agricultural research: synergies and trade-offs. Experimental Agriculture, 47(2), pp.185-203.

Water quality

Anderson, D.M., Glibert, P.M. and Burkholder, J.M., 2002. Harmful algal blooms and eutrophication: nutrient sources, composition, and consequences. Estuaries, 25(4), pp.704-726.

Anonymous, 2003. Thailand state pollution report. Pollution Control Departmentp. 28. APHA, 1995. Standard methods for the examination of water and wastewater. 2540 D.

Eaton, A.D., Clesceri, L.S., Rice, E.W., Greenberg, A.E. and Franson, M.H., 2005. Total suspended solids dried at 103–105 C. Standard methods for the examination of water and wastewater, pp.2-58.

Brown, R.M., McClelland, N.I., Deininger, R.A. and Tozer, R.G., 1970. A water quality index-do we dare. Water and sewage works, 117(10).

Carruthers, T., Wazniak, C., Wazniak, C.E. and Hall, M.R., 2004. Development of a water quality index for the Maryland coastal bays. Maryland's Coastal Bays: Ecosystem Health Assessment, pp.4-59.

Srivastava, P.K., Mukherjee, S., Gupta, M. and Singh, S.K., 2011. Characterizing monsoonal variation on water quality index of River Mahi in India using geographical information system. Water Quality, Exposure and Health, 2(3), pp.193-203.

Jha, D.K., Devi, M.P., Vidyalakshmi, R., Brindha, B., Vinithkumar, N.V. and Kirubagaran, R., 2015. Water quality assessment using water quality index and geographical information system methods in the coastal waters of Andaman Sea, India. Marine pollution bulletin, 100(1), pp.555-561.

COMAPS, 2012. Monitoring of Marine Pollution through Coastal Ocean Monitoring and Prediction System. ICMAM PD, Ministry of Earth Sciences, Govt. of India.

Dennison, W.C., Orth, R.J., Moore, K.A., Stevenson, J.C., Carter, V., Kollar, S., Bergstrom, P.W. and Batiuk, R.A., 1993. Assessing water quality with submersed aquatic vegetation. BioScience, 43(2), pp.86-94.

Gupta, A.K., Gupta, S.K. and Patil, R.S., 2003. A comparison of water quality indices for coastal water. Journal of Environmental Science and Health, Part A, 38(11), pp.2711-2725.

Sediment quality and Heavy metals:

Rodolfo, K.S., 1969. Sediments of the Andaman basin, northeastern Indian Ocean. Marine Geology, 7(5), pp.371-402.

Karunakaran, C., Ray, K.K. and Saha, S.S., 1964. A new probe into the tectonic history of the Andaman and Nicobar Islands. 22d Internat. Geol. Cong., India, Rept., pp.507-515.

Karunakaran, C., 1964. Sedimentary environment of the formation of Andaman flysch, Andaman Islands, India. In International Geological Congress, Report of the Twenty-Second Session (Vol. 15, pp. 226-232).

Keller, G.H. and Richards, A.F., 1967. Sediments of the Malacca strait, southeast Asia. Journal of Sedimentary Research, 37(1), pp.102-127.

Kuenen, P.H., 1957. Longitudinal filling of oblong sedimentary basins. Verhandelingen van het Koninklijk Nederlands Geologisch-Mijnbouwkundig Genootschap, Geologische Serie, 18, pp.189-195.

Neprochnov, Y.P., 1964. The structure and thickness of the sedimentary layer of the Arabian Sea, the Bay of Bengal and the Andaman Sea. Trans. Inst. OceanoL, Acad. Sci. USSR, 69, pp.214-226.

Flaura and fauna

Ahlawat, S.P.S., Roy, S.D., SOUNDARAJAN, R., Mandal, A.B., Chatterjee, R.N., Singh, D.B., Shiva, K.N., Madhu, K., Sheeja, T.E., KUMARI, V. and Sharma, T.V.R.S., 2002. Flora and fauna of Andaman and Nicobar Islands.

Balakrishnan, N.P., 1989. Andaman Islands-vegetation and floristics. Andaman, Nicobar and Lakshadweep: An Environmental Impact Assessment. Oxford and IBH Publication, New Delhi, India, p.5561.

Balakrishnan, M., Srivastava, R.C. and Pokhriyal, M., 2008. Biodiversity of Andaman and Nicobar Islands. Biobytes, 3, pp.9-12.

Bhargava, N., 1983. Ethnobotanical studies of the tribes of Andaman and Nicobar Islands, India. I. Onge. Economic Botany, 37(1), pp.110-119.

Balakrishnan, M., Srivastava, R.C. and Pokhriyal, M., 2008. Biodiversity of Andaman and Nicobar Islands. Biobytes, 3, pp.9-12.

Sheeja, T.E., Chattopadhayay, D. and Mandal, A.B., 2001. A glimpse on medicinal plants of Andaman and Nicobar Islands with special reference to endemic and extra Indian taxa. In Poster presented at 88th session of Indian Science Congress.

3.2 Marine protected areas (MPAs) (Sanctuaries and National Parks) in India

The MPA network in India has been used as a tool to manage natural marine resources for biodiversity conservation and the well-being of the people dependent on them. Scientific monitoring and traditional observations confirm that depleted natural marine resources are getting restored and/or pristine ecological conditions have been sustained in well managed MPAs (Halpern 2003). India has designated four legal categories of protected areas: National Park, Wildlife Sanctuary, Conservation Reserve and Community Reserve. India has created a network of PAs representing all its 10 biogeographic regions (Rodgers et al. 2002). A total of 690 protected areas have been established in India as of 1 April 2014, including 102 national parks, 527 wildlife sanctuaries, 57 conservation reserves and 4 community reserves. Besides, 26 wetlands have been designated as Ramsar sites.

In India, PAs that fall entirely or partially within the swathe of 500 m from the high tide line and the marine environment are considered to be in the MPA network. There are 25 MPAs in peninsular India and more than 105 MPAs in the country's islands (see Table 3.59 & 3.60). The 24 MPAs of the mainland have a total area of about 8214 km^2, which is about 5 % of the total area under the entire PA network of India and less than 0.3% of India's total land area. The Gulf of Mannar Marine National Park, Sundarbans National Park, Gulf of Kachchh National Park, Gahirmatha Marine Sanctuary, Coringa Wildlife Sanctuary and Chilika Wildlife Sanctuary, on the mainland, have unique marine biodiversity and provide a range of ecological services to the local communities. The total area of the Andaman and Nicobar Islands is 4947 km^2 , of which 1510 km^2 is protected under the provisions of India's

Wildlife (Protection) Act, 1972. There are 105 PAs in the Andaman and Nicobar Islands, and all are part of the MPA network of India. These MPAs cover about 60% of the terrestrial area of the islands and protect more than 40% of the coastal habitat. Mahatma Gandhi Marine National Park and Rani Jhansi Marine National Park are important MPAs here. In the Lakshadweep group of islands, Pitti Island (0.01 km^2) is the only island with an MPA status.

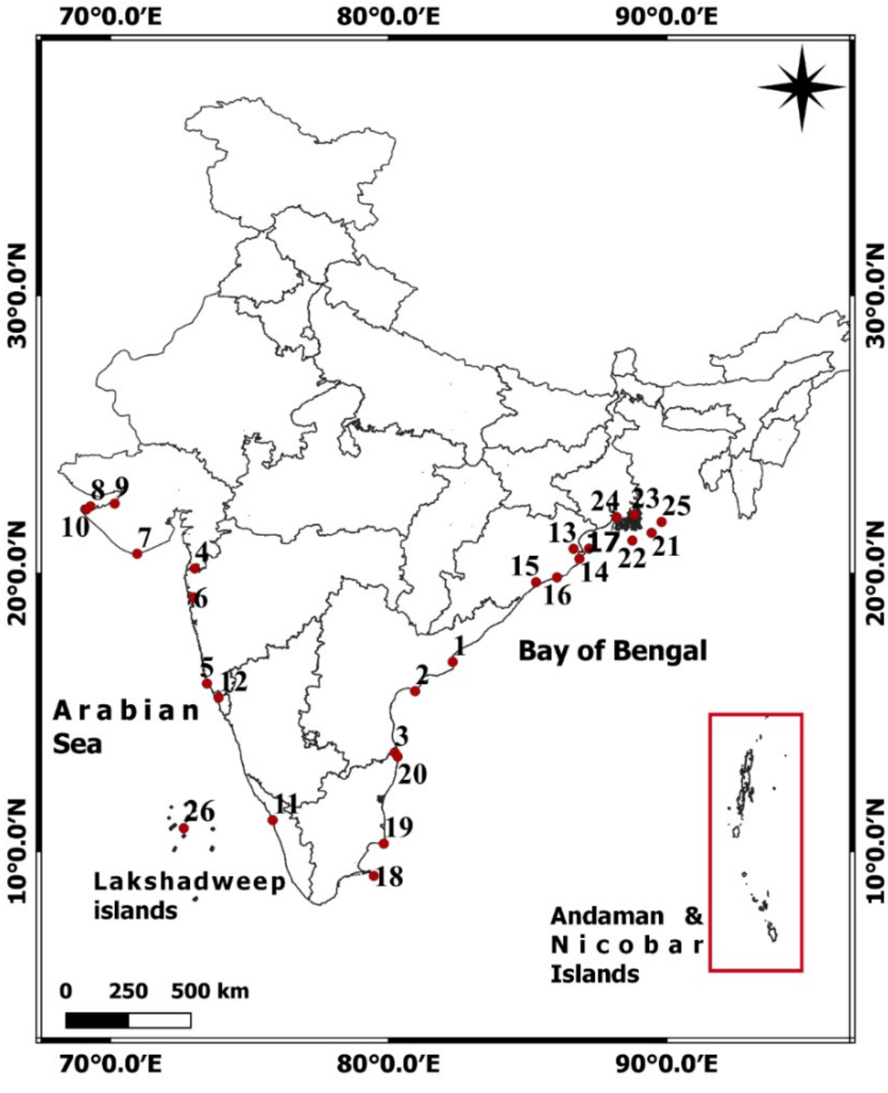

Figure 3. 9 Marine Protected areas (Sanctuaries and National Parks) in India. Red dots and numbers indicate the corresponding Sanctuaries and National Parks shown in Table 3.59. The red rectangle box indicates the Andaman & Nicobar Islands. There were a total of 100 marine protected areas, and all details, including latitude and longitude, are shown in Table 3.60.

Table 3. 58 List of Marine protected areas (MPA) in the sedimentary basins of India

Sl. No	Sedimentary Basin	Name of MPA, State	Category	IUCN category	Latitude	Longitude	Area (km2)	Year of establishment
1.	Krishna Godavari	Coringa Andhra Pradesh	Sanctuary	IV	16.823009°	82.299375°	235.7	1978
2.	Krishna Godavari	Krishna Andhra Pradesh	Sanctuary	IV	15.771591°	80.950646°	194.81	1989
3.	Krishna Godavari	Pulicat Lake Andhra Pradesh	Sanctuary	IV	13.565255°	80.218039°	500	1980
4.	Mumbai offshore	Dadra & Nagar Haveli Dadra & Nagar Haveli	Sanctuary	IV	20.183367°	73.025683°	92.16	2000
5.	Mumbai offshore	Malvan Marine Maharashtra	Sanctuary	IV	16.045375°	73.466486°	29.12	1987
6	Mumbai offshore	Thane Creek Flamingo Maharashtra	Sanctuary	NA	19.147775°	72.981736°	16.905	2015
7.	Saurashtra	Fudam Daman & Diu	Sanctuary	IV	20.712335°	70.960270°	2.18	1991
8.	Gulf of Kutch	Marine (Gulf of Kachchh) Gujarat	National park	II	22.402218°	69.200954°	162.89	1995
9.	Gulf of Kutch	Khijadia Gujarat	Sanctuary	IV	22.520360°	70.151646°	6.05	1981
10.	Gulf of Kutch	Marine (Gulf of Kachchh) Gujarat	Sanctuary	IV	22.352372°	69.157932°	295.03	1980
11.	Kerala-Konkan-Lakshadweep	Kadalundi Vallikkunnu Community Reserve Kerala	Community reserve	NA	11.130191°	75.828930°	1.50	2007
12.	Kerala-Konkan-Lakshadweep	Chorao Island Goa	Sanctuary	IV	15.536249°	73.884897°	1.78	1988
13.	Mahanadi	Bhitarkanika Odisha	National park	II	20.714089°	86.820611°	145	1998

Sl. No	Sedimentary Basin	Name of MPA, State	Category	IUCN category	Latitude	Longitude	Area (km2)	Year of establishment
14.	Mahanadi	Bhitarkanika Odisha	Sanctuary	IV	20.714164°	86.863912°	672	1975
15.	Mahanadi	Chilika (Nalaban) Odisha	Sanctuary	IV	19.690450°	85.293934°	15.53	1987
16.	Mahanadi	Balukhand Konark Odisha	Sanctuary	IV	19.864367°	86.047845°	71.72	1984
17.	Mahanadi	Gahirmatha Odisha	Sanctuary	IV	20.793142°	86.874699°	1435	1997
18.	Cauvery	Gulf of Mannar Marine Tamil Nadu	National park	II	9.126426°	79.464956°	6.23	1980
19.	Cauvery	Point Calimere Tamil Nadu	Sanctuary	IV	10.283910°	79.823913°	172.6	1967
20.	Cauvery	Pulicat Lake Tamil Nadu	Sanctuary	IV	13.417814°	80.319661°	153.67	1980
21.	Bengal	Sundarbans West Bengal	National park	II	21.835774°	88.884114°	1330.1	1984
22.	Bengal	Haliday Island West Bengal	Sanctuary	IV	21.664658°	88.631789°	5.95	1976
23.	Bengal	Sajnakhali West Bengal	Sanctuary	IV	22.123772°	88.831299°	2091.12	1976
24.	Bengal	Lothian Island West Bengal	Sanctuary	IV	21.663755°	88.328882°	38	1976
25.	Bengal	West Sundarban West Bengal	Sanctuary	IV	21.858542°	21.858542°	556.45	2013
26	Kerala-Konkan-Lakshadweep	Pitti Lakshadweep	Sanctuary	IV	10.840271°	72.632621°	0.01	2002

*NA- Not Available

Table 3. 59 List of Marine Protected Areas in Andaman & Nicobars Islands Basin

S.No.	Name of MPA	Legal Status	IUCN category	Area of MPA	Year of Notification
	Andaman & Nicobars Islands Basin				
1	Brush Island	Sanctuary	IV	0.23	1977
2	Channel Island	Sanctuary	IV	0.13	1977
3	East Island	Sanctuary	IV	6.11	1977
4	Jungle Island	Sanctuary	IV	0.52	1977
5	Landfall Island	Sanctuary	IV	29.48	1977
6	Mayo Island	Sanctuary	IV	0.1	1977
7	Narcondam Island	Sanctuary	IV	6.81	1977
8	North Island	Sanctuary	IV	0.49	1977
9	Ox Island	Sanctuary	IV	0.13	1977
10	Paget Island	Sanctuary	IV	7.36	1977
11	Peacock Island	Sanctuary	IV	0.62	1977
12	Point Island	Sanctuary	IV	3.07	1977
13	Reef Island	Sanctuary	IV	1.74	1977
14	Ross Island	Sanctuary	IV	1.01	1977
15	Shearme Island	Sanctuary	IV	7.85	1977
16	Table (Delgarno) Island	Sanctuary	IV	2.29	1977
17	Table (Excelsior) Island	Sanctuary	IV	1.69	1977
18	Temple Island	Sanctuary	IV	1.04	1977
19	Tree Island	Sanctuary	IV	0.03	1977
20	Trilby Island	Sanctuary	IV	0.96	1977
21	Turtle Island	Sanctuary	IV	0.39	1977
22	West Island	Sanctuary	IV	6.4	1977
23	Wharf Island	Sanctuary	IV	0.11	1977
24	White Cliff Island	Sanctuary	IV	0.47	1977
25	Saddle Peak	National park	II	32.54	1987
26	Bamboo Island	Sanctuary	IV	0.05	1977
27	Bennett Island	Sanctuary	IV	3.46	1977
28	Blister Island	Sanctuary	IV	0.26	1977
29	Bondoville Island	Sanctuary	IV	2.55	1977
30	Buchanan Island	Sanctuary	IV	9.33	1977
31	Curlew (B.P.) Island	Sanctuary	IV	0.16	1977
32	Curlew Island	Sanctuary	IV	0.03	1977
33	Dot Island	Sanctuary	IV	0.13	1977

34	Dottrell Island	Sanctuary	IV	0.13	1977
35	Egg Island	Sanctuary	IV	0.05	1977
36	Entrance Island	Sanctuary	IV	0.96	1977
37	Gander Island	Sanctuary	IV	0.05	1977
38	Girjan Island	Sanctuary	IV	0.16	1977
39	Goose Island	Sanctuary	IV	0.01	1977
40	Interview Island	Sanctuary	IV	133.87	1977
41	Kwangtung Island	Sanctuary	IV	0.57	1987
42	Latouche Island	Sanctuary	IV	0.96	1977
43	North Reef Island	Sanctuary	IV	3.48	1977
44	Oliver Island	Sanctuary	IV	0.16	1977
45	Orchid Island	Sanctuary	IV	0.1	1977
46	Oyster Island-I	Sanctuary	IV	0.08	1977
47	Ranger Island	Sanctuary	IV	4.26	1977
48	Roper Island	Sanctuary	IV	1.46	1977
49	Rowe Island	Sanctuary	IV	0.01	1977
50	Sea Serpent Island	Sanctuary	IV	0.78	1977
51	Shark Island	Sanctuary	IV	0.6	1977
52	Snake Island-I	Sanctuary	IV	0.73	1977
53	Spike Island-I	Sanctuary	IV	0.42	1977
54	South Reef Island	Sanctuary	IV	1.17	1977
55	Surat Island	Sanctuary	IV	0.31	1977
56	Swamp Island	Sanctuary	IV	4.09	1977
57	Middle Button Island	National park	II	0.44	1987
58	North Button Island	National park	II	0.44	1987
59	Barren Island	Sanctuary	IV	11.99	1977
60	Cone Island	Sanctuary	IV	0.65	1977
61	Elat Island	Sanctuary	IV	9.36	1977
62	Hump Island	Sanctuary	IV	0.47	1977
63	Mask Island	Sanctuary	IV	0.78	1977
64	Mangrove Island	Sanctuary	IV	0.39	1977
65	Oyster Island-II	Sanctuary	IV	0.21	1977
66	Parkinson Island	Sanctuary	IV	0.34	1977
67	Spike Island-II	Sanctuary	IV	11.7	1977
68	Stoat Island	Sanctuary	IV	0.44	1977
69	Tuft Island	Sanctuary	IV	0.29	1977
70	Mount Harriett	National park	II	46.62	1987

71	Rani Jhansi	National park	II	256.14	1996
72	South Button Island	National park	II	0.03	1987
73	Arial Island	Sanctuary	IV	0.05	1977
74	Belle Island	Sanctuary	IV	0.08	1977
75	Bingham Island	Sanctuary	IV	0.08	1977
76	Bluff Island	Sanctuary	IV	1.14	1977
77	Clyde Island	Sanctuary	IV	0.54	1977
78	Cuthbert Bay	Sanctuary	IV	5.82	1997
79	Defence Island	Sanctuary	IV	10.49	1977
80	Duncan Island	Sanctuary	IV	0.73	1977
81	East of Inglis Island	Sanctuary	IV	3.55	1977
82	James Island	Sanctuary	IV	2.1	1977
83	Kyd Island	Sanctuary	IV	8	1977
84	Montogemery Island	Sanctuary	IV	0.21	1977
85	Patric Island	Sanctuary	IV	0.13	1977
86	Pitman Island	Sanctuary	IV	1.37	1977
87	Potanma Islands	Sanctuary	IV	0.16	1977
88	Sir Hugh Rose Island	Sanctuary	IV	1.06	1977
89	Sandy Island	Sanctuary	IV	1.58	1977
90	Talabaicha Island	Sanctuary	IV	3.21	1977
91	Mahatma Gandhi Marine	National park	II	281.5	1983
92	Cinque Islands	Sanctuary	IV	9.51	1977
93	Lohabarrack	Sanctuary	IV	22.21	1977
94	North Brother Island	Sanctuary	IV	0.75	1977
95	Passage Island	Sanctuary	IV	0.62	1977
96	Sisters Island	Sanctuary	IV	0.36	1977
97	Snake Island-II	Sanctuary	IV	0.03	1977
98	South Sentinel Island	Sanctuary	IV	1.61	1977
99	South Brother Island	Sanctuary	IV	1.24	1977
100	Campbell	National park	II	426.23	1992
101	Galathea	National park	II	110	1992
102	Battimalv Island	Sanctuary	IV	5.03	1977
103	Galathea Bay	Sanctuary	IV	11.44	1997
104	Megapode Island	Sanctuary	IV	0.12	1977
105	Tillongchang Island	Sanctuary	IV	36.43	1977

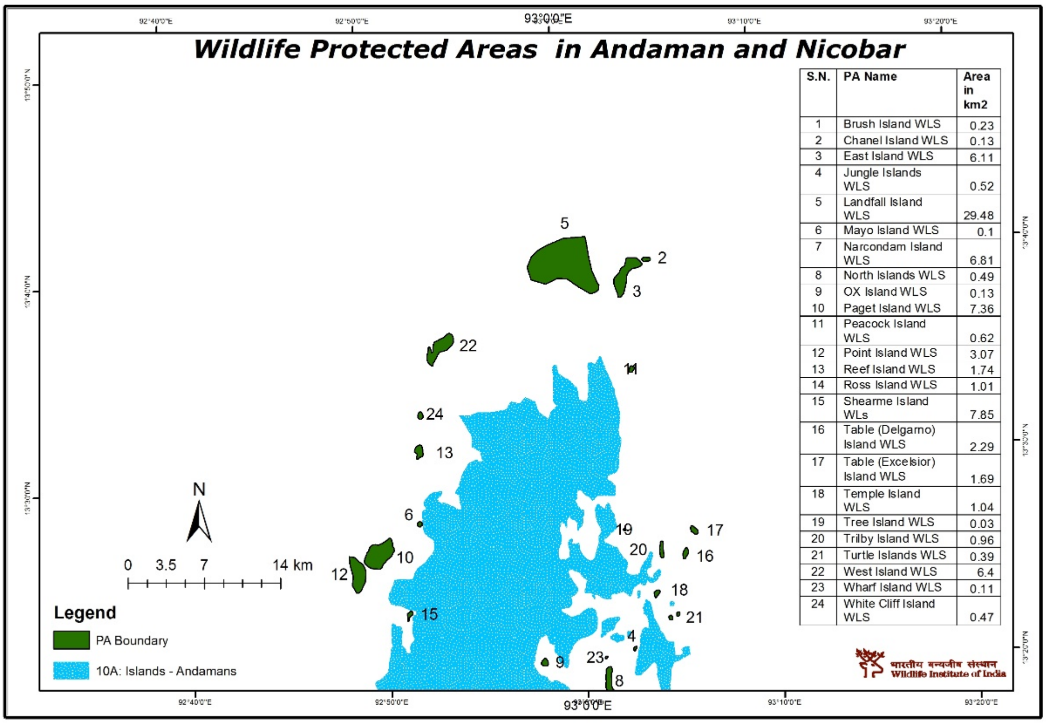

Figure 3. 10 Marine protected areas in Andaman and Nicobar Islands Tile 1.

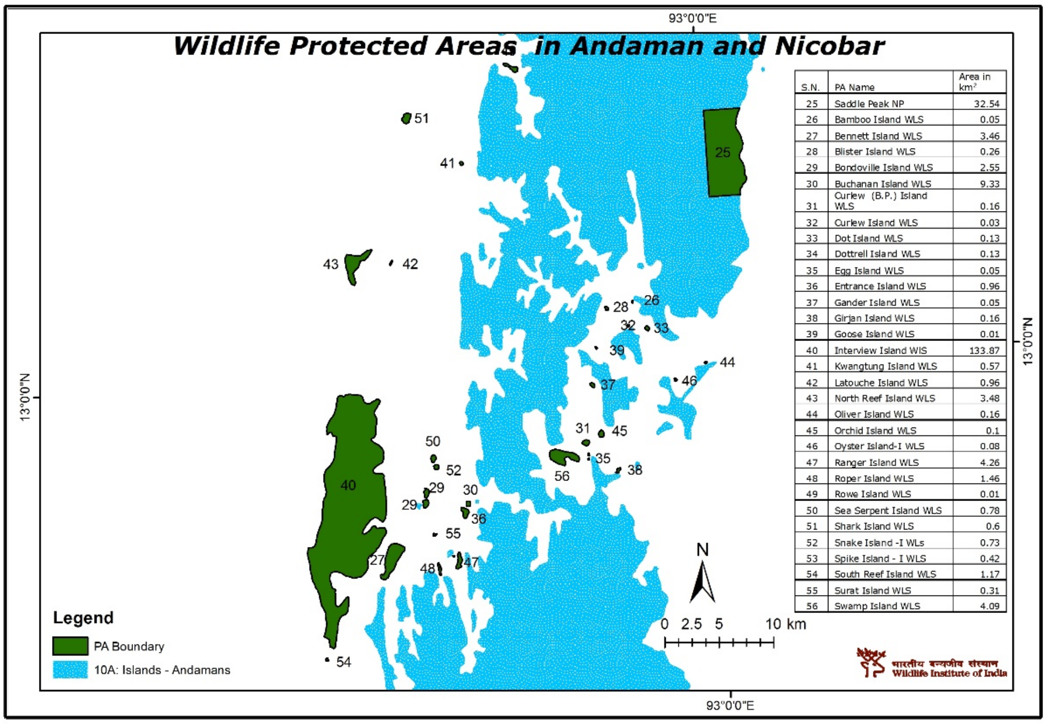

Figure 3. 11 Marine protected areas in Andaman and Nicobar Islands Tile 2.

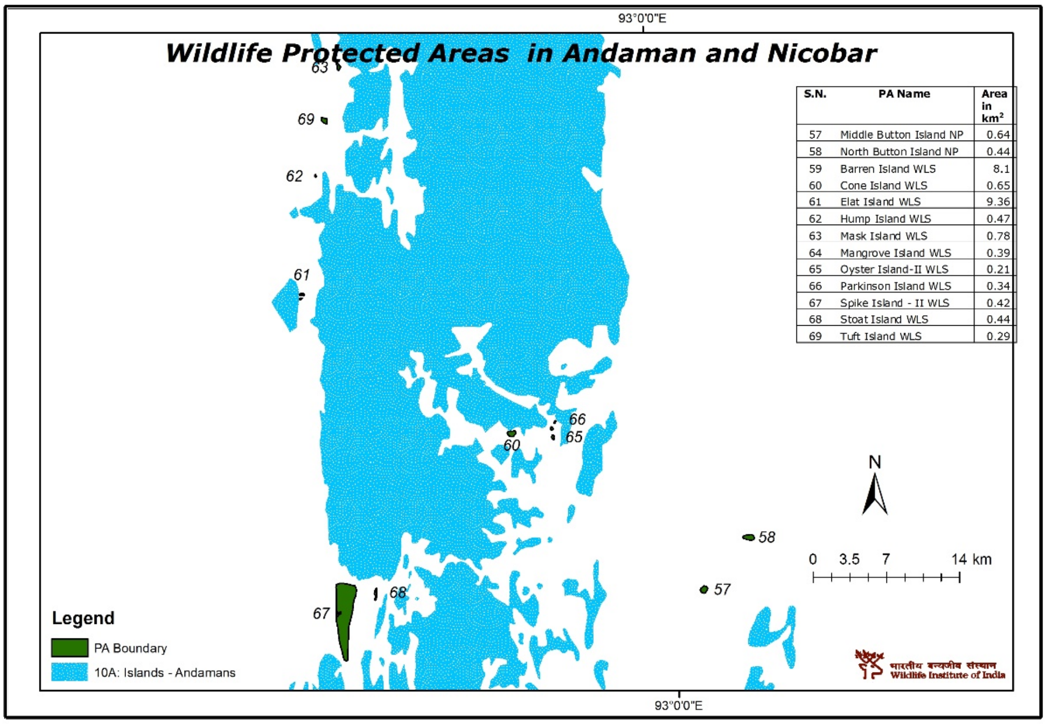

Figure 3. 12 Marine protected areas in Andaman and Nicobar Islands Tile 3.

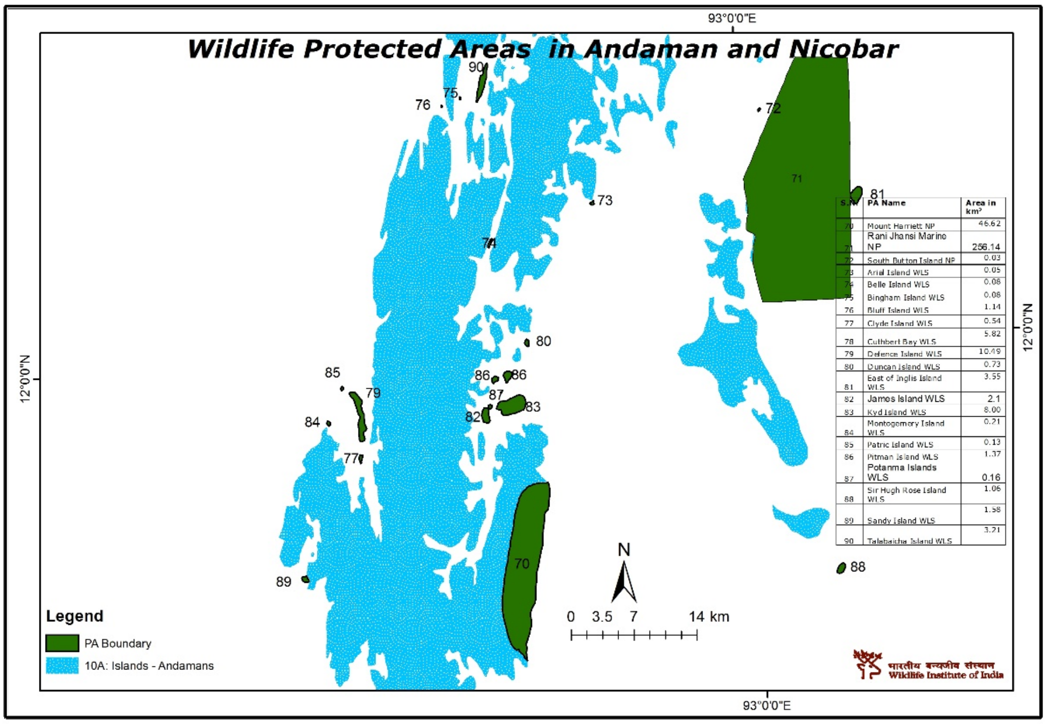

Figure 3. 13 Marine protected areas in Andaman and Nicobar Islands Tile 4.

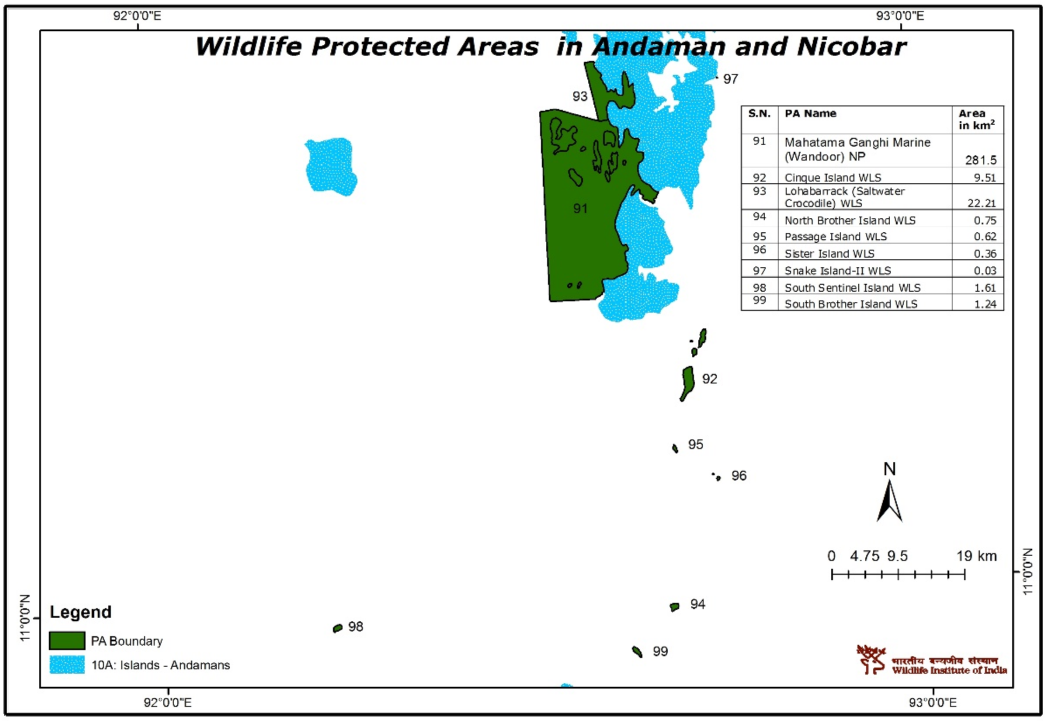

Figure 3. 14 Marine protected areas in Andaman and Nicobar Islands Tile 5.

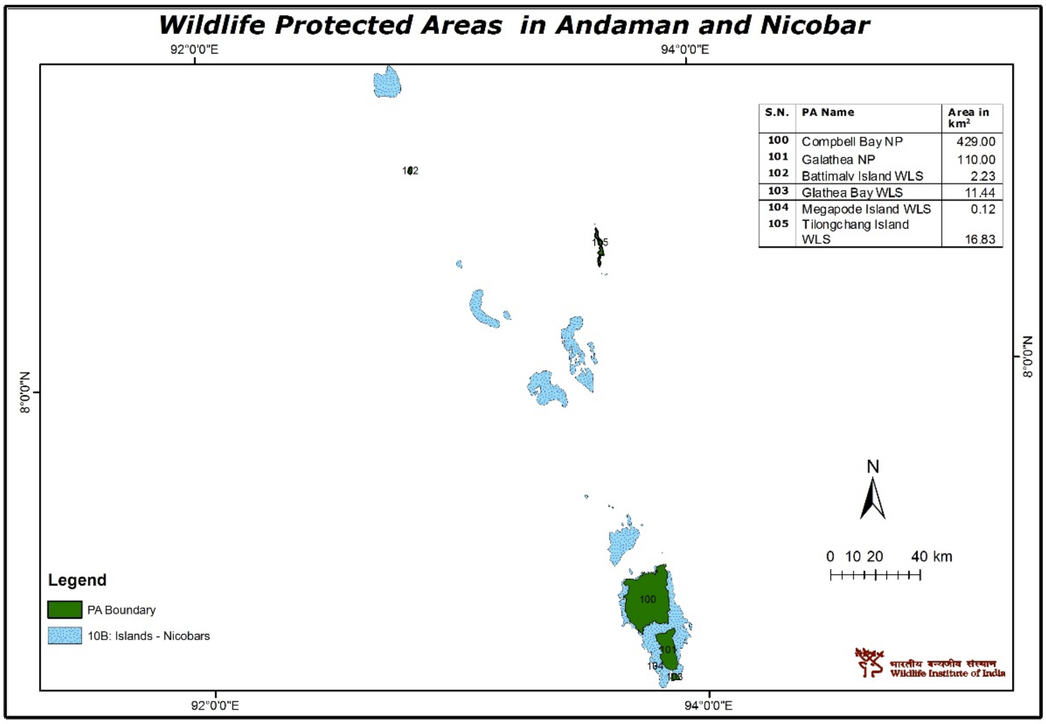

Figure 3. 15 Marine protected areas in Andaman and Nicobar Islands Tile 6.

3.3 Distribution of coral reefs in India

India has a coastline of nearly 8129 km, but the reef formation is restricted to four major centres. Gulf of Kutch. Gulf of Mannar, Lakshadweep and Andaman and the Nicobar Islands. In India, the reefs are distributed along the east and west coasts at restricted places. Fringing reefs are found in the Gulf of Mannar and Palk Bay. Platform reefs are seen along the Gulf of Kachchh. Patchy reefs are present near Ratnagiri and Malvan coasts. Fringing and barrier reefs are found in Andaman and Nicobar Islands. The Lakshadweep is the only atoll formation of our waters. The total area of coral reefs in India is estimated to be 2,375 sq. km (DOD and SAC, 1997). Coral reefs of the Indian Ocean were built up during the tertiary and quaternary periods. Coral reefs are restricted mainly in seven regions of India, such as:

1. Coral reefs in the Gulf of Manner
2. Coral reefs in Palk Bay,
3. Coral reefs in Gulf of Kutch,
4. Coral reefs in Andaman and Nicobar islands.
5. Coral reefs in Lakshadweep islands,
6. Coral reefs in the West coast of India (Including Goa and Kerala)

Gulf of Mannar

On the other hand, the Gulf of Mannar reefs is developed around a chain of 21 islands that lie along the 140 km stretch between Tuticorin and Rameswaram (Krishnamurthy, 1987). These islands are located between latitude 8°47' N and 9° 15' N and longitude 78° 12' E and 79° 14'E on the southeast coast of India 21 islands running parallel to a coastline at an average of 8 km from shore. Different types of reef forms such as shore platform, patch, coral pinnacles and atoll type are also observed in the Gulf of Mannar. The islands have fringing coral reefs and patch reefs around them. Narrow fringing reefs are located mostly at a distance of 50 to 100 m from the islands. On the other hand patch, reefs arise from depths of 2 to 9 m and extend to 1 to 2 km in length with a width as much as 50 meters. The reef flat is extensive in almost all the reefs in the Gulf of Mannar. Reef vegetation is richly distributed on these reefs. The total area occupied by the reef and its associated features is 94.3 sq. km. Reef flat and reef vegetation, including algae, occupies 64.9 and 13.7 sq. km, respectively (DOD and SAC, 1997). Visibility is affected by monsoons, coral mining and high sedimentation load. The reefs are more luxuriant and richer than the reefs of Palk bay.

Palk Bay

Coral reefs on the Tamil Nadu coast are located in Palk Bay near Rameswaram and in the Gulf of Mannar. Palk Bay is separated from the Gulf of Manner by the Mandapam peninsula and Rameswaram Island. The reef is centred on 9 °17'N and 79° 15'. There is only one fringing reef in the Palk Bay, which lies in an east-west direction along the mainland from the Pamban channel at the Pamban end of the bridge to Rameshwaram Island. This reef is 25-30 km long and generally less than 200 m wide. Visibility is poor, around 1 meter, and it is badly affected by the northeast monsoon. The reef flat is relatively broad from the Pamban channel to the southern end near Ramnad and narrow from Pamban to the south of Rameshwaram. The present-day reef growth is poor, and it is not in a pristine condition since it was quarried in the sixties (Pillai, 1996). Satellite data shows that the reef flat is barren and is followed by a sandy beach on the landward side. A small patch of reef fringes at the Dhanushkodi tip (Bahuguna and Nayak, 1994).

Gulf of Kutch

The Gulf of Kutch, located at 22°15'-23°40' N Latitude and 68°20'-70°40' East Longitude, is one of the indentations found on the northern side of the Saurashtra Peninsula. The beaches are sandy or muddy with occasional large sandstone formations. There are about 40 islands with patchy coral formations, of which the largest is Pirotan Island. Corals are found on sandstones substrate in patches. The coral fauna of the Gulf of Kutch is comparatively less diverse compared to other parts of India (Pillai, 1996). The total Area of Reefs in the Gulf of Kutch is about 352.5 sq. km. (Jayaprakas and Radhakrishnan, 2014).

Andaman and Nicobar Islands

The Andaman and Nicobar group of Islands are located in the SE of the Bay of Bengal, between 6°-14° N latitude and 91 °-94° E longitude. They consist of 350 islands. Almost all the islands of the Andaman and Nicobar groups exhibit narrow, linear and extensively well-developed fringing reefs (Vineeta Hoon, 1997). A total of 135 species divided among 59 genera is known to both Andaman and Nicobar (Pillai 1983). The total area occupied by the reef is 1021.46 sq.km (SAC, 2010). There is not enough recent information about the reefs around North Andaman and the Nicobar islands to provide a true picture of the current status of the reefs.

The Lakshadweep Islands

The Lakshadweep islands lie scattered in the Arabian Sea about 225 to 450 km from the Kerala coast. Geographically, the islands lie between 8°N - 12°3'N latitude and 71 °E-74°E longitude. The islands consist of coral formations built upon the Laccadive-Chagos submarine ridge, rising steeply from a depth of about 1500 m to 4000 m off the west coast of India. The U.T of Lakshadweep along with the Maldives and the Chagos Archipelagoes, form an interrupted chain of coral atolls and reefs on a contiguous submarine bank covering a distance of over 2000 km. This ridge is supposed to be a continuation of the Arravali Mountains, and the islands are believed to be remnants of the submerged mountain cliffs (James et al.1986). There are 36 tiny islands, 12 atolls, 3 reefs and 5 submerged banks, covering an area of 32 km2 with lagoons occupying about 4200 km2. Only 11 of the 36 islands are inhabited (Vineeta Hoon, 1997). Coral reefs of the islands are mainly atoll except one platform reef at Androth. The total area occupied by the reef is 933.7 sq. km, including a lagoon area of 510 sq. km (SAC, 2010).

West Coast of India

The west coast of India between Bombay and Goa is reported to have submerged banks with isolated coral formations (Nair and Qasim, 1978). Coral patches have been recorded in the intertidal regions of Ratnagiri, Malvan and Redi, south of Bombay (Qasim and Wafer, 1979) and at the Gaveshani Bank, 100 Km west of Mangalore (Nair and Qasim, 1978). Ponies, Coscinarares, Turbinaria, some favids and Pseudosiderastrea are reported. Down south from Quilon along the Kerala coast to Enayam in TamilNadu, hermatypic corals are reported along the shore. Pocilipora spp is the most common genus in this area. Acropora is found with the representation of three species. Pseudosiderastrea and Ponies spp are also found. A recent investigation has shown that 29 species in 17 genera of scleractinians occur in this area (Pillai, 1996).

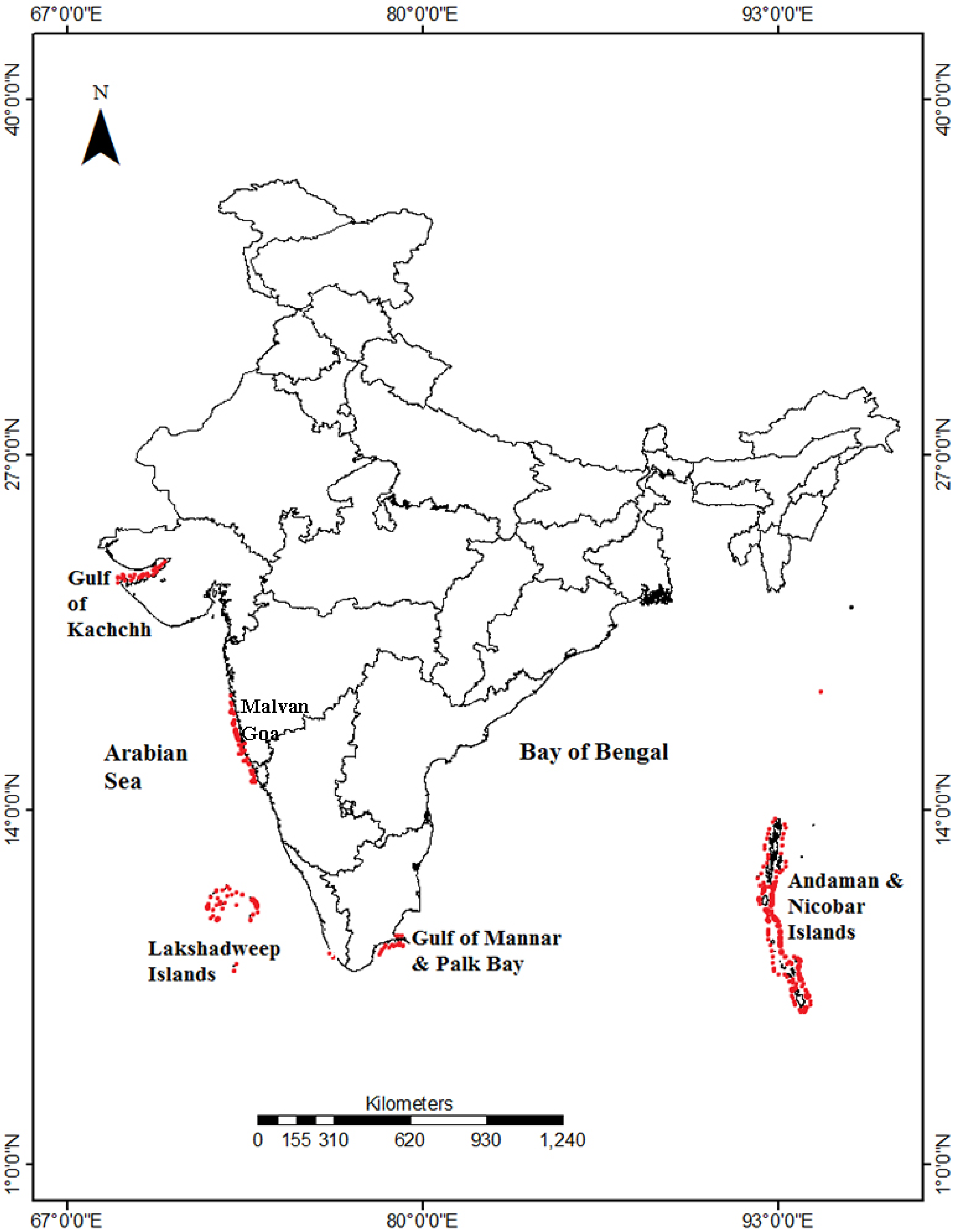

Figure 3. 16 Major Coral areas in India.

Table 3. 60 Area Estimates of Coral Reefs in the Country (Km^2)

Category	Gujrat	Tamilnadu (Pak bay, Gulf of Mannar and Tuticorin)	Lakshadweep islands	A&N Islands
Reef flat	148.4	64.9	136.5	795.7
Sand over reef	11.8	12.0	7.3	73.3
Mud over reef	117.1	-	-	8.4
Coraline shelf	-	-	230.9	45.0
Coral heads	-	-	6.8	17.5
Live coral platform	-	-	43.3	-
Algae	53.8	0.4	0.4	-
Seaweeds	-	-	0.7	-
Seagrass	-	-	10.9	-
Reef vegetation	112.1	13.3	-	8.9
Vegetation over sand	17.0	3.6	0.4	10.5
Lagoon	-	0.1	322.8	-
Sandy substrate	-	-	(67.4)	-
Reef patch	-	-	(13.4)	-
Deep	-	-	(98.5)	-
Uncertain	-	-	(143.5)	-
Total	460.2	94.3	816.1	959.3

Table 3. 61 Diversity of hermatypic corals in the Indian Ocean

Locality	Genera	species
Gulf of Kutch*	24	37
West Coast Patches*	17	29
Lakshadweep Islands	37	103
Palk bay and Gulf of Mannar	36	96
Tuticorin	19	21
Andaman Islands	31	82
Nicobar Islands	43	103
Total for India*	37	199

3.4 Ecologically Sensitive areas in the coastal regions of India

Ecologically Sensitive Areas (ESA's) have been identified and notified by the Indian Ministry of Environment, Forest and Climate Change (MoEFCC) since 1989. Notifications declaring areas as ESA's are issued under Section 5 clauses i,v, vi, viii of the Environment (Protection) Act, 1986. Pranob Sen Committee Report (2000), defined Ecological Sensitivity as the imminent possibility of a) Permanent and irreplaceable loss of extant life forms; b) Significant damage to ecological processes affecting natural evolution and specialization. ESA's as a concept emerged from peoples concern to promote habitat protection with sustainable development. It has a wider scope for protecting critical geo-morphological features. To protect the fragile marine and marginal marine ecosystem comprising coral reefs wetlands, including mangroves, which are endowed with floral and faunal diversity, the Government of India has declared such areas under the Environment (Protection) Act, 1986, banning their exploitation, followed by Coastal Regulation Zone (CRZ) Notification 1991, which prohibits development and disposal of wastes in the region with mangroves and coral reefs. Based on the recommendations of a National Committee, areas were identified as National Parks and sanctuaries and are declared as Marine Protected Areas (MPA's). These MPA's are classified into three categories with mangroves, coral reefs, algal beds, estuaries, lagoons, intertidal areas falling in Category – I and the protected areas in Andaman and Nicobar and Lakshadweep Islands grouped under Category – II. According to the notifications, there are 32 Marine Protected Areas and sanctuaries of which 19 belong to Category – I and 13 areas come under Category – II. Of the 19 areas in Category – I, 6 are National Parks, and 13 are sanctuaries. Among the 13 areas classified under category – II, 3 are National Parks, and 10 are sanctuaries. Other ecologically sensitive habitat includes Pearl Oyster culture areas, abundant seagrass areas, turtle net breeding and coastal dunes.

Major Services of Coastal and Marine Ecosystems

- Life in the sea produces a third of the oxygen that we breathe.
- The ocean absorbs approximately 30% of CO emitted by human 2 activities since the 'Industrial Revolution'; this has helped limit the overall extent of global warming substantially.
- Fisheries directly employ almost 200 million people and provide over 15% of the dietary intake of animal protein.

- Marine bio-products are raw materials for manufacturing industries such as paints, fertilizers, skin lotions, toothpaste and medicines.
- The divergent chemical deposits in the marine environment are an asset and might even yield new anti-cancer drugs.
- The shore provides for marine transportation, recreation, tourism and salt production.
- Mangroves can protect the coastal aquifers from seawater intrusion and safeguard the coastal communities from natural calamities like cyclones and tsunami
- Coastal wetlands play an important role in water quality regulation by capturing and filtering sediment and organic waste transits inland.

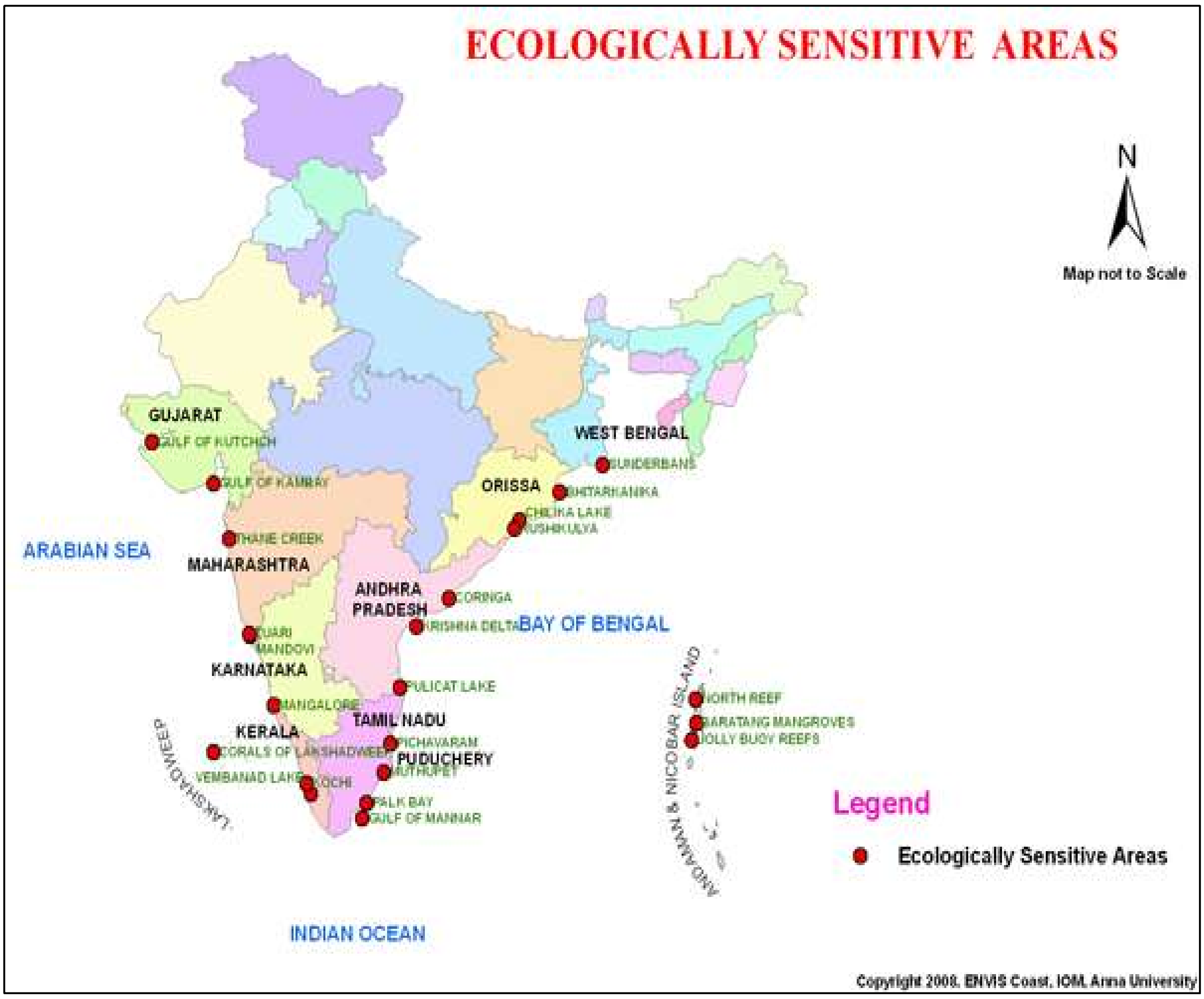

Figure 3. 17 Major ecologically Sensitive areas in India

Table 3. 62 Major Ecologically sensitive coastal areas in India

Sl. No	Major ecologically sensitive area	Latitude	Longitude
1	Gulf of Kutch, Gujarat	22.744288°	69.955034°
2	Gulf of Kambay, Gujarat	21.889111°	72.378468°
3	Thane creek, Maharashtra	19.037537°	72.981465°
4	Zuari and Mandovi, Goa	15.475647°	73.827189°
5	Mangalore	12.914142°	74.855957°
6	Vembanad Lake	9.597143°	76.398279°
7	Cochin Backwaters	9.968817°	76.259191°
8	Corals of Lakshdweep	10.825645°	72.178172°
9	Palk Bay	9.493637°	79.255135°
10	Gulf of Mannar	9.149287°	79.383751°
11	Muthupet, Tamil Nadu	10.394922°	79.493946°
12	Pichavaram, Tamil Nadu	11.422549°	79.774836°
13	Pulicat Lake, Andhra Pradesh	13.559263°	80.209822°
14	Krishna Delta, Andhra Pradesh	15.738637°	80.944129°
15	Coringa, Andhra Pradesh	16.778907°	82.313066°
16	Rushikulya, Odisha	19.360657°	84.918700°
17	Chilika Lake, Odisha	19.844959°	85.478802°
18	Bhitarkanika, Odisha	20.715147°	86.865944°
19	Sundarbans, West Bengal	21.949727°	89.183330°

Table 3. 63 Eco-sensitive Zones in India

State	Sl. No	Eco Sensitive Zone	Latitude	Longitude
Andhra Pradesh	1	Pulicat Wildlife Sanctuary	13.698164°	80.117916°
	2	Great Indian Bustard Rollapadu Wildlife Sanctuary	15.736685°	78.363601°
	3	Kambalakonda Wildlife Sanctuary	17.826725°	83.304106°
	4	Rajiv Gandhi National Park	14.730292°	78.550024°
	5	Nelapattu Bird Sanctuary	13.825053°	79.949571°
	6	Sri Lankamalleswara Wildlife Sanctuary	14.587022°	78.899933°
Andaman and Nicobar Islands	7	105 Protected Areas in the Union Territory of Andaman and Nicobar Islands Mentioned in Table 3.60.	Refer Table 3.60 and corresponding figures 3.10 to 3.15	Refer Table 3.60 and corresponding figures 3.10 to 3.15
Assam	8	Amchang Wildlife Sanctuary	26.184218°	91.862133°
Bihar	9	Kusheshwar Asthan Bird Sanctuary	25.724436°	86.225790°
	10	Rajgir Wildlife Sanctuary	24.996129°	85.418666°
	11	Baraila Lake Salim Ali Jubba Sahni Bird Sanctuary	25.766518°	85.545769°
	12	Kaimur Wildlife Sanctuary	24.907502°	83.531665°
	13	Udaipur Wildlife Sanctuary	26.807647°	84.429267°
	14	Bhimbandh Wildlife Sanctuary	25.073564°	86.438639°
	15	Gautam Buddha Wildlife Sanctuary	24.571303°	85.528269°
	16	Valmiki Wildlife Sanctuary	27.379990°	84.143514°
	17	Valmiki National Park	27.379990°	84.143514°
	18	Valmiki Tiger Reserve	27.379990°	84.143514°
Chandigarh	19	Bird Sanctuary, Union Territory, Chandigarh	30.728585°	76.779458°
	20	Sukhna Wildlife Sanctuary, Chandigarh.	30.772946°	76.857140°s
Chattisgarh	21	Barnawapara Wildlife Sanctuary	21.479745°	82.531358°
	22	Pamed Wildlife Sanctuary	18.223775°	80.910056°
Dadra Nagar Haveli	23	Dadra and Nagar Haveli WLS	20.177860°	73.026724°
Delhi	24	Asola Bhatti Wildlife Sanctuary, NCT, Delhi	28.494067°	77.267502°
Goa	25	Dr. Salim Ali Wildlife Sanctuary	15.488188°	73.866405°

	26	Cotigao WLS	14.976031°	74.206193°
	27	Netravali WLS	15.083670°	74.232054°
	28	Madei WLS	15.556591°	74.253696°
	29	Bhagwan Mahaveer WLS	15.366760°	74.272034°
	30	Bondla WLS	15.440110°	74.106380°
Gujarat	31	Marine National and Marine Sanctuary	22.433179°	69.463091°
	32	Girnar Reserve Forest	21.531152°	70.500353°
	33	Narayan Sarovar Wildlife Sanctuary	23.667874°	68.545248°
	34	Purna Wildlife Sanctuary	20.943367°	73.724249°
	35	Vansda NP	20.776127°	73.476081°
	36	Barda Wildlife Sanctuary	20.627116°	73.624186°
	37	Thol Bird Sanctuary	23.140131°	72.392840°
	38	Shoolpaneshwar Wildlife Sanctuary	21.760622°	73.794852°
	39	Porbandar Wildlife Sanctuary,	21.637299°	69.618216°
	40	Gaga Sanctuary	22.018806°	69.403316°
	41	Nalsarovar Bird Sanctuary	22.828550°	72.057471°
	42	Hingolgadh Wildlife Sanctuary	22.153109°	71.317121°
	43	Velavadhar Wild Life Sanctuary	22.049075°	72.026977°
	44	Khijadiya Wildlife Sanctuary	22.515794°	70.153747°
	45	Rampara Wildlife Sanctuary	22.530152°	70.955388°
	46	Jessore Wildlife Sanctuary	24.416954°	72.499440°
Haryana	47	Sultanpur NP	28.468076°	76.891794°
	48	Khol Hi Raitan Wildlife Sanctuary	30.694277°	76.979317°
	49	Bir Shikargarh Wildlife Sanctuary	30.776563°	76.959535°
	50	Khaparwas Wildlife Sanctuary	28.568540°	76.501492°
	51	Kalesar National Park and Kalesar Wildlife Sanctuary	30.410887°	77.471685°
	52	Bhindawas Wildlife Sanctuary	28.534141°	76.550740°
	53	Chhilchhila Wildlife Sanctuary	29.937127°	76.681162°
Himachal Pradesh	54	Daranghati Wildlife Sanctuary	31.419618°	77.853110°
	55	Majathal Wildlife Sanctuary	30.957056°	77.160037°
	56	Shimla Water Catchment WLS	31.111608°	77.219688°
	57	Rakchham-Chitkul Wildlife Sanctuary (previously known as Sangla Valley)	31.385710°	78.361083°

	58	Talra Wildlife Sanctuary	31.028020°	77.764620°
	59	Sechu Tuan Nala Wildlife Sanctuary	31.028019°	77.764626°
	60	Inderkila National Park	32.228197°	77.411655°
Jammu and Kashmir	61	Jasrota Wildlife Sanctuary	32.485793°	75.405356°
Jharkhand	62	Dalma Wildlife Sanctuary, Jharkand-West Bengal	22.893291°	86.166895°
Karnataka	63	Bandipur NP	11.778764°	76.464683°
	64	Mookambika Wildlife Sanctuary	13.833145°	74.894943°
	65	Brahmagiri Wildlife Sanctuary	12.172650°	75.644084°
	66	Attiveri Bird Sanctuary	15.868268°	74.494916°
	67	Ghataprabha Bird Sanctuary	16.239458°	74.758577°
	68	Ranebennur Blackbuck Sanctuary	14.648084°	75.684210°
	69	Rangayyanadurga Four Horned Antelope Wildlife Sanctuary	12.801495°	77.572984°
	70	Gudekote Sloth Bear Sanctuary	14.836482°	76.631748°
	71	Gudavi Bird Sanctuary	14.446407°	75.008540°
	72	Pushpagiri Wildlife Sanctuary	12.662805°	75.687131°
	73	Cauvery Wildlife Sanctuary	11.979011°	77.653425°
	74	Malai Mahadeshwara Wildlife	12.012954°	77.576646°
	75	Melukote Wildlife Sanctuary	12.650775°	76.615581°
	76	Talacauvery Wildlife Sanctuary	12.432201°	75.455816°
	77	Ranganthittu Bird Sanctuary	12.424360°	76.656349°
	78	Ramadevarabetta Vulture Sanctuary	13.308238°	77.159301°
	79	Nugu Wildlife Sanctuary	11.945697°	76.461804°
Kerala	80	Chulannur Peafowl Sanctuary	10.726104°	76.477998°
	81	Eravikulam National Park	10.135559°	77.059730°
	82	Chinnar Wildlife Sanctuary	10.306797°	77.206024°
	83	Anamudi Shola National Park	10.190306°	77.177279°
	84	Pampadum Shola National Park	10.126626°	77.258170°
	85	Kurinjimala Sanctuary	10.228781°	77.267605°
	86	Shendurney Wildlife Sanctuary	8.857829°	77.217522°
	87	Malabar Wildlife Sanctuary	11.557539°	75.957897°
	88	Silent Valley National Park	11.069423°	76.428002°
	89	Thattekkad Bird Sanctuary	10.129791°	76.687118°
	90	Peechi-Vazhani Wildlife Sanctuary	10.483488°	76.433168°

	91	Mathikettan Shola National Park	9.984674°	77.246263°
	92	Aralam Wildlife Sanctuary	11.922379°	75.792458°
	93	Periyar Tiger Reserve	9.462155°	77.236847°
	94	Chimmony Wildlife Sanctuary	10.431039°	76.491012°
	95	Idukki Wildlife Sanctuary	9.782400°	76.964305°
	96	Neyyar and Peppara Wildlife Sanctuaries	8.534067°	77.150266°
	97	Parambikulam Tiger Reserve	10.447006°	76.815691°
	98	Kottiyoor Wildlife Sanctuary	11.868152°	75.867743°
	99	Manglavanam Bird Sanctuary	9.988740°	76.272524°
Madhya Pradesh	100	Son Gharial Wildlife Sanctuary	24.513066°	82.141492°
	101	Gandhi Sagar WLS	24.671923°	75.521996°
	102	Ghatigaon Hukna Wildlife Sanctuary	26.061563°	77.977953°
	103	Satpura Tiger Reserve	22.570533°	78.143774°
	104	Dinosaur National Park	22.339134°	74.778438°
	105	Bandhavgarh National Park	23.698916°	80.976878°
	106	Panpatha Wildlife Sanctuary	23.856320°	81.010312°
	107	Bagdara Wildlife Sanctuary	24.664538°	82.496042°
	108	Ghughua Fossil National Park	23.184593°	80.698046°
	109	Ken Garial Wildlife Sanctuary	23.110085°	80.613363°
	110	Madhav National Park	25.431745°	77.739108°
	111	Sanjay National Park and Sanjay Dubri Wildlife Sanctuary	23.867828°	82.062504°
	112	Karera Wildlife Sanctuary	25.456807°	78.127936°
	113	Nauradehi Wildlife Sanctuary	23.541534°	79.211258°
	114	Ratapani and Singhori WLS	22.917767°	77.722294°
	115	Van Vihar National Park	23.230612°	77.365229°
	116	Narsinghgarh Wildlife Sanctuary	23.714738°	77.088085°
	117	Orchha Wildlife Sanctuary	25.335361°	78.639817°
	118	Kheoni Wildlife Sanctuary	22.776543°	76.905652°
Maharashtra	119	Nagzira Wildlife Sanctuary and New Nagzira Wildlife Sanctuary	21.248170°	79.986590°
	120	Koka Wildlife Sanctuary	21.203159°	79.790869°
	121	Navegaon Wildlife Sanctuary and Navegaon National Park	20.975568°	80.165184°
	122	Painganga Wildlife Sanctuary	19.580085°	78.004085°

	123	Gautala Autramghat Wildlife Sanctuary	20.325289°	75.137234°
	124	KARNALA Wildlife Sanctuary	18.891036°	73.121918°
	125	Umred Karhandla Wildlife Sanctuary	20.828661°	79.593265°
	126	Gangewadi New Great Indian Bustard Sanctuary	17.826818°	75.868750°
	127	Phansad Wildlife Sanctuary	18.404930°	72.937970°
	128	Bhamragarh Wildlife Sanctuary	21.248170°	79.986591°
	129	Yedshi Ramling Ghat WLS	18.309446°	75.947461°
	130	Dyanganga Wildlife Sanctuary	20.566685°	76.377809°
	131	Sagareshwar WLS	17.152414°	74.378243°
	132	Kalsubai Harishchandragad Wildlife Sanctuary	19.386389°	73.778056°
	133	Melghat Tiger Reserve	21.406042°	77.148516°
	134	Sanjay Gandhi National Park	19.228809°	72.918178°
	135	Jaikawadi Bird Sanctuary	19.509042°	75.375325°
	136	Pench National Park	21.649487°	79.245051°
	137	Mansinghdeo Wildlife Sanctuary	21.466883°	79.316746°
	138	Thane Creek Flamingo Sanctuary	19.147775°	72.981736°
Manipur	139	Kailam WLS	24.268160°	93.404356°
	140	Yangoupokpi Lokchao Wildlife Sanctuary	24.322778°	94.232069°
	141	Bunning Wildlife Sanctuary	24.478798°	93.839523°
	142	Keibul Lamjao National Park	24.478798°	93.839523°
	143	Jiri – Makru Wildlife Sanctuary	24.896947°	93.291264°
Meghalaya	144	Narpuh Wildlife Sanctuary	25.130120°	92.413906°
	145	Nongkhyllem Reserved Forest Sanctuary	25.130142°	92.413914°
Mizoram	146	Khawnglung Wildlife Sanctuary	23.122798°	92.942570°
	147	Tawi Wildlife Sanctuary	23.539011°	92.952563°
	148	Pualreng Wildlife Sanctuary	23.812527°	93.248306°
	149	Murlen National Park	23.657365°	93.278482°
	150	Thorangtlang Wildlife Sanctuary	23.288888°	92.509723°
	151	Lengteng Wildlife Sanctuary	23.812527°	93.248306°
	152	Dampa Tiger Reserve	23.503433°	92.417972°
Odisha	153	Chandaka Dampara Wildlife Sanctuary	20.348776°	85.664037°
	154	Kapilash Wildlife Sanctuary	20.707406°	85.801685°

	155	Balukhand-Konark WLS	19.864371°	86.047862°
	156	Bhitarkanika Wildlife Sanctuary	20.714157°	86.820174°
	157	Gahirmatha (Marine) Wildlife Sanctuary	20.793879°	86.874414°
	158	Debrigarh Wildlife Sanctuary	21.500646°	83.771163°
	159	Kuldiha Wildlife Sanctuary	21.409625°	86.733471°
	160	Bir Moti Bagh Wildlife Sanctuary	30.287571°	76.401324°
	161	Harike Wildlife Sanctuary	31.159024°	74.996062°
	162	Jhajjar- Bachauli Wildlife	31.262609°	76.517369°
	163	Bir Aishwan WLS	30.226609°	75.887361°
	164	Bir Gurdialpura Wildlife Sanctuary	30.049663°	76.189612°
	165	Kathlaur-Kushalia Wildlife Sanctuary	32.241484°	75.460562°
	166	Bir Bhunerheri Wildlife Sanctuary	30.187321°	76.470766°
	167	Takhni – Rehmapur Wildlife Sanctuary	31.663471°	75.920518°
	168	Bir Mehas WLS	30.350251°	76.179823°
	169	Bir Bhadson Wildlife Sanctuary	30.516392°	76.219984°
	170	Nangal WLS	31.383195°	76.376571°
Rajasthan	171	Todgarh Raoli Wildlife Sanctuary	25.687287°	73.972018°
	172	Van Vihar WLS	26.702518°	77.893391°
	173	Sajjangarh Wildlife Sanctuary	24.594375°	73.641647°
	174	Sitamata Wildlife Sanctuary	24.222551°	74.431997°
Sikkim	175	Khangchendzonga NP	27.667245°	88.324556°
	176	Fambonglho Wildlife Sanctuary	27.386160°	88.536061°
	177	Kyongnosla Wildlife Sanctuary	27.338818°	88.627798°
	178	Pangolakha Widllife Sanctuary	27.333333°	88.766667°
	179	Maenam Wildlife Sanctuary	27.307605°	88.363125°
	180	Shingba Rhododendron Sanctuary	27.801286°	88.769520°
	181	Barsey Rhododendron Sanctuary	27.194200°	88.118300°
	182	Kitam Bird Sanctuary	27.108020°	88.350646°
Tamil Nadu	183	Chitrangudi Bird Sanctuary	9.322985°	78.487397°
	184	Karaivetti Bird Sanctuary	10.982782°	79.044731°
	185	Koonthankulam Bird Sanctuary	8.492706°	77.750930°
	186	Udayamarthandapuram Bird Sanctuary	10.449195°	79.554303°
	187	Mudumalai Tiger Reserve	11.562277°	76.534522°

	188	Therthnagal Bird Sanctuary	9.456589°	78.771945°
	189	Sakkarakottai Bird Sanctuary	9.358036°	78.846050°
	190	Srivilliputhur Grizzled Squirrel Sanctuary	9.534609°	77.529007°
	191	Kanjirankulam Bird Sanctuary	9.356562°	78.481330°
	192	Vallanadu Black Buck Sanctuary	8.720013°	77.881050°
	193	Vettangudi Bird Sanctuary	10.111744°	78.510227°
	194	Melaselvanur-Kelaselvanoor Bird Sanctuary	9.214107°	78.551889°
	195	Kanyakumari Sanctuary	8.487666°	77.408224°
	196	Gulf of Mannar National Park	9.127823°	79.466155°
Telangana	197	Pakhal Wildlife Sanctuary	17.952579°	80.005979°
	198	Manjeera Wildlife Sanctuary	17.659502°	78.060304°
	199	Pocharam Wildlife Sanctuary	18.123384°	78.197765°
	200	Mahavir Harina Vanasthali National Park	17.342085°	78.585373°
	201	Kinnerasani Wildlife Sanctuary	17.673115°	80.656928°
Tripura	202	Rowa Wildlife Sanctuary	24.292776°	92.166514°
Uttarakhand	203	Valley of flowers Wildlife Sanctuary	30.728040°	79.605303°
	204	Nandhaur Wildlife Sanctuary	29.134329°	79.675172°
	205	Nandadevi National Park	30.658764°	79.838654°
	206	Kedarnath Musk Deer Sanctuary	30.753446°	79.064506°
	207	Gangotri National Park	30.942604°	79.154853°
	208	Rajaji National Park	29.991733°	78.289643°
Uttar Pradesh	209	Okhla Bird Sanctuary	28.559812°	77.316568°
	210	Kaimur Wild Life Sanctuary	24.685001°	83.068353°
	211	Ranipur Wildlife Sanctuary	24.968388°	81.063533°
	212	Saman Bird Sanctuary	27.023486°	79.189458°
	213	Parwati Arga Wildlife Sanctuary	26.948767°	82.170003°
	214	Sohagi Barwa Wildlife Sanctuary	27.144603°	83.562173°
West Bengal	215	Jaldapara National Park	26.690778°	89.276970°
	216	Neora Valley National Park	27.082450°	88.700689°
	217	Singalila National Park,	27.037135°	88.076223°

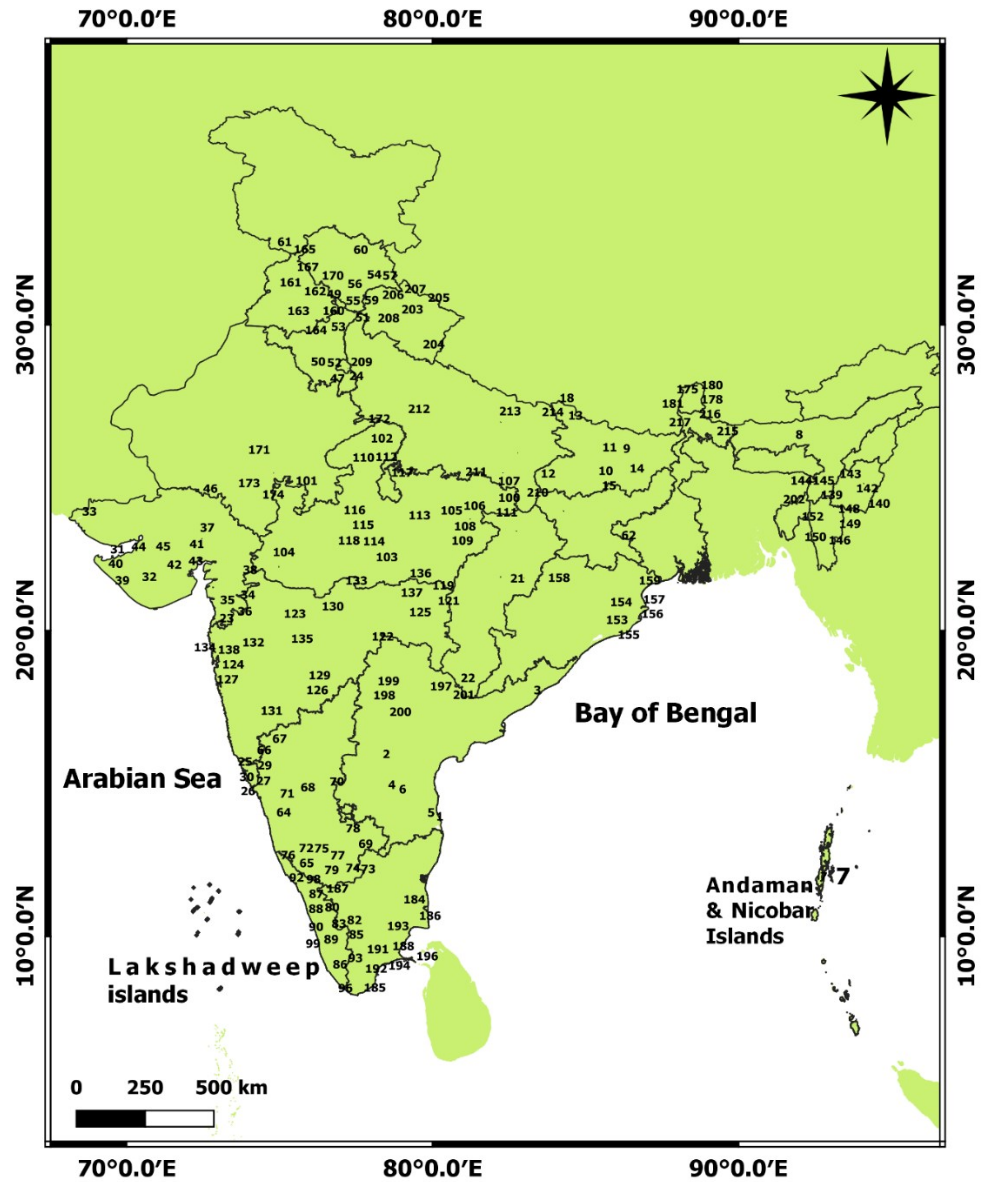

Figure 3. 18 Eco-sensitive zones in India. Refer to Table 3.64 for corresponding location details.

Chapter 4: Environmental Impact Assessment and Mitigation Measures related to the Offshore Oil and Gas sector

4.1 Environmental Impact Assessment

Environmental impacts of oil and gas operations may affect water quality and influence species, populations, assemblages, or ecosystems by modifying various ecological parameters (e.g., biodiversity, biomass, productivity, etc.). At the project level, potential impacts are generally assessed through a formal process, termed an environmental impact assessment (EIA). These typically involve identifying, predicting, evaluating, and mitigating impacts prior to the start of a project. Key standard components of an EIA include:

(i) Description of the proposed development, including information about the size, location, and duration of the project,

(ii) Baseline description of the environment,

(iii) Description of potential impacts on the environment,

(iv) Proposed mitigation of impacts and

(v) Identification of knowledge gaps.

Mitigation in current oil and gas projects is recommended to follow the mitigation hierarchy: avoid, minimize, restore, and offset (World Bank, 2012). Environmental management strategies, particularly those to prevent and minimise the environmental impacts of projects, are set during the EIA process and may become operation conditions. As a result, this element of the EIA process is crucial in pre-emptively avoiding severe impacts to the marine environment (Beanlands and Duinker, 1984). Establishing appropriate baseline data and control reference sites is critical to effective EIA development and subsequent assessment and monitoring of EIA predictions.

EIAs include predictions of how an ecological “baseline” condition may change in response to development and activities. Regulatory bodies generally offer advice on the appropriate assessment of potential impacts on ecological parameters such as biodiversity as

(i) Gains or losses in the variety of species,

(ii) Gains or losses in the variety and abundance within species,

(iii) Gains or losses in the amount of space for ecosystems and habitats,

(iv) Gains or losses in the physical connectedness of ecosystems and habitats, and

(v) Environmental changes within ecosystems and habitats.

The reliability of EIA predictions depends mainly on the quality of existing ecological data (e.g., spatial and temporal coverage, measures of natural variation, taxonomic resolution, types of fauna observed, and collected, etc.) and empirical data or model predictions of how ecological features react to human stressors. Even in the best-known deep-sea environments, the need for planned, coherent, and consistent environmental data to inform EIAs may necessitate substantial new survey operations.

Testing EIA predictions and the effectiveness of implemented mitigation measures with well-designed and consistent environmental monitoring is a critical next step. Generally, some form of “before-after/control-impact” (BACI) monitoring approach is appropriate (Underwood, 1994), as this will enable the detection of accidental impacts in addition to impacts anticipated from typical operations (Wiens and Parker, 1995; Iversen et al., 2011). However, this often receives less attention and resources than the EIA itself, and most jurisdictions have minimal requirements for monitoring programs. Long-term monitoring in the deep sea is generally rare (e.g., Hartman et al., 2012), and long-term environmental monitoring of deep-water oil and gas developments is extremely limited. Monitoring should also be carried out after production has ceased and throughout de-commissioning.

Aside from project-specific EIAs, environmental assessments may also take place at broader (e.g., regional or national) levels, for example, in the form of Strategic Environmental Assessments (SEAs). Such broad assessments may cover a single industrial sector or multiple sectors and may involve broad analyses of environmental and socio-economic impacts of development plans. These assessments are typically aimed at assisting regulatory bodies with identifying development options that can achieve both sustainable use and national and international conservation goals (Noble, 2000; Jay, 2010). Despite the recognized benefit of integrating strategic/regional assessments into the planning and management process, their application in offshore activity planning is still relatively limited (Noble et al., 2013).

4.1.1 Broad aspect of Environmental Impact Assessment

In the assessment of the environmental impact associated with offshore oil and gas operations, the starting step is to define various activities related to a project/operation that could result in an environmental impact. These can include surveying, drilling, construction, production and decommissioning operations. Following the identification of the activities, the associated aspects which could result in an environmental impact are identified. Elements are grouped as follows: marine use, emissions, discharges, wastes and unplanned events. Each aspect grouping has more specific aspects, such as discharges of hydro test water, produced water, or ballast water. Once the aspects have been identified, the potential impacts and receptors (such as marine mammals or water quality) can be considered. Environmental impacts resulting from proposed actions can be grouped into the following categories:

- Beneficial or detrimental
- Naturally reversible or irreversible
- Repairable via management practices or irreparable
- Short-term or long-term
- Temporary or continuous
- Occurring during the construction phase or operational phase
- Local, regional, national or global
- Accidental or planned (recognized beforehand)
- Direct (primary) or Indirect (secondary)
- Cumulative or single

4.1.2 Direct impacts

Direct impacts occur through the direct interaction of an activity with an environmental, social, or economic component. The oil and gas exploration and productions activities may contaminate the basic environmental media. For example, the discharge of wastewaters would directly impact the water and soil quality in the vicinity and, finally, the health of the workers.

4.1.3 Indirect impacts

Indirect impacts on the environment are those which are not a direct result of the project, often produced away from or as a result of a complex impact pathway. The indirect impacts are also known as secondary or even tertiary level impacts. An indirect impact is a decline in water quality due to the discharge of wastewaters and other crude oils into the sea. This may, in turn, lead to a secondary indirect impact on aquatic flora in that water body and may not be any further fishing activities. Reduction in fishing harvests, affecting the incomes of fishers, is a third level impact. Such impacts are characterized as socio-economic (third level) impacts. The indirect impacts may also include growth-inducing impacts and other effects related to induced changes to the pattern of land use or additional road network, population density or growth rate. In the process, air, water and other natural systems, including the ecosystem, may also be affected.

4.1.4 Cumulative impacts

Cumulative impact consists of an impact created due to the combination of the project evaluated in the EIA and other projects in the same vicinity causing related impacts. These impacts occur when the incremental impact of the project is combined with the cumulative effects of other past, present and reasonably foreseeable future projects.

4.1.5 Induced Impact

The cumulative impacts can be due to induced actions of projects and activities that may occur if the action under assessment is implemented, such as growth-inducing impacts and other effects related to induced changes. Induced actions may not be officially announced or be a part of any official plan. An increase in the workforce and nearby communities contributes to this effect. They usually have no direct relationship with the action under assessment and represent the growth-inducing potential of action. New roads leading from those constructed for a project, increased recreational activities (e.g., hunting, fishing), and construction of new service facilities are examples of induced actions. However, the cumulative impacts due to induced development or third level or even secondary indirect impacts are difficult to be quantified. Because of higher uncertainties, these impacts cannot usually be assessed over a long time horizon. An EIA practitioner can only guess as to what such induced impacts may be and the possible extent of their implications on the environmental factors. The respective expert appraisal committee may exercise their discretion on a case-by-case basis to consider the induced impacts.

4.1.6 Significance of Impacts

The significance of impacts first and proceeds to delineate the associated mitigations and measures. So the significance here reflects the “worst-case scenario” before mitigation is applied. Therefore, it provides an understanding of what may happen if mitigation fails or is not as effective as predicted. For establishing the significance of different impacts, understanding the responses and interaction of the environmental system is essential. Hence, the impact interactions and pathways are to be understood and established first. Such an understanding will help in the assessment process to quantify the impact as accurately as possible. Complex interactions, particularly in the case of certain indirect or cumulative impacts, may give rise to non-linear responses, which are often difficult to understand and therefore might be difficult to assess their significance. It is hence understood that indirect or cumulative impacts are more complex than direct impacts. Currently, the impact assessments are limited to direct impacts. In case mitigation measures are delineated before determining the significance of the effect, the sign represents the residual effects. However, the ultimate objective of an EIA is to achieve sustainable development.

The development process shall invariably cause some residual impacts even after implementing an EMP effectively. What could be the tolerable level of environmental impact within the sustainable development framework? As such, it has been recognized that every ecosystem has a threshold for absorbing deterioration and a certain capacity for self-regeneration. These thresholds based on the concept of carrying capacity are as follows:

- Waste emissions from a project should be within the assimilative capacity of the local environment to absorb without unacceptable degradation of its future waste absorptive capacity or other important services.
- Harvest rates of renewable resource inputs should be within the regenerative capacity of the natural system that generates them; depletion rates of non-renewable inputs should be equal to the rate at which renewable substitutes are developed by human invention and investment.

This model aims to curb over-consumption and unacceptable environmental degradation. But because of limitations in available scientific basis, this definition provides only general guidelines for determining the sustainable use of inputs and outputs.

4.2 Environmental Impact and Mitigation Measures for the offshore Oil and Gas field

This section broadly tabulates various project activities in the offshore Oil and Gas sector and identifies the potential impact on the marine environment (Table 4.1)

Table 4. 1 Potential impact on the environment

Activity	Source	Potential impact	Component affected	Comments
Seismic operations	Seismic equipment	Noise	B	• Acoustic sources, disturbance to marine organisms (may need to avoid sensitive areas and consider seasonality). • Short-term and transient.
	Vessel operations	Emissions and discharges	At/Aq/T	• Atmospheric emissions from vessel engines; discharges to ocean: bilges, sewage; spillages; waste and garbage disposal to shore.
		Interference	H	• Low-level, short-term, transient. • Interaction with other resource users (e.g. fishing)
Exploratory and appraisal drilling (offshore)	Site selection	Interactions	H/B/Aq	• Sensitivitie to biota, resource use, seasonality. • Secondary impacts related to

				support and supply requirements and potential impact on local ports and infrastructure.
	Operations	Discharges Emissions Wastes	H/At/B/Aq/T	• Discharges to the ocean—muds, cuttings, wash water, drainage, sewage, sanitary and kitchen wastes, spillages and leakages. • Emissions from plant equipment; • Noise and light; • Solid waste disposal and impact • Disturbance to benthic and pelagic organisms, marine birds. • Changes in sediment, water and air quality. • Loss of access and disturbance to other marine resource users. • Emissions and discharges from well test operations,

	Decommissioning	Footprint	B/Aq	• Produced water discharges, burning and flare, additional noise and light impact. • Effects of vessel and helicopter movements on human and wildlife. • Short-term and transient. • Proper controls during operations and careful decommissioning should effectively remove risk of long-term impact. • Improper controls can result in sediment and water contamination, damage to benthic and pelagic habitats, organisms, biodiversity. • Onshore in terms of solid waste disposal, infrastructure and resource conflicts
Development and production	Site selection	Interactions	H/B/Aq	• Long-term site selection is based upon biological

(offshore)				and socio-economic sensitivities and minimum disturbance. • Risk of impact to sensitive species, commercially important species, resource conflict, access. • Long-term support and supply base requirement and impacts on local port infrastructure.
	Operations	Discharges Emissions Waste	H/At/B/Aq/T	• Long-term, chronic effects of discharges on benthic and pelagic biota; sediment and water quality. • Impact of drill cuttings and mud discharges, produced water, drainage, sewage, sanitary and kitchen wastes, spillage and leakage. • Emissions from power and process plant and

				impact on air quality. • Noise and light impact from facilities and flaring. • Solid waste disposal.
		Socio-economic Cultural	H	• Increased vessel movements. • Loss of access and resource use interactions. • Local port, harbour and community interactions related to supply and support functions.
H = Human, socio-economic and cultural; T = Terrestrial; Aq = Aquatic; At = Atmospheric; B = Biosphere				

4.2.1 Marine Environment-Impact Assessment and mitigation measures

(a) Physical Process

Impact Assessment: The marine environment of the project domain will be significantly influenced by the physical objects, including surface and subsurface structures and vessels. Surface structures include drilling units, drill-ships, platforms, FPSO vessels, Floating Storage and Regasification Units (FSRU) and Floating Liquefied Natural Gas (FLNG) facilities. Subsea infrastructure include pipelines, risers, flowlines, manifolds etc. Project-related vessels include survey vessels, barges, tugs, support, heavy lift and anchor handling vessels, intervention vessels, and trenching and pipe laying vessels.

The Presence of facilitates/infrastructure in the project domain may exert substantial impact right from the developmental stage to the decommissioning stage. Anchoring the seabed (for mobile structures) and installing foundations (for fixed structures like platforms) may cause loss temporary or permanent habitat. The increased vessel traffic in connection with the project activities may increase the chance of vessel collision/oil spill and invite obstruction to the other potential users. All the above activities have the following environmental impact and risks:

1. Increased suspended sediment concentration in the water column (causes remobilisation of pollutants from the sediments to the water column)
2. Disturbance to or loss of benthic (seafloor) habitat and associated biota
3. Creation of artificial habitat and/or modification of existing habitats
4. Introduction of marine invasive species
5. Disturbance to migration, feeding and breeding patterns or areas, and deviations to the migration pathway
6. Visual/aesthetic impact to seascape resulting in social and cultural impacts
7. Interaction with other marine users may lead to potential displacement

Mitigation measures: The following mitigation measures can be adopted to address the disturbance in the marine environment:

1. Consider sensitive marine habitats and lifecycle periods for relevant species and communities during the site selection and design stage
2. Undertake benthic habitat surveys to identify sensitive habitats and biota and, where feasible, avoid these areas
3. Minimise physical footprint where feasible
4. Consider potential impacts from offshore structures, both positive and negative. In some cases, restoration may be needed to assist the recovery of damaged or destroyed habitat or offsets considered. Consider dynamic positioning on drill rigs to avoid or minimise the need for anchors
5. Develop exclusion zones for various key stakeholders, including local fishing communities, and promote awareness of exclusion zones with all stakeholders

6. Ensure all facilities/infrastructure has the appropriate navigation lighting and all facilities/infrastructure and subsea infrastructure is gazetted and included on navigational charts
7. Issue a 'Notice to Mariners' through the relevant government agencies, detailing the area of operations
8. Develop and implement Collison Risk Management Plans for project vessels
9. Ensure all vessels adhere to International Regulations for Preventing Collisions at Sea (COLREGS), which set out the navigation rules to be followed to prevent collisions between two or more vessels
10. Optimise vessel use to ensure the number of vessels required and length of time that vessels are on site is as low as practicable

(b) Dredging/Trenching and Rock Dumping

Impact Assessment: Dredging and pipeline lying involves removing sediments during the project's construction, installation, and commissioning phases. Maintenance dredging can also be necessary over the entire project period. Dredge spoil and is usually disposed of offshore. Dredging/trenching/rock dumping and the offshore disposal of dredge spoil will create turbid plumes in the sea, changes sediment transport characteristics, alters the sedimentation pattern in the particular oceanic area and make underwater noise.

In the Deep Sea, the sediments are unlikely to contain contaminants, while certain areas rich in metal ores or areas with significant pollutant loading may release significant levels of metals and organic pollutants into the water column, which poses a detrimental impact on flora and fauna. Some specialised marine environments (coral reefs, seagrass meadows and fish breeding and nursery areas) are more sensitive to dredging impacts and require high levels of protection. The possible impacts during dredging/trenching/rock dumping activities include habitat modification, destruction of sensitive marine habitat, increase in suspended sediment concentrations resulting in the burial of sessile flora and fauna and interfering with locating prey and altering the movement of larval fish, increased sedimentation or placement of material resulting in burial of sessile/sedentary flora and fauna, alteration to hydrodynamic processes, reduced productivity of fisheries and high levels of noise.

Mitigation measures: The following management plan is proposed to mitigate these impacts:

- The site selection and design and the demarcation, placement and timing of dredging zones should be selected by considering sensitive marine habitats and lifecycle periods for relevant species identified during the detailed baseline environmental monitoring.
- Use state of the art dredging technology that minimises the disturbance, reduce footprint, duration and volume of dredging, rock dumping and dredge disposal to the minimum required.
- Formulate and implement a dredge management plan that describes measures to minimise impacts and deploy suitable management techniques when critical values for marine water quality are exceeded.
- Develop plans for exclusion zones in consultation with key stakeholders, including local fishing communities; raise awareness of exclusion zones with all stakeholders.
- Obtain permits for approved disposal routes

4.2.2 Emissions

(a) Acoustics (Underwater Noise and Vibration)

Impact Assessment: Noise is used or generated to varying degrees during all the project phases, i.e., from exploration to decommissioning. Geophysical surveys are initially used to image the subsurface and identify potential hydrocarbon reserves. Marine seismic surveys target subsurface formations, whereas high-resolution geophysical surveys target the seabed and shallow structures.

Seismic noise is characterised by high energy pulses of low-frequency sound. A compressed air sound source is produced by an array of ‘air guns’ towed behind a vessel during a marine seismic survey. The seismic signal is created as bubbles from the source collapse in the water column, producing a pulse of energy directed predominantly downwards. The noise produced will depend upon the configuration, tow depth, and strength (volume) of the air guns used. The returning signal is detected by receivers (hydrophones) also towed behind the vessel. Noise-generating activities during construction include piling, dredging, and trenching. The noise produced by grab and dredgers is broadband, continuous in nature, and sporadically—offshore construction different types of vessels including heavy lift, barges, anchor handling, and supply vessels. The thrusters and engines for positioning (dynamic positioning, DP) generate higher noise levels than vessels fixed by anchors. Offshore drilling is typically carried out using drillships, semi-submersibles and jack-up rigs. Sources of underwater noise include ground vibrations at the drill-rock interface, mechanical vibration of the drill in water, machinery, generators and pumps on platforms and vessels, and wellhead choke valves used to control flow from the reservoir.

Shipping noise is the largest contributor to low-frequency noise in the oceans. Vessel noise varies with the size, speed, engine type and activity being undertaken. Noise is generated by machinery on the vessel, such as generators, engines, pumps, etc., which transmit sound through the hull into the water and the propulsion systems. Propellers are a dominant source of radiated underwater noise, and a number of vessels will use DP thrusters instead of an anchor to maintain position. During decommissioning, underwater noise is created from vessel propulsion and positioning, machinery, equipment and pumps, and potentially from abrasive cutting and explosives use. Decommissioning of offshore infrastructure may require the use of explosives to cut through well casings and platform legs, resulting in very high underwater noise levels over a short period.

Underwater noise emissions significantly impact marine fauna (cetaceans, fish, seabirds, turtles, etc.). Marine fauna use sounds as a medium for communication (social interaction, foraging and orientation). A high noise level may induce behavioural changes (changes in swimming behaviour, breeding and migratory regimes), auditory interference (noise interference with other biologically important sounds, such as communication, echolocation, and sounds produced by predators or prey), and auditory impairment in marine fauna. The varying response of marine fauna to underwater noise depends on several factors, including distance from the noise source, hearing sensitivity, type and duration of noise exposure, and the animal's activity at the time of exposure. Cetaceans include some of the most sensitive species to underwater noise and utilise their highly sensitive acoustic senses to monitor their environment and communicate, socialise, breed, and feed. Background noise can mask vital sounds and cause stress reactions, behavioural changes, or even physical damage, resulting in long-term population impacts.

In fish, anthropogenic noise may interfere with acoustic communication, predator avoidance, prey detection, reproduction, and navigation. The effects of noise on fish include avoidance reactions and changes in shoaling behaviour. Avoidance of an area may interfere with feeding or reproduction or cause a stress-induced reduction in growth and reproductive output. Sound provides birds with information for the recognition of individuals and is also used to aid foraging and avoid predators. Diving birds may suffer direct impacts from seismic exploration or piling noise, including physical damage or normal behaviour disturbance. Sea turtles use sound for navigation, locating prey, and the avoidance of predators. It is possible that exposure to seismic air gun activity could result in mortality to sea turtles that are very close to the noise source; however, their resilience to high-intensity explosives suggests that they would also be resilient to damage from air guns.

Mitigations measures- Exploration: For a seismic survey, avoid sensitive locations and times of year for critical activities such as migration, breeding, calving and pupping, as well as fishing areas during key periods. Utilise a qualified Marine Mammal Observer to identify the sensitive species in each project domain and undertake surveys only during daytime.Use the lowest practicable source levels to image the target structures. Start acoustic activity at the lowest practicable level and gradually increase it to the required level to give marine life the opportunity to move away from the source. Undertake a 30-minute pre-shooting search (60 minutes in waters deeper than 200 m due to deeper diving mammals).

Mitigations measures- Construction: Construction and installation activities should consider critical seasonal activities. Use 'soft-start procedures for piling operations and dredging. For ships, ensure gradual start-up of engines and thrusters where possible to allow species to take evasive action. Assess whether anchoring or the use of DP would be more appropriate for maintaining a ship's position. Anchoring will lead to seabed disturbance, while DP will result in noise disturbance.

Mitigations measures- Drilling and production: Offshore facilities/infrastructure should consider engineering measures to minimise operational noise emissions.

(b) Light

Impact Assessment: Some fauna use visual signals for orientation, and navigation and artificial light sources may disorient, attract, or repel fauna. They can cause changes in fauna movements and behaviour (e.g., foraging, movement, and breeding activity.) Artificial light can cause migratory and non-migratory birds to strike the structure or fly into flares, resulting in injury or death. Migratory bats may also be attracted to artificial light (and the insects the light attracts) in coastal waters and further offshore. The impact of artificial light on sea turtles is primarily related to onshore lighting, which can disorientate turtle hatchlings on beaches. Hatchlings need to find the ocean as quickly as possible and will use the brightest light (usually the moonlight reflecting off the sea) to move towards the ocean.

Mitigations measures: Minimise external lighting as much as possible to that required for navigation, safety and safety of deck operations, except in the case of an emergency and limit the occurrence and duration of flaring, where possible.

(c) Combustion Emissions

Impact Assessment: The emission of gases is associated with various phases in oil and gas exploration, mainly due to electric power generation, gas flaring, and helicopters for regular transport of personnel and supplies during production. Hydrocarbons are used as fuels in the form of fuel gas or diesel, or on some occasions, other products such as propane are used. When combusted, various pollutants are produced and released into the atmosphere. These pollutants and their potential environmental impact are as follows:

- Greenhouse gases (carbon dioxide, nitrous oxide and methane) and these gases contribute immensely to global warming and climate change.
- Nitrogen oxides contribute to acid rain
- Sulphur dioxide contributes to ocean acidification and acid rain
- Carbon monoxide-air pollutant that can be toxic at high concentrations

Mitigation measures: These trace gas concentrations must be within the ambient quality guidelines, and standards as per the national legislated standards and main management and mitigation measures are as follows:

- Use of high-efficiency equipment to minimise power requirement
- Use of low sulphur diesel
- Power generation plants incorporating low emissions technology
- Renewable energy sources into developments
- Regular plant maintenance
- Regular maintenance and emission control devices on vehicles and machinery

(d) Combustion

Impact Assessment: Fugitive emissions do not originate from point sources that can occur during all project phases, from well drilling to decommissioning. The major fugitive emission is methane, and the monitoring of fugitive emissions is necessary to determine the total greenhouse gas emissions of the infrastructure.

Mitigation measures: Mitigation protocols for the management of fugitive emissions are the following:

- Use of appropriate valves, flanges, fittings, seals, and packings, considering safety and suitability requirements as well as their capacity to reduce gas leaks and fugitive emission.
- Implementation of effective and regular leak detection and maintenance

- Ensuring new systems/processes do not use ozone-depleting chemicals or chemicals that cause global warming.

(e) Venting

Impact Assessment: Venting is the intentional or unintentional release of gas into the atmosphere during project activities. Venting releases methane and other volatile organic compounds in the atmosphere that can significantly contribute to global warming and climate change.

Mitigation measures: Mitigation measures include the adoption of measures consistent with the Global Gas Flaring and Venting Reduction Voluntary Standard (part of the Global Gas Flaring Reduction Public-Private Partnership), when considering venting options for offshore activities, tightly controlled and managed flow of gas and a preferential flare rather than vent, vapour recovery units installed as needed for hydrocarbon loading and unloading operations and in the event of an emergency or equipment failure, excess gas should not be vented but sent to an efficient flare gas system.

(f) Flaring

Impact Assessment: Gas may be flared intentionally during the production process or also as an unplanned event to regulate the pressure in the wellhead. The major emission during this process is carbon dioxide, a major contributor of global warming, climate change and ocean acidification.

Mitigation measures: The following management strategies are advised to reduce the environmental impacts:

- Ensuring a tightly controlled and managed flow of gas
- Careful flow tip design, implementation of state of the art technology, reduction of levels of nitrogen oxides, particulate matter and carbon dioxide emissions to the atmosphere during flaring
- Adoption of measures consistent with the Global Gas Flaring and Venting Reduction Voluntary Standard (part of the Global Gas Flaring Reduction

Public-Private Partnership) when considering flaring options for offshore activities

- Design of flare gas metering and tip design to minimise the need for flaring through recirculation, off-gas recovery, and/or flare gas recovery process design
- Maximise flare combustion efficiency by controlling and optimising flare fuel, air, and streamflow rates to ensure the correct ratio of assist stream to flare stream
- Strictly adhering to safety regulations, minimise flaring from purges and pilots through the adoption of various measures (installation of purge gas reduction devices, vapour recovery units, inert purge gas, soft seat valve technology, and installation of conservation pilots)
- Minimise risk of pilot blowout by ensuring sufficient exit velocity and providing wind guards
- In the event of emergency or equipment breakdown, or during facility upset conditions, excess gas should be flared, not vented if possible

4.2.3 Discharges

(a) Sewage, Greywater, and Food Waste

Impact Assessment: Sewage discharges from showers, toilets, kitchen facilities, and food wastes from offshore marine facilities and ships are regularly discharged into the marine environment. This may increase the nutrient concentration in the oceanic area, increase primary production and algal bloom, ultimately increase the biological oxygen demand, and lead to water column hypoxia and anoxia. Behavioural changes of marine fauna to these discharges as an alternative food source is also likely to occur. The attraction of fishes and seabirds to organic food sources, microbial contamination and deposition and accumulation of solids leading to a decrease in sediment quality is anticipated.

Mitigation measures: Discharge water from showers, toilets, and the kitchen should be treated in an appropriate eluent treatment plant on-site. Minimise the organic waste from the kitchen as much as possible.

(b) Deck Drainage and Bilge Water

Impact Assessment: Deck drainage from offshore structures and ships mainly consists of water from precipitation and sea spray, water after equipment cleaning and fire drills. It may deck spilt materials such as oil, lubricants, detergents, drilling muds, cementing chemicals, etc., that have been. Water collected from machinery spaces in offshore facilities and support vessels is termed bilge water and may contain a mixture of water, oily fluids, lubricants, and cleaning fluids. The discharges mentioned above may have a detrimental impact to the ambient water and sediment quality by the input of metals (Fe, Cu, Mn, Pb etc.) and organic contaminants (hydrocarbons, surface-active substances, flame retardants etc.). Both inorganic and organic contaminants may pose significant environmental damage and accumulate in the aquatic food chain.

Mitigation measures: Management measures include; the use of vessels/ships with a valid International Oil Pollution Prevention Certificate; Chemicals storage areas are to be free from residues/spills, vessels to maintain an Oil Record Book, including the discharge of dirty ballast or cleaning water; discharge into the sea of oil or oily mixtures is prohibited except when the oil in water content of the discharge without dilution does not exceed 10 ppm; contaminated deck drainage and bilge water to be contained and treated prior to discharge in accordance the prevailing norms. Suppose treatment to this standard is not possible. In that case, these waters should be contained and shipped to shore for disposal and extracted hydrocarbons from oil-in-water separator systems to be stored in suitable containers and transported to shore for treatment and/or disposal by a certified waste oil disposal contractor.

(c) Cooling Water and Brine

Impact Assessment: Cooling water used to regulate or maintain the temperature in the production facility ultimately discharges into the sea can generate local temperature plumes. This eventually affects the native flora and fauna. The antifouling biocides mixed with this coolant water may invite significant environmental contamination. The brine discharged from on-site desalination plants may generate a saline plume over the region, and the brine also consists of lower concentrations of ant scale chemicals used in the desalination plant. Overall, the high temperature, salinity, and organic containments may substantially impact the native flora and fauna.

Mitigation measures: Appropriate coolant water and brine disposal locations should be selected after undertaking detailed dispersion modelling studies. A minimum dosage of biocides and other chemicals and the generation of minimum freshwater for the operational requirement is the major mitigation measures to be adopted in this regard.

(d) Hydrotest Water

Impact Assessment: Hydrotest water consists of filtered inhibited seawater containing chemicals, including mono ethylene glycol, triethylene glycol, biocides, corrosion inhibitor, scale inhibitor, dye, and oxygen scavengers. A temporary decline in water quality due to the discharge of oxygen-deficient water and toxic chemicals is noticed in connection with hydro-testing.

Mitigation measures: Hydro-testing at the onshore facility before the loading and installation of equipment in the offshore facility, minimising the quantity and the dosage of toxic chemicals of hydro-test water and sending this water to the onshore facility of treatment and discharge are the major mitigation measures that can be adopted when dealing with hydro-test water. The chemicals used for hydro testing must be easily biodegradable. Toxicity (96 hr LC50 > 30,000 mg/l for most abundant biota and IUCN red list organism as in table 6.12, if any) should be minimum as per the criteria, which can be discharged off-shore intermittently, at an average rate of 50 bbl/hr/well from a platform so as to have proper dilution & dispersion without any adverse impact on the marine environment.

(e) Produced Water

Impact Assessment: Produced water contains metals, suspended particles, particulate and dissolved hydrocarbons, fatty acids and other natural and synthetic organic compounds. It also contains trace concentrations of chemical additives like scale and corrosion inhibitors, hydrate inhibitors, etc. The type and location of reservoirs significantly influence the volume and composition of produced water. Produced water exhibits high temperatures due to geothermal heating. Produced water can be sent to onshore facilities for treatment and disposal or treated for disposal offshore either by reinjection into formation wells or discharge into the marine environment. When treated and discharged offshore, the potential impacts to the marine environment are dependent on a number of factors such as discharge volume, components of the produced water (i.e., metals and production chemicals), toxicity of the produced water, the dispersion of the produced water and the sensitivity of the marine environment. In summary, reduced water quality due to high concentrations of hydrocarbons, metals and other chemicals used in production and subsequent toxicity to marine flora and fauna as well as the thermal shock is the anticipated impact due to the discharge of produced water from the offshore facility.

Mitigation measures: The following mitigation and management practices should be followed to minimise the impacts:

- Adopt methods to minimise the quantity of produced water
- Recycle and re-use produced water
- Evaluate options for treatment and disposal, including ship to shore, re-injection or discharge offshore
- When disposal/re-injection should be done without the leakage of the disposed water
- Where disposal to the sea is necessary, all means to reduce the volume of produced water should be considered

- The produced water discharge outfall should be designed to maximise dispersion of produced water in the sea so as to reduce the concentration of constituents that have the potential for environmental impact
- Production chemicals should be selected carefully by taking into account their application rate, toxicity, bioavailability, and bioaccumulation potential.
- Periodic comprehensive assessment of the marine environment should be undertaken, and various management strategies should be employed depending on the levels of pollution due to the project activities.

(f) Ballast Water

Impact Assessment: Translocation and release of invasive marine species is expected due to the ballast water exchange operations in connection with the project activities. *Mitigation measures:* Strict compliance with local regulatory-authority guidelines should be ensured, and all the ships in international traffic are required to manage their ballast water and sediments in ballast tanks to minimise the risk of invasive marine species.

(g) Produced Sand and Scale

Impact Assessment: The anticipated environmental impacts associated with the treatment and disposal of produced sand and scale offshore are reducing water and sediment quality and seabed disturbance. These may pose substantial toxic effects to marine flora or fauna and displace the benthic flora and fauna.

Mitigation measures: The management strategies include transporting produced sand removed from process equipment to shore for treatment and disposal or routed to offshore injection disposal well if available. If discharge to the sea is the only feasible option, the discharge should meet the guideline stipulated for marine disposal. Any oily water generated from the treatment of produced sand should be recovered and treated to meet the guideline values for produced water.

(h) Drilling Discharges

Impact Assessment: Drilling activities normally generate drill cuttings, drilling muds (fluids) and cement. Drilling fluids are required to carry drill cuttings from the hole, cool and clean the drill bit, reduce friction, maintain bore stability and provide down-hole hydrostatic pressure. The ingredients of drilling fluids vary considerably. Water-based drilling fluids (Water-Based Muds) and non-aqueous drilling fluids (NADF) include oil-based and synthetic fluids/muds. Water-Based Muds may include seawater or freshwater based fluid, bentonite, barite, brine and gellents (e.g., guar gum or xanthum gum). Synthetic based muds (SBM) include a synthetic based fluid (which may consist of olefins, paraffin, or esters), organophilic clays, barite, fluid loss control agents, lime, aqueous chloride, rheology modifiers, bridging agents, and emulsifiers. The anticipated environmental impacts of drilling discharges include increased turbidity in the water column, displacement and loss of benthic organisms, and alteration of sediment particle size/texture. The changes in the marine environment's physical (mainly turbidity) and chemical characteristics (oxygen depletion, metals and organic contaminants) may pose serious toxicity to benthic and pelagic organisms.

Mitigation measures: The following mitigation measures are recommended to deal with the drilling discharges:

- Reduce the number of drilling wells and also reduce the generation of drill cuttings and drill fluids
- Use of appropriate drilling fluid components with minimum toxicity
- Recover drilling muds and return to the drill rig. Retain, store and transfer to shore for disposal of NADF
- Solids control equipment available on-board the drill rig to reduce the amount of residual drill fluids on cuttings prior to discharge
- The following guideline should be adopted if the sea disposal is unavoidable: The depth of water below the discharge outlet should be sufficient to allow acceptable dispersion of the cuttings to occur, bulk cement and additives discharge to be regulated.

4.2.4 Waste

(a) Process and Production Chemicals

Impact Assessment: A number of chemicals may be used during processing and production (please see section: produced water for details).

Mitigation measures: Usage of low toxicity and water-soluble control fluid, collect the waste fluid in closed systems and send to the onshore facility of treatment and disposal. Design of equipment to reduce the volume of fluid and acids should be neutralised before disposal. Use chemical systems in relation to their concentration, toxicity, bioavailability, and bioaccumulation potential.

(b) Hazardous Waste

Impact Assessment: Hazardous wastes such as solvents, spent chemicals, paint, oil adsorbents, medical wastes, waste oil, mercury removers and contaminated containers) would only enter the marine environment by an accidental loss or spill. Temporary reduction in ambient water quality, toxicity to marine organisms, damage and loss of benthic fauna due to the settlement of dense particles and entanglement, ingestion or smothering of floating materials by marine fauna is anticipated due to these accidental spills or discharge.

Mitigation measures: Segregation of hazardous waste in hazardous drums or tanks prior to disposal and hazardous waste should be managed, handled, and stored according to their Safety Data Sheet.

(c) Non-hazardous Solid Waste

Impact Assessment: This includes paper, rope, cardboard, sacking, timbers, scrap metal, packaging items and plastic. Ingestion or entanglement of materials (plastic and solid wastes) by marine fauna or avifauna potentially leading to injury or death, damage and loss of benthic fauna due to the settlement of dense particles, and deterioration in water quality are the anticipated impacts.

Mitigation measures: Proper segregation of wastes (recyclable and non-recyclable) and offshore disposal strictly adhering to the regulatory guidelines should be adopted.

4.2.5 Unplanned Events

(a) Accidental Release of Chemicals

Impact Assessment: Accidental releases of chemicals to the marine environment (water-based muds, non-aqueous drilling fluids cement, barite, bentonite, methanol, hydraulic fluids, paint, waste oil, detergents etc.) may result in the temporary decline in water and sediment quality which in turn detrimental to the marine flora and fauna.

Mitigation measures: Chemical spill containment and recovery equipment will be available near chemical inventories, chemical transfers are only undertaken in suitable weather conditions, and the vessels/drilling units have a valid International Oil Pollution Prevention Certificate. These are the major mitigation measures that can be adopted.

(b) Spills – Collision/Tank/Pipeline Rupture

Impact Assessment: Leaks and spills can occur in trough pipelines and tanks through which the hydrocarbons are stored and transported. Faulty design, corrosion and physical damage may invite spills or leaks. The grounding of a vessel or a collision with facilities, support vessels, offshore fishing and shipping vessels has the potential to result in the breach of the hull and subsequent rupture of a fuel tank. A major spill to sea as a result of vessel collision/grounding may occur. The following are the anticipated impacts due to such leakage and spill:

- Reduction in water and sediment quality
- Surface coasting of oil to marine megafauna and seabirds
- Potential toxic effects to marine biota
- The negative impact to other marine users due to the presence of surface oil layer

- Toxicity, bio-accumulation and bio-concentration of contaminants

Mitigation measures: Vessels should maintain suitable lighting, shapes, and navigation, at all times to inform other users of the position and intentions of the vessel, hydro testing to ensure leaks free in pipelines, protection of pipelines by trenching and burial is recommended.

(c) Spills during Refuelling and Bunkering

Impact Assessment: A reduction in water quality in the vicinity of the vessel and associated toxicity to flora and fauna is anticipated due to low levels of an oil spill during the refuelling and bunkering activities.

Mitigation measures: Mitigation measures should include:

- Refuelling to be conducted in port, where spill risk factors are more easily controlled
- Refuelling at sea to be undertaken by trained personnel using defined procedures, during daylight hours except where safety considerations take priority and when sea conditions are sufficiently calm
- Regular inspection of transfer hose integrity, limiting volumes of fuel held in the transfer hose and by the use of fail-safe valves to ensure rapid shutdown of fuel pumps
- Continuously monitor tank levels to prevent overflow

(d) Spills from Exploration and Production Facilities

Impact Assessment: The severity and extend of hydrocarbon spills strongly depend on the source and release locations, flow rates, spill duration, etc. A blowout can happen during exploration drilling and or during production phases. A blowout can occur due to the failure of existing technical well barriers. The anticipated impacts in connection with the release of hydrocarbons to the marine environment are: reduction in water and sediment quality, toxic or physiological effects on marine and coastal plants and animals, chemical contact with shoals/banks, reefs, and islands, at concentrations that result in adverse impacts, alteration of biological communities as a result of the effects on key marine biota, social impacts on commercial fishing, traditional and subsidence fishing, tourism, recreation, scientific research, health, and commercial shipping. *Mitigation measures:* Oil spill modelling or dispersion modelling should be undertaken to determine the potential impact to the surrounding environment; Blowout prevention measures to focus on maintaining wellbore hydrostatic pressure by effectively estimating fluid formation pressures and the strength of subsurface formations; well integrity testing should be performed; Well Operations Management Plan (WOMP), Well Control Contingency Plan (WCCP) should be in place. If well workover/intervention is required, well isolation barriers and well intervention procedures should be in place. Contingency plans should be prepared for well operations and should include identification of provisions for well capping, relief well drilling and other response measures, including plans for the mobilisation of resources, in the event of an uncontrolled blowout; Spill preparedness measures and emergency response procedures in place; Implementation of ongoing maintenance and inspection procedures to maintain facility integrity.

(e) Collision with Marine Fauna and Introduction of Invasive Marine Species

Impact Assessment: Collision with marine fauna blocks the feeding areas and migration pathways, and the seismic vessel equipment can cause entanglement with marine fauna.

Mitigation measures: Monitor for presence and movements of large cetaceans, pinnipeds, and turtles so that avoidance actions can be taken where marine fauna is observed on a collision course with vessels and the application of species-specific management actions to minimise adverse interactions; reduce the potential for entanglement of marine animals in the seismic equipment and rescue and release of entangled animals to the sea. Development of Invasive Marine Species Management Plan and Comply with the International Convention on the Control of Harmful Anti-Fouling Systems on Ships. Ensure vessels have a valid International Anti-Fouling System Certificate and regular inspections of the hull, including niche areas, cleaning, dry-docking, and regular renewal of anti-fouling coatings, should be adopted in this regard.

The following table (Table 4.2) summarises the potential impact on the marine environment due to the activities in the offshore Oil and Gas sector and its mitigation/protection measures

Table 4. 2 Environmental protection and mitigation measures

Activity	Source of the potential impact	Environmental protection measures
Seismic operations (offshore)	Seismic equipment	•Use environmental assessment to identify protected areas and local sensitivities—scheduled operations during the least sensitive period.
	Vessel Operations	•Consult local authorities and other stakeholders regarding survey programme, permitting and notifications. •Remain on the planned survey track to avoid unwanted interaction. •Dispose of all waste materials and oily water properly to meet local, national and international regulations (Refer to MARPOL). •Apply proper procedures for handling and maintenance of cable equipment, particularly cable oil. •All towed equipment must be highly visible. •Make adequate allowance for deviation of towed equipment when turning. •Prepare contingency plans for lost equipment and oil spillage (see IMO guidance Shipboard Oil Pollution Emergency Plans 1992). •Attach active acoustic location devices to auxiliary equipment to aid location and recovery. •Label all towed equipment. •Store and handle explosives according to

		operators procedures and local regulations. •Consider using a guard boat in busy areas. •Report all unplanned interactions with other resource users or marine life to the authorities. •Use local expertise to support operations e.g. spotting marine mammals, wildlife etc.
Exploration and appraisal drilling (offshore)	Site selection	•Use environmental assessment to identify protected areas and sensitivities—schedule operations during least sensitive periods. •Consult with local authorities regarding site selection and support infrastructure-ports, vessel and air traffic. •Select a least sensitive location within confines of bottom target/drilling envelope. Consider directional drilling to access targets beneath sensitive areas. Consider cluster well drilling. •Local conditions must be fully assessed-wave, wind and currents. •In coastal areas, select sites and equipment to minimize disturbance, noise, light and visual intrusion.
	Access	•Exercise strict control on access and all vessel and rig activity. •In coastal areas where sensitivities dictate use vessels in preference to helicopters.
	Operations	•Consult with local authorities regarding emissions, discharges and solid waste disposal/notifications in regard to other resource users •Requirements specified in planning process must be met, including supply vessel operations. •**Aqueous discharges.** Oily water from deck washing, drainage systems, bilges etc. should be treated prior to discharge to meet local, national and international consents.

		• Sewerage must be properly treated prior to discharge to meet local and international standards. • Treatment must be adequate to prevent discolouration and visible floating matter. • Biodegradable kitchen wastes require grinding prior to discharge if permitted under local regulations. • Most spills and leakage occur during transfer operations ensure adequate preventative measures are taken and that spill contingency plan requirements are in place. • Store oils and chemicals properly in contained, drained areas. Limit quantities stored to a minimum level required for operational purposes. Ensure proper control documentation and manifesting and disposal. Do not dispose of waste chemicals overboard. • Produced water from well tests must meet local regulations or company specified standards prior to discharge. • Preferentially separate and store oil from well test operations. If burnt, ensure burner efficiency is adequate to prevent oil fallout onto sea surface. • **Solid wastes.** Ensure requirements specified in the planning process are met with regard to waste treatment and disposal. • Collect all domestic waste and compact for onshore disposal. Ensure proper documentation and manifesting. Ensure onshore receiving and disposal meet local requirements. • Consider waste segregation at source for different waste types—organic, inorganic industrial wastes etc. • No debris or waste to be discarded overboard from rig or supply vessels. • Waste containers must be closed to prevent loss overboard.

		• Spent oils and lubes should be containerized and returned to shore. • Consider bulk supply of materials to minimize packaging wastes. • **Muds and cuttings.** Preferentially use low toxicity water-based drilling muds. Minimize use of oil-based muds (OBM). • Mud make-up and mud and cuttings disposal requirements addressed in the planning process must be met. • Do not dispose of whole OBM to sea. Any oily cuttings discharged must meet local regulations or company specified standards • Consider downhole disposal of OBM wastes. • **Atmospheric emission/noise/light**. Ensure requirements addressed in the planning phase are met with regard to emissions, noise and light. • Well test burners must be efficient, maintained and effectively burn gas and oil. • H_2S emissions must be effectively controlled.
	Decommissioning and restoration	• All debris must be removed from seabed. • Decommissioning of onshore support facilities must meet planning requirements.
Development and production (offshore)	Site selection and access	• Long-term occupation of sites, including supply and support base, will require detailed assessment of environmental implications, particularly where resource use conflicts arise and commercially important species may be affected. • All aspects identified for exploration drilling should be applied to permanent sites. • Consult with local authorities. • Consider site and route selection for flowlines and pipelines.

	Operations	• Evaluate construction and drilling activities and impacts separately from operational activities. • Maximize use of central processing facility and use of satellite and cluster wells to minimize footprint. • All aspects identified for exploration drilling should be applied to permanent sites. • Consult with local authorities. • Assess full implications of well treatment and workover, process, storage, power generation and other support and accommodation facilities in terms of long-term disturbance and impact. • Evaluate implications of development on local infrastructure, in particular, infrastructure related to onshore service functions-port and harbour operations, resource use conflicts, waste treatment and disposal, socio-economic implications, employment, local services and supply, support infrastructure for employee and family accommodation. • Incorporate oily water treatment system for both produced water and contaminated water treatment to meet local, national and international discharge limits. • Include sewerage treatment system, particularly if close to shore, to meet local requirements. • Assess treatment of waste gases and emission limits, particularly where gas is flared. Avoid gas venting. • Treatment and disposal of solid, toxic and hazardous wastes onshore will require proper planning, particularly if local infrastructure is limited in capacity and capability. A detailed waste management plan will be required. • Prepare detailed contingency plans, personnel training and regular exercise of response, taking into consideration storage

		and export systems. • Establish consultation and local liaison activities. • Monitor waste streams in order to meet compliance requirements.
	Decommissioning and rehabilitation	• Develop a full decommissioning and rehabilitation plan in consultation with local authorities. • Any facilities and infrastructure handed over to local authorities must include proper instructions for use, maintenance, and proper training procedures. • Decommissioning of offshore structures is subject to international and national laws and should be dealt with on a case by case basis with local authorities. • Record and monitor site as required after appropriate decommissioning activities

Chapter 5: Environmental Monitoring Programme

5.1 Introduction

The primary aim of the environmental monitoring program is to formulate a systematic, site-specific plan for monitoring the environmental parameters within the impact area, during and after commissioning of the project, which would aid in assessing the effectiveness of mitigation and environmental protection measures implemented for the proposed project based on the existing environmental scenario and the probable environmental impacts appraisal. The efficacy of the mitigation measures being followed during production to decommissioning phases of the project can be assessed, and the measures can be revised, made more stringent and reinforced based on the monitoring results. The environmental attributes to be monitored during production to decommissioning phases of the project, specific description along with technical details of environmental monitoring including the monitoring parameters, methodology, sampling locations and frequency of monitoring are presented following section of this chapter

5.2 Objectives

- Ensure day-to-day operational activities are conducted in a manner in compliance with the applicable regulatory approvals.
- Evaluate the adequacy of mitigation and pollution control measures implemented for reducing the adverse impacts caused during the construction and operation stage and suggest additional mitigation measures, if appropriate, in light of the results.
- Define a detailed framework to monitor and document for achieving full compliance with statutory requirements.
- Encourage good environmental management practices through planning, commitment, and continuous improvement.
- Develop a clearly defined environmental monitoring program designed to assess the nature and extent of environmental impacts of the proposed operations and progressively refine such programs against the target.

- Define the roles and responsibilities of site personnel and ensure that all people on site are fully informed of their responsibilities and accountabilities concerning the environment.
- To comply with all regulations stipulated by the Central Pollution Control Board (CPCB)/ State Pollution Control Board (SPCB) related to air emission and liquid effluent discharge as per air and water pollution control act/ laws.
- Review, improve and update environmental management procedures and standards.
- The efficacy of the mitigation measures being followed during production to decommissioning phases can be assessed, and the measures can be revised, made more stringent and reinforced based on the monitoring results.
- Establish response procedures for actual/potential environmental impacts, including community complaints, and ensure corrective action.
- Perspective budgeting and allocation of funds for environmental management expenditure, Continuous development, and search for innovative technologies for a cleaner and better environment.

5.3 Purpose of offshore environmental monitoring

The purpose of offshore environmental monitoring is to provide an overview of the environmental status and trends over time seen concerning offshore oil and gas activities. Monitoring is intended to indicate whether the environmental status of the offshore oceanic environment is stable, deteriorating or improving, due to operators' activities. In addition to identifying trends, the results are to as far as possible provide a basis for projections for future developments. Overall, the environmental monitoring contributes to describing to what degree a station or a wider area around an installation or in a region is impacted because of discharges from oil and gas activities. It is important that results from offshore environmental monitoring can be used to verify predictions and conclusions of the environmental impact assessment study for the respective field or the region. Environmental monitoring of offshore oil and gas activities includes monitoring the water column and benthic habitats (sediments, soft-bottom fauna and hard-bottom fauna).

Operators and authorities use monitoring results as

• A source of information and as grounds for decision making regarding new measures to be implemented offshore.

• Input for developing and reporting on national environmental indicators for the offshore oil and gas industry

Environmental monitoring can be defined as the systematic sampling of air, water, sediment, and biota to observe and study the environment and derive knowledge from this process. Monitoring can be conducted for a number of purposes, including to establish environmental "baselines, trends, and cumulative effects", to test environmental modelling processes, to educate the public about environmental conditions, to inform policy design and decision-making, to ensure compliance with environmental regulations, to assess the effects of anthropogenic influences, or to conduct an inventory of natural resources. Environmental monitoring can be achieved on biotic and abiotic components of any of the Earth spheres, as shown in figure 5.1. It can help to detect baseline patterns and patterns of change in the *inter* and *intra* process relationships among and within these spheres. The interrelated processes that occur among the five spheres are characterised as physical, chemical, and biological processes. The sampling of air, water, and soil through environmental monitoring can produce data that can be used to understand the state and composition of the environment and its processes.

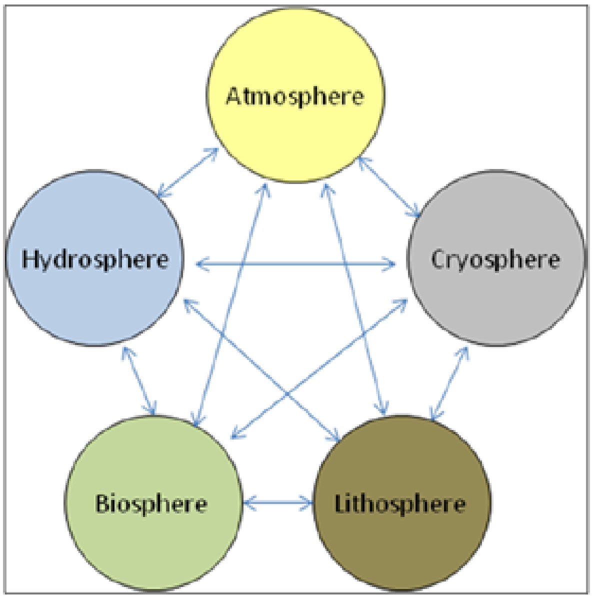

Figure 5. 1 *Inter* and *intra* process relationships among various components in the EIA process

Environmental monitoring has increased and become more sophisticated as concerns around the ecological impacts of offshore drilling and production have grown. Environmental monitoring is now integrated into the full life cycle of an offshore oil field, from early seismic evaluations through production to decommissioning. Traditionally, water column analyses and physical, chemical and biological analyses of sediments have composed the basic elements of an environmental monitoring program. These analyses have often been coupled with dispersion modelling assessments that estimate the spatial footprint of drilling and production discharges within the water column and on the seafloor. More recently, new technologies are becoming part of the environmental monitoring toolbox. These include subsea chemical and physical sensors attached to subsea landers, remote observational vehicles equipped with video, sensor and sampling capabilities, whole effluent toxicity testing, and biomarkers in organisms caught or caged within the oilfield.

5.4 Environmental monitoring applied to offshore Oil & Gas platforms

The environmental monitoring data needs of an offshore oil & gas project are dependent on the local regulatory regime, company-specific requirements and the environmental sensitivity of the project in terms of location and project activities. Environmental monitoring programmes should be “Fit for purpose”. Oil & gas projects differ in size, complexity and environmental sensitivity, and these factors should be taken into account when deciding on a monitoring programme. For instance, a single exploratory well with no evidence of significant surrounding biological communities does not require the same level of assessment as a 20 developmental well programme near sensitive marine habitats and resources. A heterogeneous area will also require a more comprehensive monitoring programme than a homogeneous one. Environmental monitoring programmes are often conducted as part of a project’s environmental impacts assessment (EIA). It includes a characterisation of the area of interest, including regional and local biodiversity, locations of sensitive habitat and resources, and other users of the resource, e.g. commercial and artisan fishing. Offshore environmental monitoring supports the objectives of the EIA by generating specific environmental information at the site of interest to understand the baseline conditions. Baseline surveys enable an operator to identify sensitive marine communities prior to field development and take action to avoid or minimise impacts. Surveys can also be conducted to monitor any changes to the marine environment during the project's life cycle. These efforts often require data collection on the physical, chemical and biological properties of the water column and sediments.

5.5 Sampling strategy

During production operations, operational discharges occur, which will impact the water column; hence, monitoring may be appropriate. Monitoring the water column compartment generally focuses on effects from continuous rather than occasional activities. When discharges cease, effluent concentrations in the water column often decrease quickly, subsequently reducing impacts very rapidly. When assessing ecological impacts in the water column, field assessments generally focus on chemical and physical analyses of the receiving water. In special cases, biota, e.g. free-swimming fish or caged organisms, may be sampled to assess potential bioaccumulation. Whole effluents discharged from offshore facilities are also routinely monitored. Oil and grease is the most common analyses measured. Discharges are also often analysed for heavy metals, specific hydrocarbons, salinity and other constituents. In some countries, effluent toxicity of discharges is evaluated using standardised bioassays. With an understanding of the dilution of a discharge, these whole effluent data can be extrapolated to determine whether there is the potential for receiving water impacts.

The sediment compartment is a sink for many contaminants in the marine environment. Solids that enter the water column, through either disturbance of seabed sediments or through the discharge of waste solids, may be transported from the site of discharge. Soluble materials that enter the water column may precipitate due to chemical changes or adsorb to natural sediment particles present in the water column. Precipitated materials or sediment particles with adsorbed contaminants then settle on the seabed, where they may directly affect benthic communities or indirectly affect water column organisms. Although marine processes can redistribute and dilute solids that settle to the seabed, particularly in shallow water, the sediment compartment has a strong tendency to accumulate particles and associated contaminants over time. Potential sediment impacts are often monitored as described in Table 5.1. When assessing ecological impacts on the seafloor, field assessments generally focus on the populations of sediment-dwelling fauna. Sediment dwelling organisms can be reliable and sensitive indicators of habitat quality. This is because they live in bottom sediments where exposure to contaminants and oxygen stress are most frequent. They are also effective indicators of local conditions because they have limited mobility and cannot migrate to avoid stressful situations.

Table 5. 1 Factors affecting impacts of oil & gas projects on sediments

Parameters	Description
Physical	Particle size distribution
Chemical	Sediment concentrations of metals and hydrocarbons
Biological	Number and distribution of benthic organisms

5.5.1 Site selection plan for sampling

One of the first steps in conducting an offshore environmental sampling study is to develop a site sampling plan. The plan identifies the location and number of stations, sampling methodologies and analytes to be measured. The location and number of stations should also be related to the project objective, activity, and development size. When available, bathymetry and met-ocean data should be used to define sampling locations. Dispersion modelling may also be useful in selecting sampling sites by predicting the deposition of constituents. Attention should be given to understanding previous and current activities in and around the study area and how these activities may influence the obtained results. A typical sampling programme (Figure 5.2) should include at least one reference station, measurement stations that reflect presumed gradients and stations that resect potential nearfield and far-field impacts. This type of programme should allow comparison between affected and unaffected sites and discern between project-related impacts and natural variation. When possible, the sampling design should be adequately robust to allow for statistical analysis of the data.

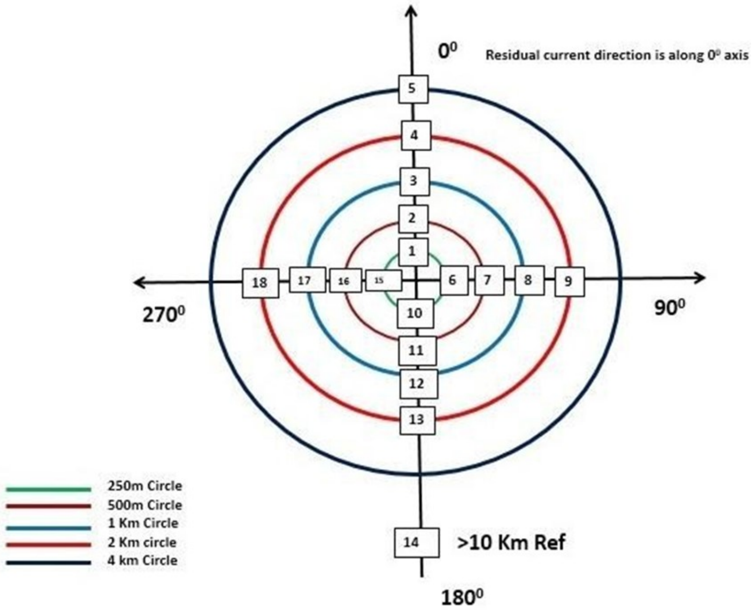

Figure 5. 2 Sampling Strategy

5.5.2 Sampling

Selection of methods used to collect water column or sediment samples for environmental monitoring should be guided by the project phase and the type of survey to be carried out, for example, a baseline study, a trend study or compliance monitoring, and the objectives of each study. Video and photographic monitoring techniques can also be used.

5.5.3 Water column sampling

Measurements of bulk water column variables such as temperature, turbidity, conductivity/ salinity and dissolved oxygen may be carried out on discreet samples but can also be measured using multi-parameter probes. Sensor technology has advanced so many parameters can now be continuously measured by specialised instruments (e.g. CTD with rosette water sampler) deployed at the seafloor. The measurement of concentrations of substances of presumed concern, such as trace metals, frequently poses significant analytical challenges due to their occurrence at trace levels. However, sensitive analytical methods have been established that allow for accurate detection of these substances both in sediments and the water column. In some environmental research projects, semi-permeable membrane devices (SPMDs) or baskets containing live bivalves have been deployed around offshore facilities to assess the presence of polyaromatic hydrocarbons in the receiving water. SPMDs and bivalves accumulate (concentrate) the lipophilic hydrocarbons, which allow for the chemical analysis below conventional analytical detection limits. The suite of analytes to be measured is determined by the objectives of the monitoring programme (and which may include national regulatory requirements). Examples of monitoring parameters are included in Table 5.2. Water should be collected and sampled as specified by the applicable analytical protocol.

5.5.4 Biological water column sampling

Depending on the purpose of the survey, marine organisms may be sampled to assess possible adverse effects on their health. These organisms can either be feral or caged. Sampling can also be performed to measure the fitness of marine products for human consumption (USEPA, 2000).

5.5.5 Sediment sampling

The choice of methods for sediment sampling is influenced by the sediment characteristics (where known), the type of measurement(s) to be made on the sample, the water depth (size of macrofauna relative to water depth may affect sieve size), and the amount of sediment needed for the analyses of interest. Surface deployed equipment for collecting sediment samplings includes various grab-type, box or multicore samplers. The multi-corer/spade corers/box corers can be used to take undisrupted sediment samples from the seabed. Sediment cores can also be obtained using remotely operated vehicles (ROV). This approach provides the advantage that the location to be sampled can be selected with precision, e.g. pre- and post-drill sampling. The required amount of sediments varies according to the type of measurement being made. Physiochemical analyses require approximately $0.1m^2$ of sediment (to a depth of 10 cm) per sample, whereas analyses of the community structure of macrofauna require a larger sample, e.g. $0.3\text{-}0.5m^2$ to a depth of 10cm, in order to ensure that sufficient biomass of organisms is collected to provide the basis for a representative count. Samples taken for characterisation of benthic biological community structure are usually processed by washing in a sieve with seawater to remove sediment particles and isolate the biota. The sieve mesh size should be determined by the type of organisms and ecosystems of interest. Benthic macrofauna is the usual focus of these assessments. Organisms<0.5mm are classed as benthic meiofauna and are not usually evaluated in offshore survey

5.5.6 Sample storage and preservation

Sampling plans should specify the type of container, storage conditions and maximum holding times for each type of analysis. Sample containers should be clean and properly stored to avoid contamination. For the water column monitoring, the tissue samples must be taken and prepared onboard the boat immediately after the organisms are brought onboard. Sediments sub-sampled for chemical analyses are stored in containers appropriate for measurement, e.g., glass jars for organic compound analyses and plastic jars for metals analyses. Biota samples should be appropriately preserved and stained to facilitate later analyses. A frequently used approach is to chemically preserve the organisms and stain them with 'Rose Bengal'. Storage and preservation conditions e.g. refrigeration and maximum holding times, should be specified based on the target analyte and method.

5.6 Quality assurance and quality control

Quality assurance and quality control (QA/QC) procedures are used in environmental monitoring programs to ensure that the results obtained will meet the project's technical and business objectives. Documentation of the steps taken to ensure that the desired data quality is achieved is necessary to provide initial users with confidence in the reliability of the results. Although programme objectives and resources may sometimes limit the QA/QC procedures applied, adherence to accepted standards of quality and control, including chain of custody documentation, sampling storage requirements and holding times, and to the practice of conducting measurements according to established QA/QC guidance will maximise the long term usability and value of monitoring data (ISO/IEC 17025:2005; and USEPA 2008).

5.7 Defining Data Statistics/Analyses Requirements

The data analyses to be conducted are dictated by the objectives of the environmental monitoring program. The statistical methods used to analyze the data should be described in detail prior to data collection. This is important because repetitive observations are recorded in time and space. Besides, the statistical methods could also be chosen so that uncertainty or error estimates in the data can be quantified. For e.g., statistical methods useful in an environmental monitoring program include: 1) frequency distribution analysis; 2) analysis of variance; 3) analysis of covariance; 4) cluster analysis; 5) Abundance and Biomass Curve; 6) Diversity Index; 7) multiple regression analysis; 8) time series analysis; 9) Application of statistical models (ADB- Green, 1979).

5.8 Subsea monitoring technologies

Lander systems (or multi-sensor platforms), such as remotely operated vehicles (ROVs) are examples of surveillance technologies. Marine scientists and industry are increasingly employing them to couple traditional environmental data gathering approach with multi-sensor probes, computing and communication instrumentation. They also often include photographic and video capabilities. Landers and ROVs are normally equipped with cameras and bathymetric monitoring equipment. Landers can also carry physical/chemical sensors that measure temperature, salinity, turbidity, oxygen and chlorophyll-a. Some ROVs are also capable of taking sediment core samples. Some of the key advantages of these technologies include: Allow a large number of assessments to be made over a wide temporal and spatial area and track natural seasonal and global changes—possibility for real-time measurements, dependent on the setup. Photographic surveys are non-invasive and provide material that is both useful to scientists and understandable by public audiences.

5.9 Use of Secondary Data

The program for EIA can at best address temporal and/or spatial variations limited to a limited extent because of cost implications and time limitations. Therefore analysis of all available information or data is essential to establish the regional profiles. So all the relevant secondary data available for different environmental components should be collated and analyzed.

5.10 Environmental modelling to support monitoring plans

Technology advances in predictive modelling allow better predicting the fate, effects and risk of offshore discharges and emissions. While models do not substitute for site-specific environmental data, they often reduce the field data necessary to make a sound technical assessment. They are also useful to help focus on the most critical aspects of a site-specific assessment and thereby pinpoint where environmental data needs to be collected. Environmental modelling offshore has generally focused on produced water and drilled cuttings discharges. Discharge modelling of produced water and drilled cuttings models estimate the vertical and horizontal distribution of the produced water outfall and cutting on the seafloor, respectively. Several models are presently available for evaluating the dispersion of produced water discharges.

These models have numerical fate modules which compute the physical dispersion and biogeochemical transfer of chemical compounds in the marine environment based on physical and chemical characteristics of the compounds (produced water discharge) and local conditions, such as salinity, currents and winds. Unlike produced water, drilling muds and cuttings settle on the seafloor and can sometimes persist for extended periods of time. Dispersion modelling is an important tool when estimating the size of the drilling discharge footprint on the seafloor. In addition, there is MUDMAP (ASA, US), which was specially developed to predict the transport and dilution of drill fluids. Cuttings dispersion is dependent on drill cuttings volume discharged, cuttings density, water depth and currents.

5.11 Reporting

Visual surveys are a relatively recent development when it comes to offshore environmental monitoring. Guidelines and requirements for reporting may change as more surveys are carried out and more experience of this method is gained. Some points that should be included in the reports are listed below, but these are to be considered as suggestions since the methodology is still being tested. The target group for the report includes the oil and gas companies, environmental authorities, research institutions and consultancy firms.

- Field methodology and execution;
- Analytical parameters;
- Methods used for data analysis and quality assurance
- Results and conclusions of the survey;
- Issues that should be given priority in future surveys;
- Assessment of the analytical methods and proposals for improvements.

Contents

The summary should include:

- A short description of the purpose for the survey
- A description of the fieldwork and the methods used
- The most important results and discussion (shown in figures and tables if necessary)
- The most important trends and comparisons with any earlier surveys or between this year's surveyed areas
- Conclusions and recommendations.

Structure of Environmental Monitoring Report

a) *Introduction*

The following should be described for the surveyed area(s):

- Description of the area

- Field history and plans for the future
- Earlier surveys summed up (table);
    - o Results from acoustic mapping, if available
    - o Biological investigations, if available.

b) Methods

The methods section should include the following:

- Map with coordinates, map scale, depth contours, etc.;
- Reasons for the choice of stations/survey lines;
- Brief description of the completed field program, including time frame for conducting the survey, number of stations or surveyed areas, equipment, positioning system, any problems or deviations from the survey program, with reasons;
- Description of equipment used
- Description of survey route (description of sampling design, map over and length of survey lines)
- Description of methods used to characterize benthic communities, including calculations and diversity, dominance etc., as well as methods for comparing the faunal structure to relevant environmental parameters (such as incidence of trawling tracks),
- Principles for quality assurance routines in the field (brief if the consultancy firm is accredited for the analysis in question);
- Accreditation status and proof if applicable (to be included in an appendix);
- Where and how the processed material (video material, still images, databases) is stored, responsibility for the material, results, and availability.

Results and discussion

- This chapter presents the results of the survey and discusses them in light of the survey's objective. Relevant findings should be summarized and presented in maps and tables, including relevant information on type of substrate, topography, fauna characteristics and anthropogenic impact for the field. Reference to the utilized map datum must be included in maps. Findings of redlisted / OSPAR habitats or other potentially vulnerable habitats should be specified (preferably with geographic position).

Overall evaluation and conclusions

- The chapter should contain a brief summary of the main findings and any concluding comments regarding the environmental status in the individual fields.

Recommendations

- An evaluation of the survey and of the analytical methods used should be conducted.
- Comments and proposals for improvements should be discussed, as well as recommendations to perform further surveys if results of the present survey indicate such a need.

Summary and application of results

- This report provides guidance to offshore operators on when and how to conduct an environmental monitoring programme. Environmental monitoring can be driven by regulatory requirements as well to meet internal environmental requirements and stewardship expectations. Whatever the objective, there is value in applying the consistent, science-based methodologies discussed in this report. Some of the key considerations surmised in this document include:
- Use established and consistent methods when conducting assessments to allow comparison in time and space.
- Employ a scientifically sound study design to discern significant changes from environmental variability, account for overlapping inputs from neighbouring wells and facilities and recognize that data needs change through the lifecycle

of an offshore project. Consider new monitoring technologies such as biomarkers and the use of fixed or mobile subsea sensor platforms such as landers and ROVs.

- Use modelling to better design a sampling plan and optimise the amount of field data necessary to make a sound technical assessment.

5.12 Change Management

Once the common assessment method is defined and specific ones (per habitat and pressure type), compatible monitoring programmes need to be in place to produce relevant data. There are currently many gaps in the methods, ongoing relevant monitoring and data availability, to assess or even test for all habitats and pressure types. Figure 5.3 highlights data flows that will have to be established according to the policy on data sharing of each network and institution to each habitat and pressure types to be assessed.

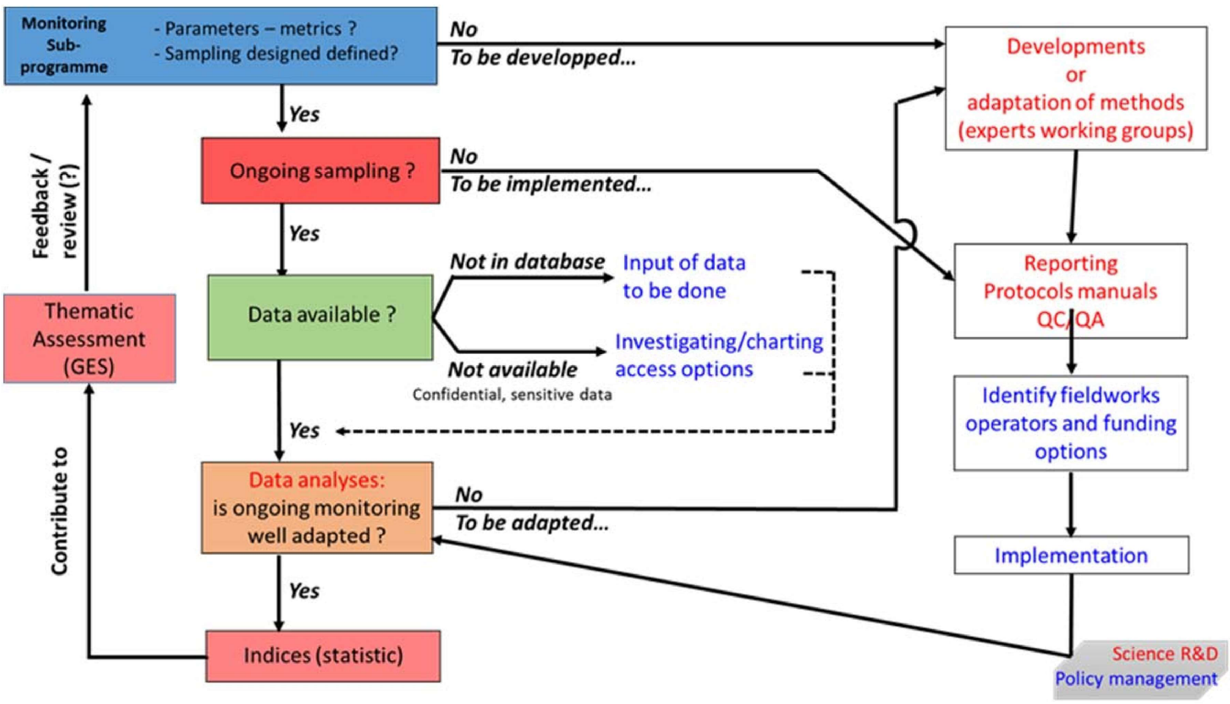

Figure 5. 3 Technical processes to implement an operational thematic assessment at an indicator or more integrated levels.

Table 5.2a Permissible Limit of effluent discharge and the oil content related to the Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles in the Indian EEZ

S.No.	Parameter	Offshore discharge standards
1	pH	5.5-9.0
2	Temperature	Ambient ± 3 ^{o}C
3	Suspended Solids	100 mg/l
4	Oil and Grease	10 mg/l – 40mg/l*
5	Cyanides	0.005 mg/l
6	Fluorides	1.5 mg/l
7	Chromium(Cr)	0.1 mg/l
8	Copper	0.05 mg/l
9	Lead	0.05 mg/l
10	Mercury	0.01 mg/l
11	Zinc	0.1 mg/l
12	Nickel	0.1 mg/l

*Discharge of effluents, the oil content of the treated effluent without dilution shall not exceed 40 mg/l for 95% of the observation and shall never exceed 100 mg/l. Three 8–hourly grab samples are required to be collected daily, and the average value of oil and grease content of the three samples shall comply with these standards.

Table 5.2b Permissible Limit/baseline values of water column and sediment parameters related to the Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles in the Indian EEZ

	Parameters	Sedimentary Basin							
		Gujarat	Saurashtra	Mumbai	Kerala Konkan Lakshadweep	Cauvery	KG	Mahanadi	Andaman Sea
Water	pH	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5	7.5-8.5
	BOD (mg/l)*	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0	≤ 3.0
	NO_3^- (µM)*	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0
	PO_4^{3-} (µM)*	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5
	Cr (µg/l)	ND	ND	0-29.1	ND	ND	1.0-7.0	0-0.1	<0.01
	Cu (µg/l)	ND	ND	0-29.7	0.2-6.2	0-0.5	33.9-65.9	ND	<0.01
	Zn (µg/l)	ND	ND	0-31.4	0.9-17.2	0.3-1.3	0.6-10.5	ND	<0.01
	As (µg/l)	ND	ND	0-31.2	ND	ND	42.0-70.4	0.-0.1	<0.01
	Cd (µg/l)	10.0	10.0	10	10.0	10.0	10.0	10.0	10.0
	Ba (µg/l)	ND	ND	0-27.6	ND	ND	3.9-6.1	ND	ND
	Pb (µg/l)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	Hg (µg/l)	10.0	10.0	10.0	10.0	10.0	10.0	10.0	10.0
	PHC (µg/l)	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0	<15.0
Sediment✦	Cr (µg/g)	≤ 81.0	≤ 81.0	≤ 81.0	≤ 81.0	≤ 81.0	≤ 81.0	≤ 81.0	≤ 81.0
	Cu (µg/g)	≤ 34.0	≤ 34.0	≤ 34.0	≤ 34.0	≤ 34.0	≤ 34.0	≤ 34.0	≤ 34.0
	Zn (µg/g)	≤ 150.0	≤ 150.0	≤ 150.0	≤ 150.0	≤ 150.0	≤ 150.0	≤ 150.0	≤ 150.0
	As (µg/g)	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2
	Cd (µg/g)	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2	≤ 1.2
	Ba (µg/g)	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2	≤ 8.2
	Pb (µg/g)	≤ 46.7	≤ 46.7	≤ 46.7	≤ 46.7	≤ 46.7	≤ 46.7	≤ 46.7	≤ 46.7
	Hg (µg/g)	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15	≤ 0.15
	PHC (µg/g)	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0	≤ 5.0

ND = No Data

*Surface values

✦Permissible limit for heavy metals in the sediments is prepared based on the Sediment Quality Guidelines (SQGs) developed by the National Oceanic and Atmospheric Administration (NOAA). This criterion is recommended due to the paucity of data sets in the Indian EEZ and also considering the large data variability within the basin.

Water quality standards for coastal waters and marine outfalls by CPCB is adopted for BOD, Hg, Pb, and Cd. The above limits are based on the data sets available in the Indian EEZ, and values should be revised incorporating future baseline environmental monitoring. An environmental survey should be carried out prior to the award of blocks to various operators, and the corresponding data sets should be included as the permissible limit of that particular block.

Table 5. 3 Guidance for the assessment of baseline components and attributes

Attributes	Sampling		Measurement Method	Remarks
	Network	Frequency		
A. Meteorological parameters				
Meteorological ▪ Wind speed and direction ▪ Barometric pressure ▪ Dry bulb temperature ▪ Wet bulb temperature ▪ Relative humidity ▪ Rainfall ▪ Solar radiation	One at the project site	Hourly observations - continuous records during the monitoring period	Mechanical/automatic weather station	IS 5182 Part 1-20 Sit-specific primary data is essential Secondary data from IMD, New Delhi, for the nearest IMD station
Attributes	Sampling		Measurement Method	Remarks
	Network	Frequency		
B. Noise and vibration				
Hourly equivalent noise levels	One location in the study area	At least one day continuous in a year on a working and non-working day during monitoring period	Instrument: Sensitive Noise level meter (preferably recording type)	Min: IS: 4954- 1968 as adopted by CPCB

Attributes	Sampling		Measurement Method	Remarks
	Network	Frequency		
C. Water Environment				
▪ Temperature & Salinity ▪ Turbidity ▪ Currents ▪ Dissolved Oxygen ▪ pH ▪ Nutrients (NO_3^-, NO_2^-, SiO_4^- and PO_4^{3-}) and Ammonia ▪ Dissolved Petroleum hydrocarbon ▪ Dissolved Heavy Metals	One sample from surface mid and bottom at each station (See the sampling diagram for each well)	Process-wise or activity-wise. Once per year (pre or post-monsoon)	Collected and analyzed as per protocol	The purpose of impact assessment on water (offshore environment) is to assess the significant impacts due to leaching of wastes or accidental releases and to contaminate

Attributes	Sampling		Measurement Method	Remarks
	Network	Frequency		
D. Solid Waste – Sediment Quality				
▪ Munsell Soil Colour Chart System and smell ▪ Particle size distribution ▪ Organic Carbon ▪ Heavy metal ▪ PHC	Grab and Composite samples. Recyclable components have to be analyzed for the recycling requirements	Process wise or activity-wise. Once in a year	Analysis IS 9334 : 1979 IS 9235 : 1979 IS 10158 : 1982	Impacts of hazardous waste should be performed critically depending on the waste characteristics and place of discharge.
E. Biological Environment				
Aquatic ▪ Primary productivity ▪ Aquatic weeds ▪ Bacteria, Phytoplankton, zooplankton and benthos ▪ Fisheries ▪ Heavy metals and PHC in mixed plankton and fish ▪ Diversity indices ▪ Trophic levels ▪ Rare and endangered species	Considering the probable impact, sampling points and number of samples to be decided on established guidelines on ecological studies based on-site eco-environment setting within 10 km radius from the proposed site	Process wise or activity-wise. Once in a year	Standards techniques (APHA et. Al. 1995, Rau and Wooten 1980) to be followed for sampling and measurement	Sampling for aquatic biota Plankton net Sediment dredge Depth sampler Microscope Field binocular Preliminary assessment Microscopic analysis of plankton and

▪ Sanctuaries / National park / Biosphere reserve				meiobenthos, studies of macrofauna, aquatic vegetation and application of indices, Heavy metals & PHC in mixed plankton and fishes Abundance and Biomass Curve Diversity, Shannon, similarity and dominance indices
Avifauna ▪ Rare and endangered species ▪ Sanctuaries / National park / Biosphere reserve	For the studies, chronic as well as short-term impacts should be analysed, warranting data on microclimate conditions			Secondary data to collect from Government offices, NGOs, published literature

Chapter 6: Additional Studies

6.1 The Risk Assessment

Risk assessment is the fundamental component of the risk management process. The definition of risk management is it is a process of identifying, analysing, assessing, and communicating risk and accepting, avoiding, transferring or controlling it to an acceptable level considering associated costs and benefits of any actions taken (DHS, 2010); one may notice that the foundation for a sound decision making is given by identifying, analysing, assessing and communicating the risks. And these are, in fact, the pillars of the risk assessment.

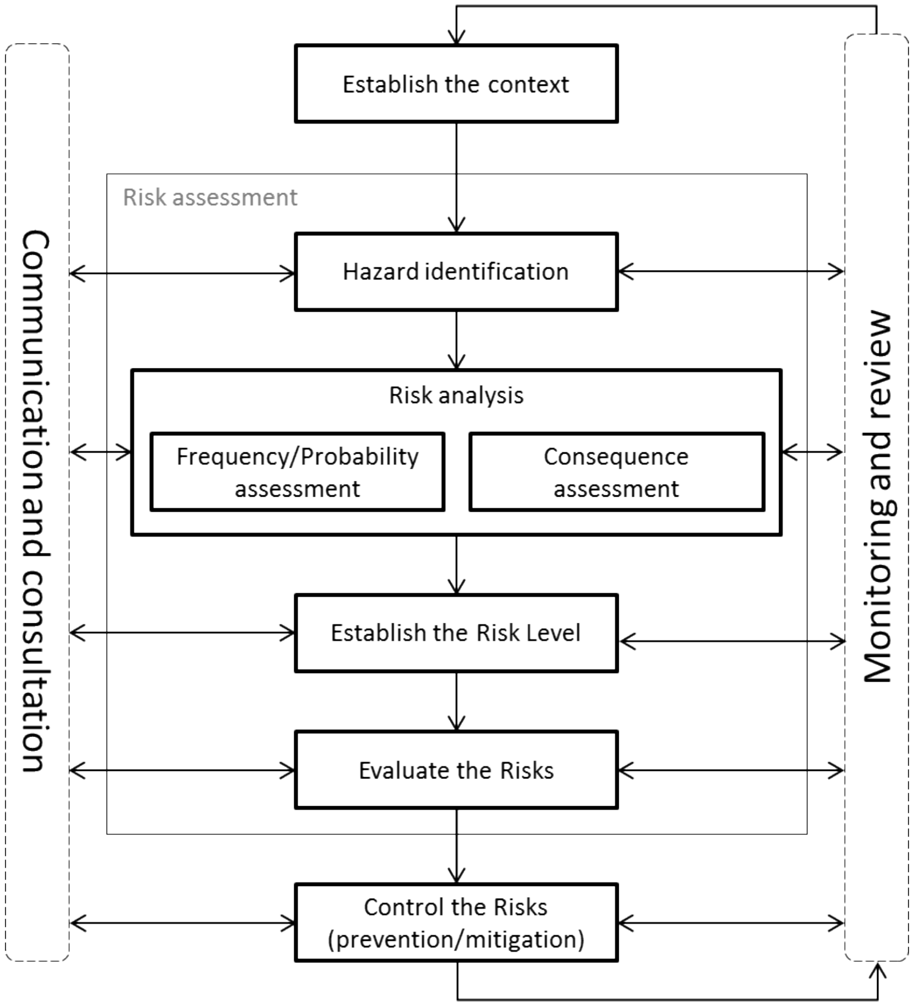

Figure 6. 1 Risk assessment in the risk management context

6.1.1 Types of risk assessment, selection of approach and level of detail

Risk assessment can be applied in qualitative, Semi-Quantitative and Quantitative approaches. The complexity and resource requirements dramatically increase from the qualitative to the quantitative assessment. It is also valid that, within the same approach, the level of detail of the analysis may vary, depending on the drivers of the assessment. The task of deciding which is the right approach stays with the project manager and depends on many factors; among these, the most important drivers are (Det Norske Veritas, 2002):

- The lifecycle stage of the facility, due to:
  - Greater or lesser flexibility in terms of design changes;
  - Availability of historical data;
  - Level of knowledge in respect to the design and operational details. Naturally, the fewer the information, the coarser models adopted.
- The major hazard potential – the greater the potential impact, the greater the need for a thorough assessment.
- The risk decision context – more novelty will push to a more thorough risk assessment.

The basic aim is risk reduction, and the key test is one of reasonable practicability. The different stages of the lifecycle offer different opportunities for risk assessment, and hence the approach may be different in each. It is a general agreement within the offshore risk practitioners and regulators in terms of complexity of the assessment in different stages in the lifespan of a project that could be summarised like in Table 6.1 (adapted from Det6 Norske Veritas, (2002)):

Table 6. 1 Risk assessment characteristics throughout the lifespan of a project

Life cycle phase	Characteristics of risk assessment
Feasibility study and concept selection	• relatively simple; • broad in scope; • address the complete lifecycle
Concept / front-end design	• based on historical data; • make use of reference designs; • make use of lessons learned;
Detailed design	• specific scope; • the most complex and thorough assessment; — used to: • check whether the safety levels are acceptable; • evaluate additional safety measures; • advise on major procedural safeguards
Operation	• based on practical experience; • part of the ongoing risk management of the installation; • small amendments to detailed design risk assessmentfindings.
Abandonment	• review of the specific assessment performed during the designphase; • focus on the environmental aspects of the abandonment; • thorough assessment on the issues identified as critical/sensitive

Source: Det Norske Veritas, (2002)

The level of information required for a proper assessment also varies widely depending on the process/system analysed, the potential impact of the hazard, and the prior know-how and best practices used when addressing a particular risk. Sometimes a screening process is sufficient to provide a sound risk evaluation; other times, the level of detail (granularity) required by the analysis increases dramatically in order to have meaningful results as valuable input for the risk evaluation phase.

The same statement is also valid in terms of the methods used for the assessment: while the use of qualitative methods are sufficient to address the frequency and consequences of some hazards, the more detailed, in-depth quantitative methods are required when addressing the ‘high risks’ hazards. Moreover, the selection of the quantitative or qualitative methods also depends on the current phase in the assessment. While the qualitative methods are recommended in the early phases (such as hazard identification, identification of initial events, identification of the possible effects) the quantitative methods are better suited as the analysis requirements grow of in terms of complexity and granularity (Figure 6.2).

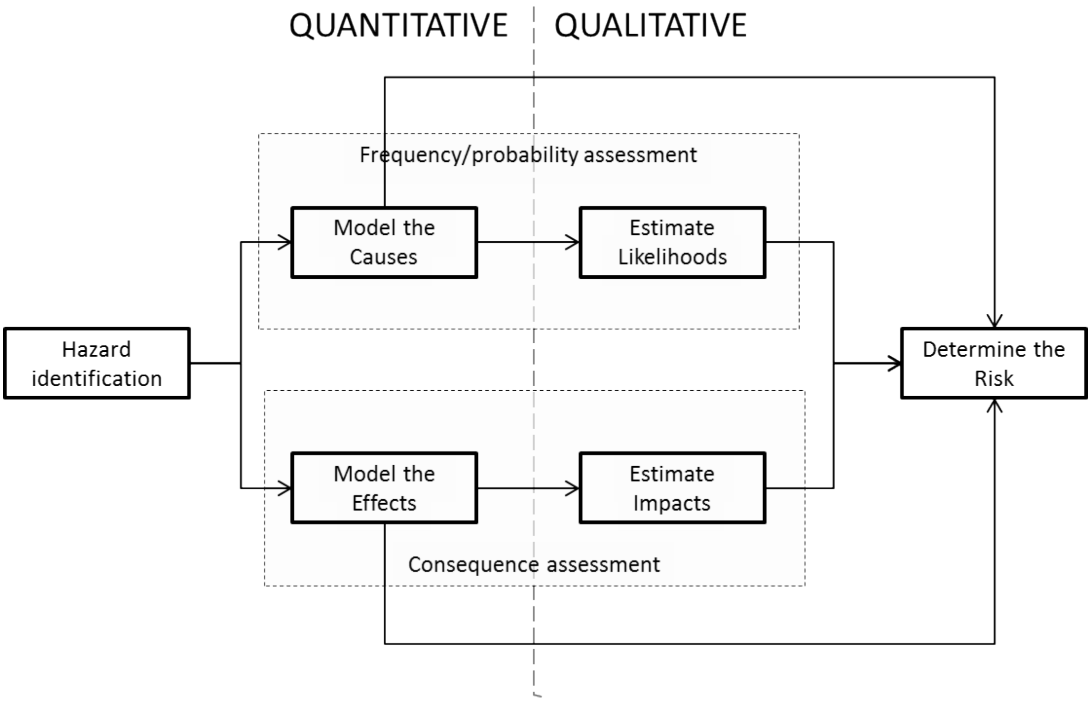

Figure 6. 2 Quantitative vs qualitative methods selection

The choice of the proper methods and tools suitable for the situation at hand is the key element for meaningful risk analysis (ABS, 2000). For emphasising the importance of this aspect, some sources consider that the selection of the methods, together with the definition of the models, represents itself a risk to be addressed when dealing with the assessment of complex and ‘high risks’ systems (Coca et al., 2014).

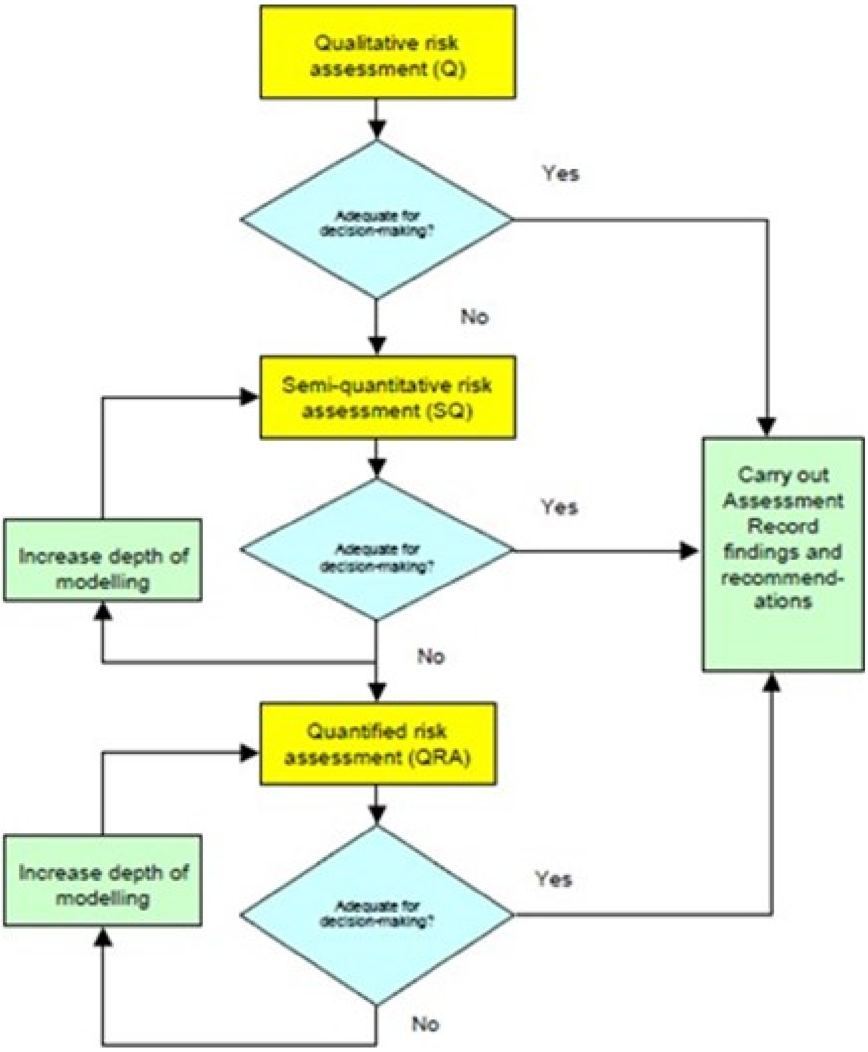

Figure 6. 3 Possible screening process for determining the appropriate assessment level Source: HSE (2006)

The choice of the qualitative over the quantitative methods, of the level of complexity of the models and the granularity of the assessment, is, in the end, driven by the need for valuable information for solid decision making. The basic philosophy could be summarised as follows: only increase the complexity of the assessment if the current results are not sufficient or are not adequate for deciding. This is a screening process that can be summarised as (HSE, 2006): Start with the qualitative approach;

- If the current level of detail cannot offer any of the following:
- The required understanding of risks;
- Discrimination between the risks of different events or

- Assistance in deciding whether more needs to be done
- Increase the detail and/or complexity of the analysis (Figure 6.3).

6.1.2 The Risk Assessment Stages

1. **Establish the Context**

The main objective in this phase is to establish the basic parameters of the risk assessment process and to set the scope and the acceptance criteria for the rest of the process. This phase should encompass the following:

- The definition of the main objectives of the current risk assessment;
- Definition of the analysed system and system boundaries;
- The definition of the scope of the assessment;
- Identification and definition of the methods, models and tools employed in the assessment;
- Definition of the risk acceptance criteria to be used.

Setting up the context ensures that the subsequent process will be suitable with respect to its intended objectives and purpose, properly tailored to the system of interest, and at a sufficient level of detail that would produce effective and meaningful results for the decision-making process.

2. **Hazard identification**

Hazard identification is the thorough examination of the process to identify the hazards, the sources of hazard and to perform a preliminary prioritisation in terms of severity. The outcomes of this phase are (Det Norske Veritas, 2002):

- A list of hazards for the subsequent evaluations using other risk assessment techniques (failure selection);
- The qualitative evaluation of the significance of the hazards and the measures for reducing the risks from them (hazard assessment).

This phase is critical in the context of risk management since an overlooked hazard (hence, risk) cannot be further assessed and controlled.

Hazard identification is a structured process itself. As a generic practice, the following phases should be addressed:

1. A broad review of all the possible hazards and sources of the accident;
2. The rough identification of the possible consequences (outcomes) of each of the hazards;
3. A rough classification into critical / non-critical hazards;
4. Identification of the control measures addressing the specific hazards (e.g. inherent safer design, possible design improvements, etc.
5. Prioritising hazards in respect to criticality; identifying which hazards require further evaluation; establishing the level of detail and the type (e.g. qualitative or quantitative) of the assessment.

Most of the methods employed in hazard identification are qualitative. The methods involve expert judgement, brainstorming and a solid knowledge of the infrastructure and/or processes addressed. To be noted the 'linguistic' confusion that may be created when referring to the qualitative term. A qualitative technique may include numerical data in the determination of the results.

The Hazard Identification technique must be a creative process to encourage the identification of all possible hazards (Det Norske Veritas, 2012); moreover, it should make use (where available) of accident experience and lessons learned.

Many techniques can be employed during the hazard identification phase. These are:

- Safety Review
- The Hazard Identification technique – HAZID
- The Hazard Review
- Preliminary Hazard Analysis
- What-if Analysis
- Checklist Analysis
- Hazard and Operability Analysis – HAZOP
- Failure Modes and Effects Analysis – FMEA
- Fault Tree Analysis – FTA
- Event Tree Analysis - ETA

It is worth mentioning that the applicability of the methods depends on the subject of the assessment (installation, process, hardware, software, etc.). Moreover, from the perspective of completeness, it should be ensured that the most important undesired consequences have been considered in the identification of the hazards. Completeness depends on the selection of identification techniques and how well the hazards are known.

For existing technologies, hazard identification heavily relies on previous experience and studies, and in this case, a simple identification technique may suffice to recognise the hazards. However, a more thorough analysis should be employed (such as HAZOP) to confer sufficient confidence that all the hazards have been identified.

3. Frequency assessment

The objective of frequency assessment is to characterise the hazards in terms of the likelihood of occurrence. The role of this analysis is to provide an estimation of the likelihood of an initial abnormal (hazardous) event, the possible outcome(s), and the frequency of its outcome(s).

The degree of detail of the analysis depends on the type of risk assessment: in the case of a quantitative assessment, a high level of detail and data from statistics are required; less details are required for qualitative assessments (IPIECA/IOGP, 2013).

The analysis methods employed during this phase can be classified as inductive and deductive. A deductive technique answers the question of how the system got here, while an inductive technique responds to the question of what happens to the system if?

Among the most frequent methods used in this phase are:

- Historical failures and accidents frequency data
- Fault Tree Analysis (FTA)
- Event Tree Analysis (ETA)
- Human reliability analysis
- Common cause failure analysis

The selection of the level of detail and tools for frequency assessment depends on the offshore project's lifecycle phase. During project planning, the qualitative assessment is sufficient due to the high level of uncertainties and limited data. A quantitative assessment is required; moreover, more reliable information is available, thus facilitating this type of analysis. The qualitative approach is taken during the operational and decommissioning phases, this time because the thorough results of the assessment are available from the project execution phase.

For offshore facilities, the same remarks are valid. Moreover, depending on the novelty of the installation (technologies, layout, design), the qualitative assessment increases for existing technologies, while the quantitative assessment stays with the new ones.

From the above, we may state that in the offshore case, frequency assessment is performed in a qualitative or semi-qualitative form in most of the cases. For most situations, the assessment is recommended to be grounded on the historical frequency of events and available statistical data relevant (Oil & Gas UK, 2012).

4. **Consequence assessment**

The consequence assessment mainly addresses the evaluation (qualitative or quantitative) of the level of impact on people, assets and environment of a loss of containment event. The process heavily relies on modelling for describing the release phenomena and the credible physical outcomes of a loss of containment event.

Loss of containment may happen in different ways and with different outcomes. This depends on various factors such as the type of the release, the location, the weather, the release medium, the physical and chemical properties of the released substance, the release form of the substance, etc. Figure 6.4 depicts the physical and consequence phenomena in a generic case of a hazardous substance loss of containment release.

The main subjects of interest in this phase are:

- Release of gas in the atmosphere, which can lead to fires, explosion (due to the formation of explosive vapour cloud) or concentrations exceeding different threshold values; the effects of such releases are acute toxicity, thermal effects and explosion (blast and fragment);
- Release of oil which can lead to fires (pool formation) or spreading and/or pollution of the environment.

We may draw upon the main categories of analytical models employed in this phase from the above. These are:

- Source term models;
- Atmospheric dispersion models
- Blast and thermal radiation models
- Aquatic transport models
- Effect models
- Mitigation models

Since the phenomenology and the physics of the release is the same, many of these are generic models (can be applied for a given task, irrespective of the industry-specific characteristics). However, the selection of these models must be carefully performed to ensure the applicability for the analysed scenario.

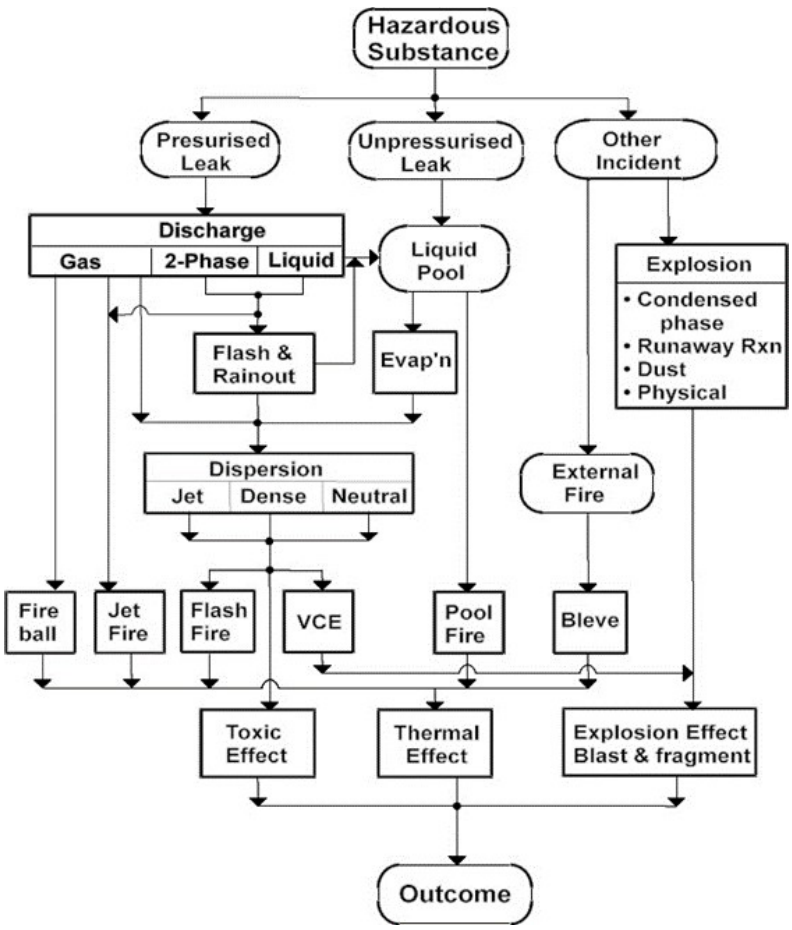

Figure 6. 4 Consequence Phenomena and their relationship, Source: IOGP (2010)

The models should address the possible outcomes and the effects of a loss of containment after an initial event. In particular, the following consequences must be considered:

1. Release/discharge – the way the pollutant gets into the environment and the physical characteristics of the release (e.g. rate of release, duration, physical form, etc.)
2. Dispersion in air – huge literature and solid history; all models address solving the advection-dispersion equation.
   - Complexity may vary from the 'simplest' (e.g. Gaussian plume) models to computational fluid dynamics (CFD)
   - In offshore safety, the CFD models play a key role in obtaining numerical solutions for ventilation, dispersion, and explosion problems (OGP, 2010). Due to the specificities of the offshore operations, the Gaussian models may not be appropriate for being applied.
   - selection of the models depends on factors such as:
     - Type of release (continuous vs instantaneous)
     - Duration of release
     - Quantity of the released pollutant which, in turn, determines the scale of the potential effects
     - Physical characteristics of the pollutant (e.g. buoyancy)
     - The availability of input data (especially for the CFD models)
   - The relevant outcomes are:
     - The concentration of pollutants in the air as a function of distance
     - The area affected
3. Dispersion in water – more complex analytically
   - Computational fluid dynamics
   - Release point (depth)
   - Release location (e.g. estuaries)
   - The characteristics of the marine environment (e.g. currents)
   - The tidal regime
4. Fire and thermal radiation: These models should be used to evaluate the impact of the different types of fires on humans/infrastructure; the following type of fires are addressed: pool, BLEVE, jet, flare, flash.
5.

- The main outcome of the computation is the heat load as a function of distance;
- In turn, using probit functions, the effects on humans (lethality percentage) can be calculated

6. Explosion
   - Two main classes: (1) vapour cloud explosion and (2) overpressure and projectiles effects.
7. Smoke and gas ingress;
8. Toxicity - the air concentration is subsequently used to determine the health effects in terms of toxicity. The process involves computing the chemical dose, which, using probit functions, can estimate the lethality percentage of the exposed individuals.

The activities employed in the consequence assessment phase may be summarised as:

1. Characterise the material or energy associated with the hazard being analysed;
2. Estimate (using models and correlations) the transport of the material and/or the propagation of the energy in the environment to the target of interest (people, structure, etc.);
3. Identify the effects of the propagation of energy or material on the target of interest;
4. Quantifying the health, safety, environmental, or economic impacts (depending on the target of interest).

The main results from the consequence assessment step are:

- An estimation of the statistically expected exposure of the target population;
- The safety/health effects related to that level of exposure;
- The impact on structures;
- The environmental impact.

5. Risk representation

Risk representation mainly deals with putting together the results obtained so far in the risk assessment (frequency and consequences) in a format easy to be communicated and relevant in the decision-making process.

The most frequently encountered methods for risk representation are:

- Risk matrix;
- F-N curve;
- Risk profile;

- Risk isopleth
- Risk index

Within the context of this document, only present the Risk Matrix, as it stands out as the most frequently used risk representation and communication method.

6.1.3 Risk matrix

Risk matrices are probably the most common approach used for representing and communicating the risk assessment results.

The risk matrix is a way of graphically putting together the consequences and the frequencies of a hazard event to provide an integrated description of risk.

The main use of the risk matrices is to deliver an expression of the size of the risks. Hence, a risk matrix allows the analyst to rank the risks in order of significance, screen out the insignificant ones and evaluate the need for further risk reduction/preventions measures to be taken in case of various hazards.

A risk matrix has two dimensions: consequence (also known as severity) and frequency (also known as likelihood or probability). Within the space defined by these dimensions, three areas are delimited, namely (Figure 6.5):

- The green area, corresponding to the low-probability, low-consequence;
- The yellow area, corresponding to the medium-probability, medium-consequences; and
- The red area, corresponding to the high-probability, high-consequences.

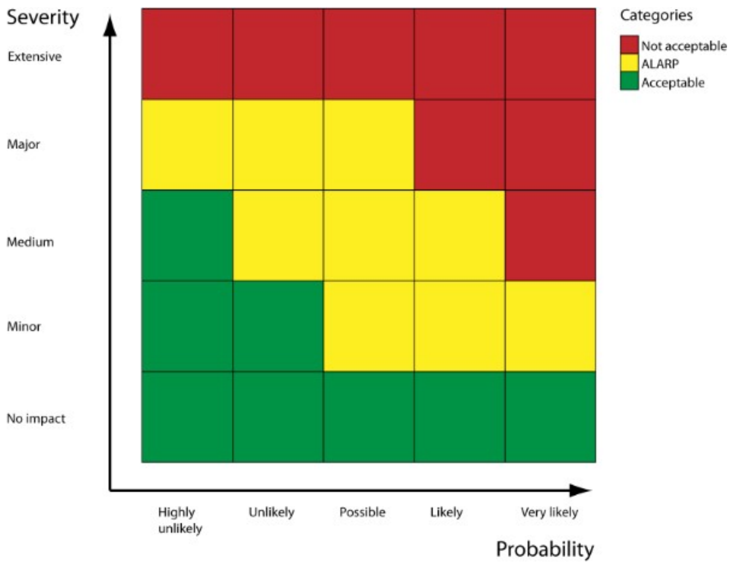

Figure 6. 5 Typical risk matrix structure and acceptance areas

Each of the dimensions of the matrix is divided into several categories (typically between 3 and 6). Each of the hazardous events identified in the hazard identification phase is placed on one of these positions, based on the results of the frequency and consequence assessment phases. The value of the risk is not absolute but relative: low, medium and high risks are chosen on the basis of acceptability criteria that express the tolerable risk of a given contest. For this reason, the position of an event in the risk matrix should be interpreted as:

- The event in the green zone – the risk of the occurrence of the event is acceptable, and no risk reduction/mitigation actions are required; the risk must, however, be part of the continuous risk management process, for further reduction;
- The event in the yellow zone – the risk should be monitored, yet at the current moment, it is controlled as low as reasonably practicable (ALARP);
- The event in the red zone – the risk is intolerable, and risk reduction/mitigation actions must be put into place.

Analysis of natural hazard impacts at offshore facilities

Natural hazards, such as storms, earthquakes, and lightning, are a major threat to industrial sites. They can cause technological accidents at chemical plants, pipelines and offshore oil and gas facilities, where they impact equipment, workers and the environment. Such accidents that involve hazardous-materials (hazmat) releases are commonly referred to as Natech accidents

Table 6. 2 Main damage mechanisms due to natural hazards based on our accident analysis

Structure	Hazards	Damage modes
Fixed structure (and stationing jackup)	Storm and hurricanes	Damage to steel jackets or jackup's legs; overturning and toppling; deck flooding; scour; damage to helideck; wind damage to derrick; wind damage to hatches, wind walls and insulating layers
	Earthquake	Damage to steel jackets or jackup's legs; scour; damage to derrick
	Lightning	Ignition of flammable material in storage tanks; flare damage
Floating structure	Storm and hurricanes	Damage to station keeping mooring system; rigs and MOUs set adrift; overturning and toppling; deck flooding; damage to helideck; wind damage to derrick; wind damage to hatches, wind walls and insulating layers
	Lightning	Ignition of flammable material in storage tanks; flare damage
Pipeline	Storm and hurricanes	Pulled when host platform is set adrift; soil erosion, cratering and subsidence; anchor dragging from drifting rigs; wave damage during pipe laying
	Earthquake	Pipeline bending because of soil cratering
FPSO/FSU	Storm and hurricanes	Damage to station keeping mooring system; support rigs and MOUs set adrift; wind damage to hatches and insulating layers; damage to the helideck
	Lightning	Ignition of flammable material in storage tanks; flare damage
Loading buoy	Storm and hurricanes	Damage to station keeping mooring system; hose damage; damage to the helideck

6.1.4 Risk Mitigation Measures

Well Planning & Design

Exploration wells are designed to manage the uncertainty in the true nature of the well to be drilled. The possibility of shallow gas, uncertainty in pore pressure and temperature, porous and permeable intervals, weak formations, etc., all need to be assessed, and the well design and drilling program developed to cater for "worst-case" scenarios. Offset well data, computation modelling, and site-specific survey data allow the geoscientists to provide the drilling engineers with information on the likely range (probabilistic) and maximum values of key design parameters. The drilling engineer designs the well (and the associated drilling programme) on the basis of maximum anticipated values. Detailed risk assessment, in terms of assigning quantitative probabilities of failure to all parts of the well design, does not feature in the design of a typical exploration well. However, risk assessment is implicit within the design process, specifically through the adoption of operational manuals and procedures and industry recognised design approaches by ONGC.

As per ONGC‟s Management Systems of Offshore Drilling and HSE, and in compliance with Petroleum and Natural Gas (Safety in Offshore Operations) Rules 2008, ensure that:

- A Well programme describing the individual activities and the equipment to be used will be prepared prior to start well activities
- The management system with associated processes, resources and operational organisation will be established;
- Steering documents, including technical documents for drilling and well testing operations, will be made available in an updated version, and the operational personnel shall be acquainted with it.
- Commissioning process prior to start-up of facilities for the first time or after technical modifications will be completed

Well barriers:

- During drilling and other related well activities, there will at all times be at least two independent and tested well barriers after surface casing a in place. Well barriers will be designed in such a manner that unintentional influx, cross-flow to deformation layers and outflow to the external environment is prevented.
- Well barriers will be designed in such a manner that their performance can be verified.

- If a barrier fails during drilling and other related well activities, no other activities will be undertaken in the well other than those to restore the barrier.
- When a well is abandoned, the barriers would be designed to provide integrity for the longest period of time in such a manner, inter alia, that outflow from the well or leakages to the external environment do not occur.
- Ensure that the necessary actions are planned, including setting casing above all known shallow gas hazard zones to handle situations of shallow gas or other formation fluids.
- During drilling and well activities, drilling and well data will be collected and monitored to verify the well prognoses in order that necessary actions may be taken and the well programme may be adjusted, if necessary.

Well control:

- Well control equipment will be designed, installed, maintained, tested and used so as to provide for well control.
- In the case of drilling of top-hole sections with riser or conductor, equipment with the capacity to conduct shallow gas and formation fluid away from the facility until the personnel has been evacuated will be installed.
- Floating facilities shall have an alternative activation system for handling critical functions on the blow out preventer.
- Accumulator for surface and subsurface well control equipment will have minimum useable fluid capacity as per industry standards in order to perform closing and opening sequences as applicable to secure the well.
- The pressure control equipment used in well interventions will have remote control valves with locking devices.
- The well intervention equipment will have a remote-control blind or shear ram as close to the Christmas tree as possible
- If well control is lost, ensure that it shall be possible to regain the well control by direct intervention or by drilling a relief well.
- Prepare an action plan describing how the lost well control can be regained

- Set operational limitations in relation to controlled well flow

Securing of wells before abandoning

- All wells will be secured before they are abandoned in such a manner that well integrity remains intact for the period abandoned.
- With regard to subsea completed wells, the well integrity will be ensured if the wells are planned to be temporarily abandoned
- Radioactive sources will not be left behind in the well.
- In case it is not possible to retrieve the radioactive sources, and these have to be left in the well, follow proper abandonment procedure as per guidelines of the Department of Atomic Energy, Government of India.
- Compensator and disconnection systems:
- The design of compensator systems will be based on robust technical solutions so that failures do not lead to unsafe conditions.
- Floating facilities shall be equipped with a disconnection system that secures the well and releases the riser before a critical angle occurs

Drilling fluid system:

- The drilling fluid system will be designed in such a manner that it will mix, store, circulate and clean a sufficient volume of drilling fluid with the necessary properties to ensure the drilling fluid‟s drilling and barrier functions.
- The high-pressure part of the drilling fluid system with associated systems will in addition, have the capacity and working pressure to be able to control the well pressure at all times.
- Availability of sufficient quantity of drilling fluid weighting material to subdue the well at any time during the drilling operation will be ensured

Cementing unit:

- The cementing unit will be designed in such a manner that it will mix, store and deliver as exact volume as possible of cement with the necessary properties to ensure full satisfactory anchoring and barrier integrity

- The unit will be designed in such a manner that remains of unmixed chemicals as well as ready-mixed cement is handled in accordance with the applicable environmental regulations.
- If the cementing unit with associated systems is intended to function as a backup for the drilling fluid system, it shall have the capacity and working pressure to be able to control the well pressure at all times.
- Casings and anchoring will be such that the well integrity is ensured, and the barrier functions are provided for the lifetime of the well.
- Equipment for completion and controlled well flow
- Equipment for completion will provide for the controlled influx, well intervention, backup well barrier elements, and plug back activities.
- Completion strings will be equipped with necessary downhole equipment, including safety valves
- During controlled well flow, the surface and downhole equipment will be adapted to the well parameters.
- Equipment for the burning of the well stream will be designed and dimensioned in such a manner that combustion residues shall not cause pollution of the marine environment
- ensure that controlling well pressure through the work string and the well flow through the choke manifold at any time

6.1.5 Selection of Equipment, Systems And People

Assessing The Ability of The Drilling Rig To Perform The Required Operation

The water depth, environmental conditions, reservoir and geophysical properties will dictate the type of rig and equipment required to perform the drilling operation. Highly technical risk assessments will be undertaken both to demonstrate that the rig can provide an acceptable working environment and determine the limits to which certain operations will be undertaken.

During this phase, the ability of the equipment and systems on the rig to provide a suitable barrier(s) to well control incidents will be reviewed (e.g., pressure rating and functionality of the BOP). The ability of a drilling rig to operate at a specific location will be assessed, usually through the application of industry recognised site assessment practice. (e.g., Site Specific Assessment of Mobile Jack-Up Units).

The risk assessment process is, to an extent, embodied within the relevant design and assessment standards applicable to the particular type of drilling rig. However, detailed, site-specific risk assessments support the application of these standards, for example, the analysis of borehole data to establish the risk of a punch-through. Where a drilling rig is deemed to be operating close to the limits of its operating envelope, more detailed risk assessments may be warranted.

The requirements of the following applicable standards for the listed equipment shall be met to demonstrate that drilling systems are in compliance with requirements of the Petroleum and Natural Gas (Safety in Offshore Operations) Rules, 2008 and Drilling Rig (MODU) is thus fit for purpose:

Fire and explosion risk assessment on MODU includes hazards from the wells and well testing operations. Following fire and explosion hazards related to wells are generally considered:

- Subsea shallow gas blow out
- Shallow gas blow out in cellar deck
- Blow out at drill floor
- Subsea blowout
- HC gas release/ignition in the mud processing area
- Fire and explosion in well-testing areas

Well programs need to be designed taking into consideration the anticipated hazards as listed above. MODUs should conform to conventions and codes of the International Maritime Organization (IMO). Fire and explosion risk management at MODU can be ensured by meeting the requirements of these codes. Following issues have been taken into consideration by MODU code:

- Structural fire protection layout plan for decks and bulkheads
- Protection of accommodation spaces, service spaces and control locations
- Means of escape

- Fire pumps, fire mains, hydrants and hoses
- Fire extinguishing systems in machinery spaces and in spaces containing fired processes
- Portable fire extinguishers in accommodation, service and working spaces
- Arrangements in machinery and working spaces
- Fire detection and alarm system
- Gas detection and alarm system
- Fireman's outfit
- Provisions for helicopter facilities
- Fire control plan
- Ensuring fit for purpose status of fire extinguishing appliances (operational readiness and maintenance is detailed in MODU Code 2009)

The number and type of portable extinguishers provided on the MODU would be based on the fire hazards for the spaces protected.

Testing & Maintenance of Critical Equipment

Blowout preventer and other pressure control equipment are critical to avoid major accidents during drilling. Therefore, the blow out preventer will be pressure tested regularly in order to maintain its capability of carrying out its intended functions. The blow-out preventer with associated valves and other pressure control equipment on the facility shall be subjected to a complete overhaul and recertified at regular intervals based on original equipment manufacturers recommendations, international standards, and recommended practices.

The major incident risks for which some level of risk assessment is undertaken normally include:

- Hydrocarbon releases result in fires, explosions or asphyxiation
- Structural failure (environmental overload, foundation failure, seismic etc.)
- Mooring failure (loss of location keeping and secondary impacts)
- Ship Collision
- Helicopter operations
- Lifting operations and dropped objects (with major incident potential)

The nature of the risk assessment exercise undertaken for each of the risk types varies from analysis of past incident data to the detailed assessment of blast overpressure resulting from hydrocarbon releases of varying sizes and from different locations.

Ensuring Marine Integrity

1. Stability:
- Ensure that floating facilities are in accordance with the requirements contained in the applicable standards concerning stability, water tightness and watertight and weather tight closing means on mobile offshore units.
- There will be weight control systems on floating facilities, which will ensure that weight, weight distribution and centre of gravity are within the design assumptions and equipment and structural parts will be secured against displacements to affect stability.
2. Anchoring, mooring and positioning:
- Floating facilities will have systems to enable them to maintain their position at all times and, if necessary, be able to move away from the position in the event of a situation of hazard and accident.
- Dynamic positioning systems will be designed in such a manner that the position can be maintained in the event of defined failures and damage to the system in case of accidents.
- During marine operations, necessary actions will be taken in such a manner that the probability of situations of hazard and accident is avoided, and those who take part in the operations are not injured.
- Requirements will be set to maintain position in respect of vessels and facilities during the implementation of such operations, and criteria will be set up for commencing and suspension of activities.
3. Collision risk management
- The Offshore Installation Manager will be the overall authority for safe operations within the safety zone of installation.

- ensure that a collision risk management system is implemented and maintained wherein the following shall be inter alia included :
  - Suitability of attendant vessels and offtake tankers and competence of their crew;
  - Assessment of the probability of collision peculiar to the installation and its location;
  - Provision of necessary risk reduction and control measures;
  - Appropriate procedures and communications for managing operations of attendant vessels developed jointly with marine service providers;
  - Provision of appropriate equipment and procedures for detecting and assessing the actions of vessels intruding into the safety zone;
  - Provision of competent personnel with an appropriate level of marine knowledge;
  - Provision of appropriate evacuation and rescue procedures and facilities; and
  - Regular audit and updating of the systems.

4. Control in the safety zone

- The master of the attendant vessel or off-take tanker will comply with instructions of the Offshore Installation Manager when in a safety zone.
- The master of the attendant vessel or off-take tanker will be responsible for the safety of his crew, the safe operation of the attendant vessel or off-take ta, and for avoiding collision with the installation or associated facilities.

5. Operations in rough weather conditions

- The operator will ensure safe working in adverse weather and tidal conditions and identify the rough weather conditions when the operations are to be discontinued, and evacuations carried out, as required.
- The operator will ensure that transfer of personnel and cargo between the vessel and installation is carried out under safe weather conditions, and such transfers should be stopped during adverse or unsuitable weather conditions

6. Cargo management

- The operator will ensure optimisation of cargo trips from and to the shore, and cargo handling time at installation by efficient planning of cargo supplies through containerisation, pre-slinging of cargo etc.

6.2 Disaster Management Plan

The inherent risk in oil well drilling and production is well known. The management of the risks calls for systematic planning, adopting engineering practices, and a positive attitude towards safety & environment protection. It was, therefore, necessary to develop a Disaster Management Plan (DMP) to facilitate necessary actions to meet emergency scenarios.

6.2.1 Purpose & Scope Of The Plan

The disaster management plan would serve the following purpose

- To set out the appropriate course of action to mitigate the impact of an emergency event. The plan allows all those involved to mobilise their resources in an orderly way and react in time effectively.
- To respond immediately to an emergency event to prevent its escalation to a disaster and also the response in the event of such an escalation. The scope of the plan is to cover all the emergencies which can influence the risk under the following situations

Table 6. 3 Disasters due to natural and manmade causes

Disasters due to natural causes	**Disasters due to manmade causes (external)**
Tsunami	Terrorist Attack
Cyclones	Hostage Crisis
Earthquake	Bomb threats
Tornado	Potential Offshore Vessel Collision
Lightning	Helicopter crash on Helideck in Offshore
Disasters due to manmade causes (operational)	Helicopter crash-Ditch in sea
Fires	Helicopter Emergency landing
Oil/gas well blowouts	Office/Offshore accommodation fire
Toxic gas releases,	Dropped object incidents
Oil / Chemical spills,	**Emergencies to offshore installations**
Hydrocarbon Release	Diving Incidents
Explosions (unconfined, confined)	Man Overboard incidents

The emergencies mentioned above can escalate to such an extent that the required response level can be mobilised or outsourced services internationally. In such cases, DMP shall be activated where national and/or international level intervention may be required for handling the crisis.

6.2.2 Updating And Exercises

The disaster management plan shall be updated as and when required but at least once in a year. Also, the plan will be exercised under the chairmanship once every year to test the communication system, action plan, and all key agencies' responses. Accordingly, a Disaster scenario will be simulated, and the "Emergency Coordinators" as defined by the plant will be required to act in a predetermined way to deal in real-time with the situation. The outcome of the exercise will be taken as input to updating the plan and improving on the lacunae, if any, on the front of preparedness as well as to plug the loopholes to meet with emergencies of any extent feasible. The exercise shall include the National Crisis Management Committee. If in any case, the exercise cannot be carried out due to operational reasons, the same shall be done as a tabletop exercise.

6.2.3 Disaster Management Preparedness

In case of emergency, Emergency Response Plan (ERP) is activated by the installation manager. He shall immediately bring it into the notice of the Asset/ Basin Manager/ Chief of Services for mobilisation of resources, should the emergency warrants so, beyond the capability of the installation/ rig/ vessel, as well as to activate the Disaster Management Plan constituting a part of the Regional Contingency Plan (RCP). In order of affixing the responsibility, the Senior most Asset Manager shall be the Chief Emergency Coordinator (CEC). In case of his absence, the next Senior Asset Manager shall be the CEC.

6.2.4 On-Scene Coordinator

Initial Phase

One who is close enough to the scene of emergency may exercise emergency coordination in the initial phase. Accordingly, the Installation Manager will assume the On-Site Coordinator (OSC) role.

Intermediate Phase

The Chief Emergency Coordinator (CEC) at the Asset level may appoint a person, normally located at the base, to take over the task of OSC at Site Control Room (SCR).

Function

The OSC will make an assessment of the situation, the type and quantity of assistance required and communicate the same to the Asset ECR. The OSC will mobilise the resources available at the site, deal with the situation and take such actions as directed by the Chief Emergency Coordinator at the Asset/ Basin/ Plant. He will transmit situation reports (SITREPS) at regular intervals prefixing a numerical sequence to each message.

Site Control Room

Location

The Site Control Room will function at the installation depending upon the situation. The alternate site control room will be set up at the closest installation.

Mobilisation

The On-Scene Co-coordinator (OSC) will set up SCR as soon as he becomes aware of the emergency situation.

Function

To make situation reports (SITREPS) from time to time and take steps to fight the emergency. Determine the type of assistance required & mobilise the same through ECR.

6.2.5 Communication

As effective communication is crucial for the overall success of the operation, a communication flowchart for such a scenario is outlined herewith. In the event of a terrorist act, timely, accurate communications will be critical for success and survival. Timely response during an emergency is extremely important. CEC at the work centre must communicate immediately as per the flow chart for first information in case any emergency is likely to come to the notice of media. This is to ensure that the management has an authentic update of the emergency to reply to the media.

6.2.6 Modelling approach for the extreme events

Natural extreme events such as Tropical cyclones, storm surges, earthquakes and Tsunami can result in catastrophic consequences to the operation and control of oil industries. Accurate modelling of these events is critical to appropriately developing planning and operation strategies. However, their accurate modelling is very difficult, exhaustive, and computationally expensive due to their stochastic, spatiotemporal, and unpredicted nature.

The major focus of the Risk Analysis and Modelling lies on:

- Quantitative modelling of extreme events and systemic risks through the use of advanced statistical techniques and multi-agent-based modelling.
- New methods for the economic modelling of natural disasters and climate extremes using diverse economic theories.
- Novel approaches for modelling stakeholder preferences and interactions, analysing institutional dynamics and social complexity.

Tropical Cyclones

Observations from space have been used to monitor tropical cyclones since the 1960s. The spaceborne data use to track the formation and progress of storms. Satellite can be used to reveal changes in the structure of the storm, the wind speed and the patterns of clouds around the eye; the intensity may also be witnessed in the affect on waves around the storm and data can be used to measure the sea surface temperature and sea surface height. Optical and radar imagery may also be used in the aftermath of a tropical cyclone to assess the situation on the ground, providing key information to first responders. The most commonly used cyclone disaster model is HAZUS, a hurricane model, which was developed by the federal emergency management agency. This model simulates cyclones progression based on historical data. models which are used to predict the storm surge includes the SLOSH model (the Sea, Lake, and Overland Surges from Hurricanes); the ADvanced CIRCulation (ADCIRC) coastal circulation and storm surge model; and (CH3D)-SMSS, the Storm Surge Modelling System with Curvilinear-grid Hydrodynamics in 3D, Delft3D (Netherlands) and the Japan Meteorological Agency (JMA) storm surge model

Tsunami

As with other natural hazards, tsunami risk can be broken down into hazard, vulnerability, and exposure. There are several numerical models available for simulating the propagation of tsunami waves. mainly TUNAMI-N2 model and

Another well-known model is the method of splitting tsunami model (MOST). The MOST model, which will be used to develop tsunami hazard mitigation tools

Earthquakes

HAZUS is a model which is used to for the earthquake modelling. This model uses historical data to model earthquake disasters. Earthquake models usually determine the peak ground acceleration which has been used as input for fragility curves of component failure models. Earthquake models have been developed incorporating intensity of earthquakes, distance between the earthquake centre and location of interest, seismic potential, and the type of the ground. A probabilistic earthquake energy transfer model has been proposed based on autoregressive (AR) estimation method

6.3 Oil Spill Contingency Plan

The oil spill contingency plan summarized in this section is in par with the guidelines provided by the National Oil Spill Disaster Contingency Plan (NOS-DCP) (https://www.indiancoastguard.gov.in/WriteReadData/bookpdf/201512281221565793 127NOSDCPCGBR771.pdf). An oil spill contingency plan is a detailed oil spill response and removal plan that addresses controlling, containing, and recovering an oil discharge in quantities that may be harmful to navigable waters, offshore areas, and adjoining shorelines. The contingency planning follows a three-tiered response concept.

6.3.1 Contingency Plan Structure

In general, the plan should be comprised of three main parts:

Strategy Section.

- Authorities and responsibilities: This should indicate the various authorities and responsibilities encompassed by the plan. It should also outline any statutory requirements that the plan may be required to adhere to, particularly if the plan interfaces with a national contingency plan or local authority regulations.

- Dimensions of the plan: This will indicate the area the plan covers and its geographical limits. For instance, it may cover a refineries operations plus the sea approaches to the marine terminal at the refinery.
- Risks: the part will describe the types of risks involved, from the chance of a hose burst or pipeline failure to the possible grounding or collision of an approaching tanker. From these scenarios, plus a knowledge of the types of oils being handled at the facility, an indication of the fate and effect of an incident can be predicted. By being able to predict the fate and effect, shoreline resources can be prioritised for protection.
- Response strategy: will define the philosophy and objectives of response. It will indicate the problems due to local limiting and adverse conditions as well as setting out the strategies for sea and coastal zones. Arrangements for dealing with waste storage and disposal will be outlined.
- Equipment: what equipment is available and how it can be effectively used in the strategies previously outlined.
- Organisation and manpower: this sub-section will clearly outline the management organisation from the on-scene commander to the cleanup workers in the field. It will also show the relationship with the relevant government authorities and how they fit into the incident management system.
- Communications: the communications network will also be described in this sub-section, listing the communications equipment fitted into the command centre and a description of the field communications equipment.

Action and Operations Section

- Initial procedures: This set out the arrangements for notifying the relevant authorities of an incident.
- Emergency activation procedures for calling out response team members and setting up the command centre. Emergency activation and mobilisation procedures will allow rapid sourcing and deployment of resources, particularly from contractors and third parties.

- Planning: What requires to be done in the form of planning in the short-medium and long term.
- Guidance on specific cleanup operations and the critical factors when deciding the final and optimum levels of shoreline cleanup.

Data Directory

Daa directory should contain all the relevant maps (particularly sensitivity maps) lists and local wind, weather, and environmental data sheets to assist in assessing the situation and developing a strategy for dealing with the situation. Such a list would contain:

- Primary oil spill equipment (manufacturer type, size, location and cost of hire where applicable.)
- Support equipment needed to deploy the equipment, i.e. workboats, tugs, tractors and trailers etc.
- Sources of manpower, contractors, local authorities etc.
- Source of experts and advisors, i.e. salvors, environmental safety etc.
- Local, national and international contacts who required to be notified of the incident and who may be able to offer assistance

6.3.2 Risk Assessment

The oil spill management plan covers the planning for handling potential off-shore emergencies and oil spillage accidents during the operation phase. Potential emergencies anticipated during the operation phase are given below:

- Spillage of Oil while handling at off-shore
- Grounding & sinking of vessels
- Collision of vessels with other cargo vessels
- Fire Hazard
- Spillage of oil in waterway due to mishandling of oil tanks while loading & unloading, accident/collision of vessels, damage of tank during the grounding of vessels, leakage of fuel tank/bilge tank.
- Natural calamities like earthquakes, tsunami, heavy floods, etc.

- Type of oil/product
- Geographic location
- Weather
- Sea conditions
- Coastline
- Vigilance
- Traffic density
- Time of day
- Navigation hazards
- Terminal design
- Condition of facilities
- Legislation
- Vessel quality/ age/ seaworthiness
- Vessel types/ sizes
- Types of operation
- Quantities handled
- Frequency of handling
- Training program
- Risk of collision
- Risk of grounding
- Hazards to navigation
- Negligence and competence of the owner/operator, master or crew
- Stowage and control of cargoes
- Environmental factors include tidal flow and weather, etc.

6.3.3 Response Policy

Response actions are developed to address the risks that are identified in the risk assessment. A carefully designed contingency plan will describe major actions that need to be taken when a spill occurs. These actions should take place immediately following a spill so as to minimize hazards to human health and the environment. The primary aims of an oil spill response are to:

- Minimize environmental damage and its economic impacts
- Protect human health and the environment
- Ensure all measures are taken during operation to curtail & prevent further deterioration of the environment.
- Restore the environment, as near as is practicable, to pre-spill conditions

The environmental impact of an oil spill can be minimized by good management and planning and by the response actions put into effect by the Combat Agency. Such actions will largely depend on several factors:

- The type of oil(s) involved
- The size of the spill
- The location of the spill
- The prevailing sea and weather conditions at the spill site
- The environmental sensitivity index of the coastline/offshore area/site impacted

6.3.3.1 Levels of Response

Under the NOSDCP, oil pollution preparedness and response requirements are categorised into three 'tiers'. The tiered approach to oil contingency planning identifies resources for responding to spills of increasing magnitude and complexity by extending the geographic area over which the response is coordinated. It provides a convenient categorization of response levels and a practical basis for planning. The NOSDCP recognizes three levels of tiered response.

Table 6. 4 Three tier concept of oil spill contingency plan

<table>
<tr><th>Tier Level</th><th>Oil Spill Quantity</th><th colspan="2">Responsibility
(Irrespective of quantity)</th></tr>
<tr><td>Tier 1</td><td>Most oil spills are small and can be dealt with locally (Qty: <700 T)</td><td rowspan="3">Offshore or nearshore</td><td rowspan="3">Indian Coast Guard(ICG)/ Oil facilities/Vessel owner/ Deputy Commissioner with assistance From ICG</td></tr>
<tr><td>Tier 2</td><td>If the extent of the oil spill is beyond the local capability or affects a larger area, an enhanced but compatible response will be required(Qty:>700 T - <10,000 T)</td></tr>
<tr><td>Tier 3</td><td>This involves a local plan for a specific facility /major/minor port or oil terminal offshore areas likelihood of impact/risk for the length of coastline from a spill. These local plans may form part of a larger regional or national plan (Qty: >10,000 T)</td></tr>
</table>

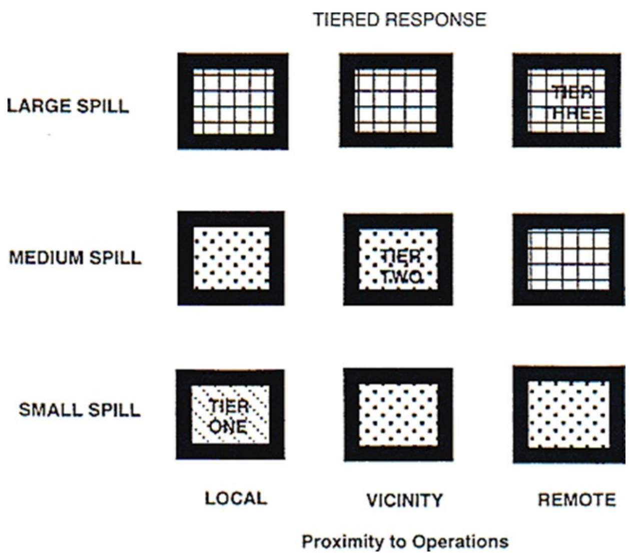

Figure 6. 6 Three tier concept

6.3.4 Emergency Response Units

In managing the counter pollution response to an incident, the hierarchy of aims is:

- First, to prevent pollution from occurring;
- Second, to minimize the extent of any pollution that occurs;
- Third, to mitigate the effects of that pollution

Separate but linked emergency response units would direct operations in the event of an incident requiring response under this plan, as indicated in Table 6.5.

Table 6. 5 Emergency Response Units

Sl	Response Unit	Role
a	Salvage Monitoring and Control Unit (SMCU)	To monitor and control salvage operations
b	Offshore control unit (OCU)	To direct response action at offshore installations
c	Marine Response Unit (MRU)	To direct response action at sea
d	Shoreline Response Centre (SRC)	To direct shoreline response
e	Environment Group (EG)	To provide environmental and public health advice to all these response units
f	Emergency Control Centre (ECG)	To monitor operations to contain any potential pollution within an offshore installation and its reservoir and a port facility jurisdiction

Not all incidents require all these emergency response units. However, the arrangements for managing the incidents must allow for the possibility of salvage operations, action at sea and action onshore taking place simultaneously. The SMCU may be co-located with the MRU, or ECC, if need be. Each oil installation and sea-port facility shall have the provision of an Emergency Control Centre (ECC), preferably with a backup arrangement. The ECC shall be away from potential hazards and provide maximum safety to personnel and equipment. Preference should be given to a non-combustible building of either steel frame or reinforced concrete construction.

The shoreline response centre (SRC) in coastal States may be equipped as required, with specifications for ECC as guidelines.

Each response unit will be supported by an Administration Team responsible for the general management of the unit and provided personnel for:

- Communication links between the units;
- The distribution of messages within the units;
- Keeping records of messages and expenditure;
- Taking minutes during meetings to record decisions;
- Typing services;
- Updating situation boards and charts; and
- Providing catering to the units.

The relevant Indian Coast Guard MRCC acts as a communication hub and provides communication support for all response units.

6.3.4.1 Marine Response Unit

In almost all cases involving a national response, whether ship or offshore installation related, the Indian Coast Guard establishes a Marine Response Unit (MRU) at the nearest MRCC or suitably equipped port ECC. It contains the following persons, although some of the Coast Guard staff may play more than one role.

- An ICG Pollution Response Officer, to manage seaborne and airborne operations;
- Where a ship is involved, an MMD officer to manage cargo transfer operators;
- A Coast Guard Logistics Officer, to organize the deployment of the equipment needed and control all Coast Guard financial commitments;
- If the incident involves a port or its services, a representative of the port authority;

- An officer of the state fisheries department, to advise on the impact on fisheries and to liaise with the fishing organisation;
- A local administration official to act as liaison officer with the Shoreline Response Centre;
- An Environmental Liaison Officer (ELO) nominated by the Environment Group; and
- A Defence Public Relations Officer, to liaison with the media

The Coast Guard will depute additional manpower, including officers and men, to the MRC to assist in the response.

6.3.5 Incident Management Team (IMT)

The facility oil spill contingency plan (OSCP) shall identify the safe transition from normal operation to emergency operations and systematic shut down if any, and the delegation of authority from operations personnel to emergency response personnel. For this purpose, persons in charge of seaports and oil installations shall identify in the facility OSCP an emergency response organization with appropriate individuals to perform designated responsibilities through specified lines of authority with succession planning and actuating the response management in accordance with relevant contingency plan requirements. Responsibilities for decision making shall be clearly shown in an emergency organization chart. The plan shall identify each responder's position, mission, duties and reporting relationship.

Overall objectives of the facility oil spill emergency control organization shall be:

- To promptly control oil pollution problems as they develop at the scene;
- To prevent or limit the impact of oil pollution on other areas and off-site;
- To provide emergency personnel, selected for duties compatible with their normal work functions wherever feasible, with duties and functions assigned making full use of existing organizations and service groups such as fire, safety, occupational health, medical, transportation, personnel, maintenance, and security;

- To provide for employees who must assume additional responsibilities as per laid down procedure of the facility oscp in the event of oil spill contingency;
- To provide for round-the-clock coverage, with shift personnel being prepared to take charge of the emergency control functions or emergency shutdown of the system if need be until responsible personnel arrive at the site of emergency; and
- To provide for an alternate arrangement for each function.

Table 6. 6 Typical facility-level IMT for control of an oil spill

Chief Incident Controller	
Site Incident Controller	
Support Services	Fire safety and fire team/HSE coordinator
Administration and communication coordinator	Operational Team, Technical Team, etc.

Support Services include Communication Services, Engineering/ Maintenance Services, Medical and Occupational Health, Human Resource and Welfare services, Security, Media/ Public Relations, Transport and Logistics, Finance, Contract and Procurement and Environmental Services. The number of staff required to fill positions in the IMT of the emergency organisation can be varied according to the size and complexity of the incident and the number of staff available. In a major incident, all positions may be filled, but one person may fill a number of positions in a lesser incident. In a very small incident, the Site Incident Controller (SIC) will be able to carry out all management functions. Persons in charge of seaports and oil installations ensure that persons with appropriate experience and skills are identified so that they can be appointed to the various positions in the emergency organisation in the event of a marine pollution incident. If agency input into a response is required, the Coast Guard may place its liaison officer/s within the IMT so as not to burden personnel that will be fully engaged in response activities. The concerned Coast Guard Commander takes overall responsibility for the management of the response in the event of tier 2 or tier 3 oil spill and assumes charge of senior government, industry and media liaison.

6.3.5.1 Chief Incident Controller

Persons in charge of seaports and oil installations shall identify appropriate individuals to act as a Chief Incident Controller (CIC). The CIC is responsible for managing and coordinating response operations at the scene of a pollution incident to achieve the most cost-effective and least environmentally damaging resolution to the problem. During a major incident, the CIC is responsible to the relevant Coast Guard Commander for the operational aspects of the response. The Chief Incident Controller (CIC) shall be responsible for protecting personnel, site facilities, and the public before, during, and after an emergency or disaster. The CIC shall be present at the ECC for counsel and overall guidance. Responsibilities of the Chief Incident Controller shall include the following:-

- Preparation, review and update of the OSCP;
- Assessment of situation and declaration of an oil spill emergency;
- Mobilisation of main coordinators and key personnel;
- Activation of ECC;
- Taking decision on seeking assistance from mutual aid members and external agencies;
- Continuously reviewing the situation and deciding on appropriate response strategy;
- Taking stock of casualties and ensuring timely medical attention;
- Ensuring correct accounting and position of personnel after the emergency;
- Ordering evacuation of personnel as and when necessary;
- Taking a decision in consultation with local Coast Guard and District Authorities, when a tier 2 or tier 3 spill is to be declared

6.3.5.2 Site Incident Controller

The Site Incident Controller (SIC) shall be identified by the Chief Incident Controller and will report directly to him. The entity should nominate SIC in each shift of 24 hours. The SIC shall have overall responsibility for managing the response during lesser incidents. Persons in charge of seaports and oil installations should ensure that a response team assists the SIC with appropriate planning, operational, technical, scientific, chemical, environmental, logistical, administrative, financial, and media liaison skills.

Responsibilities of the Site Incident Controller shall include the following:-

- To maintain a workable oil spill emergency control plan, establish emergency control centres, organize and equip the organization with OSCP and train the personnel;
- To make quick decisions and take full charge;
- To communicate to the ECC where it can coordinate activities among groups;
- To be responsible for ensuring that appropriate local and national government authorities are notified, preparation of media statements, obtaining approval from the CIC and releasing such statements once approval received;
- To ensure that the response to the oil pollution emergencies is in line with entity procedures, and to coordinate business continuity or recovery plan from the incident;
- To coordinate any specialist support required for the above purpose; and
- To decide on seeking the assistance of mutual aid members and external agencies

6.3.5.3 Administration and Communication Coordinator

Responsibilities of the administration and communication coordinator shall include the following:-

- To coordinate with mutual aid members and other external agencies;
- To direct them on the arrival of external agencies to respective coordinators at desired locations;
- To mobilize oil spill responders and resources for facilitating the response measures;
- To monitor mobilization and demobilization of personnel and resources;

- To provide administrative and logistics assistance to various teams;
- To be responsible for all financial, legal, procurement, clerical, accounting and recording activities, including the contracting of personnel, equipment and support resources; and
- To be responsible for the management of the ECC.

6.3.5.4 Support Services

The following additional coordinators will be nominated at the seaports and oil installations and delegated the specific responsibilities falling under the basic functions of SIC and/ or CIC:-

- Human Resources Services Coordinator
- Logistics Services Coordinator
- Media and Public Relations Coordinator
- Operations and Technical Coordinator
- Environmental and Scientific Coordinator

6.3.5.5 Local Action Group

The Local Action Group (LAG) provides support to the Union and State Governments in the event of a major oil pollution incident, specifically in the roles of response managers and response team leaders. Each coastal State nominates personnel to the LAG as indicated in table 6.7, except Goa, Puducherry, Daman and Diu, Lakshadweep and Minicoy, and Andaman and Nicobar, which will nominate one response team leader instead of five.

Table 6. 7 Composition of Local Action Group

Role	Positions per State
Planning Coordinator	1
Operations and Technical Coordinator	1
Logistics and Administration Coordinator	1
Response Team Leader	5

6.3.5.6 Local Action Group Support Team

The Local Action Group Support Team (LST) is required to support an incident. The following roles have been identified for a national capacity:

a. Environmental Advisers
b. Finance & Administration Officer
c. Wildlife Officer
d. Equipment Operator
    - Offshore Containment/Recovery
    - Inshore Containment/Recovery
    - The engine driver and Laskar
    - Vessel-based dispersant spraying
    - Shoreline Assessment
    - Shoreline Cleanup

6.3.6 Environment Advice and Monitoring group

Response to any maritime incident requiring a regional or national response would involve the establishment of an Environment Group. All those involved in operations at sea (including salvage) and shoreline clean up need timely environmental advice. The Environment Group would:-

- Perform a purely advisory role;
- Advice on environment aspects and public health impacts of the incident and associated response operations both, real and potential;
- Being a common facility, provide comprehensive advice to all response units and represent all environmental and public health interests considered being at risk;
- As well as provision of expert advice based on immediately available and prepared data and information, may encourage the collection of real-time environmental data by the relevant government agencies; such environment data may provide accurate baseline data of vulnerable environmental features

immediately before the impact of the pollution plume, so that risk can be identified and the damage can be quantified;

- Track the success of preventive and counter pollution measures throughout the incident, and begin to assess the overall long term environmental impact, dependent on the timely provision, from each response unit, of all relevant information on the fate and modelling of pollutants, and each unit's forecasts, plan actions and outcomes; and
- If a marine pollution incident is expected to have a significant impact on the marine environment or the shoreline, promptly make arrangements to monitor and assess the impact in the longer term.

Response units will make all reasonable efforts to consult the Environment Group or its chair about any proposed action that is likely to have a lasting impact on the environment. Suppose time does not permit the response unit to consult before acting. In that case, it will circulate a written report to the Environment Group and all other response units as soon as possible after the action (or decision) has been taken. The statutory environment protection or fishery authority will consult locally with the standing Environment Group members. The Coast Guard would initiate the request on the relevant civil, administrative authority to form the Environment Group. The core membership of the Group would come from the relevant statutory authorities and include relevant civil administration authorities, forest and wildlife authorities, fisheries authorities, Block Development Officer, local public health officials and relevant non-governmental organisations for appropriate expert advice. The Group may also include a Coast Guard representative. The chair decides when it is necessary to convene the Environmental Group at the scene of the incident and appoint an Environment Liaison Officer for each response unit established

6.3.7 Statutory and Combat Responsibilities

Responsibilities for responding to oil spills in Indian waters are shared between the Indian Coast Guard, State Governments, Port Authorities and Corporations, and the oil industry. Liability for clean-up of both oil and HNS spills remains with the polluter.

6.3.7.1 Statutory Agencies

The Statutory Agency is responsible for the institution of prosecutions and the recovery of cleanup costs on behalf of all participating agencies. The Statutory Agencies for oil spills are appended in table 6.8.

Table 6. 8 Statutory agencies for oil spills

Source/Location	Statutory Agency
from ships	the relevant Designated Authority under the Merchant Shipping Act, 1958
from offshore installations and upstream pipelines	the relevant Designated Authority under the Petroleum Act, 1934
from shore terminals, refineries and downstream pipelines	the relevant Designated Authority under the Petroleum and Natural Gas Regulatory Board Act, 2006
in major ports	the relevant Port Authority under the Major Ports Act
in non-major ports	the relevant Designated Authority in the Coastal State, or Union Territory

6.3.7.2 Combat Agencies For Oil Spills

Combat Agencies have the operational responsibility to take action in order to respond to an oil spill in the marine environment in accordance with the relevant contingency plan. The Combat Agency responsible for responding to marine oil spills in various locations is at table 6.9.

Table 6. 9 Combat Agency for oil spills

Source / Location	Combat Agency
at oil terminals	The relevant oil company or terminal operator using industry mutual-aid arrangements as required. Should a situation develop where the necessary response is beyond the oil company or terminal resources, or mutual-aid arrangements, responsibility for control will transfer to the Statutory Agency, with response assistance from other National Plan stakeholders as required
in ports	The port operator or responsible State Government authority, with response assistance from other National Plan stakeholders as required
within shoreline and in intertidal zones	The responsible State Government authority with response assistance from other National Plan stakeholders as required
beyond baseline	The Ministry of Defence via Indian Coast Guard, with response assistance from other National Plan stakeholders as required. In incidents close to shore when oil is likely to impact the shoreline, the State Government via the Statutory Agency will be the Combat Agency for protecting the coastline, whilst DG Shipping assumes responsibility for ship operational matters, for example, containing the oil within the ship, organizing salvage, etc.
spills emanating from offshore petroleum ops	The relevant company with assistance from the Statutory Agency and other National Plan stakeholders as required

6.3.8 Oil Spill Response and Action Strategy

Whenever there is an emergency following steps shall be followed:

- Identification / Notification of emergency
- Activation of spill management response strategy for cleanup

- Positioning and activation, and communication of cleanup committee
- Cleanup completion intimation
- Documentation

To mitigate any possible oil spill/incident/accident during the voyage, the following shall be provided by the concerned Authority

Coordination & Control of Emergency

- A coordination cum monitoring committee will be formed at the concerned authority centre for round the clock monitoring of the voyage of the vessel
- Important telephone no/contact detail of port emergency handling team, district administration officials, police, hospitals, fire stations etc., shall be maintained.
- The concerned authority should have tie-ups with nearby hospitals to take up the emergency case on priority & mutual aid programmes.
-

The risk of accidental spillage of oil from ship and cargo handling poses a threat to marine and land-based resources. This requires careful and advanced planning to ensure that the oil spill's impact on the environment is minimized or contained. Proactive measures such as the display of zero tolerance information boards for all kinds of pollution in all important areas of operation are expected to lead to extra care regarding pollution. "Zero Tolerance for any kind of pollution" will be adopted as the core philosophy of the environmental monitoring plan. This plan delineates the response to the emergency actions to be taken during oil spillage. Based on the suggestions and guidance from an appropriate agency such as Indian Coast Guard official's oil spill response equipment such as brush skimmer system, containment booms, absorbent booms, storages for recovered oil etc., will be acquired.

6.3.8.1 Communication Facilities

Communication facilities for transmitting information related to the emergency are given below:

- The incident control room at the project site
- Wireless services will be available to coordinate with emergency control units

- Adequate communication system onboard including PPEs, Firefighting, Emergency contact nos., lifesaving equipment's, First Aid services, Signals etc. Oil spill management assistance is expected to reach the incident spot within 1 to 2 hrs. of accidents/spills.

6.3.9 Oil spill management facilities

Oil is one of the most abundant pollutants in the oceans. About 3 million metric tons of oil contaminate the oceans annually. However, oil spills vary in severity and the extent of damage they cause. This can be attributed to variations in the oil type, the location of the spill, and the weather conditions present. In addition, the spread and behaviour of spilled oil in the seas is governed by various chemical, physical and biological processes. But irrespective of these, oil spills are a serious concern as they can inflict a lot of damage to the ecosystem. The effects are experienced not only in the area of the spill but also expand over vast regions to negatively impact shorelines and terrestrial wildlife thousands of metres away from the site of the spill. Since oil density is lesser than water, it floats on the water surface when it leaks or spills (saltwater or freshwater). For this reason, it is much easier to clean up an oil spill. It is easy to imagine the difficulty in cleaning up a spill if oil was denser than water, and as a result, formed a layer along the bottom of the seas instead of the surface. Oil spills will continue to be a pressing problem and source of pollution as long as ships move most of the petroleum products around the world, and exploration of oil from oceanic resources is steadily on the rise. Nevertheless, oil spills mostly occur accidentally, and thus it becomes increasingly important to employ various cleanup methods for tacking the menace they could pose to the marine ecosystem.

6.3.9.1 Details of different types of oil spills clean-up methods

The Coast Guard District or Regional Commander decides on actions to contain, disperse, or neutralise pollution and remove potential pollutants from the scene. These decisions include the different methods of response, namely, assessment and monitoring, dispersant spraying operations, mechanical recovery operations, and cargo transfer operations. The aim of any cleanup operation is to minimize the damage (environmental, ecological, amenity or financial) that the spill would cause. Once the oil has been spilled, urgent decisions need to be made about the options available for clean-up so that environmental and socioeconomic impacts are kept to a minimum.

Different methodologies can be adopted to clean up oil spills. Some of the few important and commonly used methods can be explained as follows:

1. Using Oil Booms

Containment booms are used to control the spread of oil, reduce the possibility of polluting shorelines and other resources, and concentrate oil in thicker surface layers, making a recovery easier. In addition, booms may be used to divert and channel oil slicks along desired paths, making them easier to remove from the surface of the water. Although there is a great deal of variation in the design and construction of booms, all generally share four basic characteristics:

- An above-water “freeboard” to contain the oil and to help prevent waves from splashing oil over the top of the boom
- A flotation device
- A below-water skirt to contain the oil and help reduce the amount of oil lost under the boom
- A “longitudinal support,” usually a chain or cable running along the bottom of the skirt that strengthens the boom against wind and wave action; may also serve as a weight or ballast to add stability and help keep the boom upright

2. Using Skimmers

Once the oil has been confined by using oil booms, skimmers or oil scoops can be deployed onto boats to remove the contaminants from the water surface. Skimmers are machines specially designed to suck up the oil from the water surface like a vacuum cleaner. They are used to physically separate the oil from the water to be collected and processed for re-use. Skimmers may be self-propelled and may be used from shore or operated from vessels. The efficiency of skimmers depends on weather conditions. Skimmers tend to recover more water than oil in moderately rough or choppy water. There are three types of skimmers— weir, oleophilic, and suction. Each type offers advantages and drawbacks, depending on the type of oil being cleaned up, the conditions of the sea during cleanup efforts, and the presence of ice or debris in the water.

3. Using Sorbents

Sorbents are materials that soak up liquids. They can be used to recover oil through the mechanisms of absorption, adsorption, or both. Absorbents allow oil to penetrate into pore spaces in the material they are made of, while adsorbents attract oil to their surfaces but do not allow it to penetrate into the material. To be useful in combating oil spills, sorbents need to be both oleophilic and hydrophobic (water-repellant). Although they may be used as the sole cleanup method in small spills, sorbents are most often used to remove final traces of oil or in areas that skimmers cannot reach. Once sorbents have been used to recover oil, they must be removed from the water and properly disposed of on land or cleaned for re-use. Any oil that is removed from sorbent materials must also be properly disposed of or recycled

4. Using Dispersants

When the spilt oil cannot be contained by using booms, the only option left is to accelerate the disintegration of oil. Dispersal agents, such as Corexit 9500, are chemicals that are sprayed upon the spill with the help of aircraft and boats, which aid the natural breakdown of oil components. They allow the oil to chemically bond with water by increasing the surface area of each molecule. This ensures that the slick does not travel over the water's surface and is easier to degrade by microbes. Dispersants are most effective when applied immediately following a spill, before the lightest components in the oil have evaporated.

5. Hot Water and High-Pressure Washing

This procedure is mainly used when the oil is inaccessible to mechanical removal methods such as booms and skimmers. It is used to dislodge the trapped and weathered oil from generally inaccessible locations to machinery. Water heaters are used to heat water to around 170°C, then sprayed by hand with high-pressure wands or nozzles. The oil is thus flushed to the water surface, which can be collected with skimmers or sorbents.

6. Using Manual Labour

As the name suggests, the method requires hand-held tools and manual labour to clean up the contaminants. It involves using manual means like hands, rakes, shovels etc., to clean the surface oil and oily debris and place them in special containers to be removed from the shoreline. Sometimes, mechanized equipment may be employed for providing any additional help and reaching out to any inaccessible areas.

7. Biological agents

Biological agents are nutrients, enzymes, or microorganisms that increase the rate at which natural biodegradation occurs. Biodegradation is a process by which microorganisms such as bacteria, fungi, and yeasts break down complex compounds into simpler products to obtain energy and nutrients. Biodegradation of oil is a natural process that slowly— over the course of weeks, months, or years—removes oil from the environment. However, rapid removal of spilled oil from shorelines and wetlands may be necessary in order to minimize potential environmental damage to these sensitive habitats. Bioremediation technologies can help biodegradation processes work faster. Bioremediation refers to the act of adding materials to the environment, such as fertilizers or microorganisms, that will increase the rate at which natural biodegradation occurs. Furthermore, bioremediation is often used after all mechanical oil recovery methods have been used.

8. Chemical Stabilisation of oil by Elastomizers

Right after an oil spill, the immediate concern is to prevent the oil from spreading and contaminating the adjacent areas. While mechanical methods like using oil booms effectively contain the oil, they have certain limitations to their use. Experts have recently been using compounds like 'Elastol', which is basically poly iso-butylene (PIB) in a white powdered form, to confine oil spills. The compound gelatinizes or solidifies the oil on the water surface, thus preventing it from spreading or escaping. In addition, the gelatin is easy to retrieve, and this makes the process highly efficient.

9. Natural Recovery

The simplest method of dealing with the oil spill cleanup operation is to use the vagaries of nature like the sun, the wind, the weather, tides, or naturally occurring microbes. It is used in certain cases when the shoreline is too remote or inaccessible, or the environmental impact of cleaning up a spill could potentially far outweigh the benefits. Due to the constancy of these elements, the oil generally evaporates or is broken down into simpler components.

The treatments follow a general rule: (All distances measured from the shoreline)

Table 6. 40 Distance from the shore and treatments

Distance from shore	Treatment methods
200 nautical miles and beyond	No treatment is used unless the case is very severe
Between 20 and 200 nautical miles	Booms and skimmers may be used
Between 20 and 10 nautical miles	Dispersants are used
For areas very close to the shoreline	Biological agents are used

These are only general rules and can be altered based on the type of oil that has been spilled and the prevailing weather conditions. No two oil spill cases are the same, so each one is evaluated individually based on its own merit.

6.3.10 Salvage

If there is a threat of significant pollution the MRCC contacts the salvor or, if not yet appointed, the master or owner of the ship, and the harbour master, if the incident is in a port or its approaches, and offers assistance. The MRCC states that intervention powers may be exercised and instructs those in command of the vessel to provide the Indian Coast Guard information which must include:

- Whether the owner has appointed a salvor and, if so, its name and contact details;
- The broad nature of the contract between owner and salvor;
- Information on the intentions of the salvor; and
- Any other important information that has not yet been gathered.

Simultaneously, as a pollution prevention tactic, the MRCC may also task the contracted emergency towing vessel (ETV) to proceed to the area. The Indian Coast Guard District, Regional or Seaboard Commander decides whether it is necessary to set up a SMCU based on the merits of the incident. The members of the SMCU are;

- The Indian Coast Guard District or Regional Commander;
- The Salvage Manager from the salvage company appointed by the shipowner;
- The harbour master, if the incident involves a harbour or its services;
- A single representative nominated by agreement between the shipowner and insurers (for both the physical property and their liabilities);
- The District or Regional Pollution Response Officer;
- A Surveyor from the Mercantile Marine Department;
- A Surveyor from the Indian Register of Shipping, if required; and
- An Environment Liaison Officer, nominated by the Environment Group.

In the event that the SMCU is co-located with an MRU, the membership of the SMCU needs to include the members of the MRU with Indian Coast Guard staff fulfilling more than one role. The Indian Coast Guard District, Regional or Seaboard Commander uses all the information to assess whether the actions proposed are in the public interest. One of the actions could be the consideration of appropriate places of refuge. And what could happen if the current salvage plan goes wrong or the incident escalates in severity.

6.3.10.1 The Role of The Coast Guard For Offshore Installation

Incidents occurring at an offshore installation fall under the remit of the installation’s oil spill response plan. In general, when there is a release of oil from an installation, the tasks of containing and responding to the oil on the water are identical to when a ship spills oil. The installation manager is in control of the implementation of the emergency plan at the installation, while onshore, the company activates its ECC. The role of the ECC is to support the installation manager offshore. The company has a duty to implement its plan to contain the spill and minimize the environmental damage caused. There is unlikely to be a need to exercise the Central Government's powers of intervention. Nevertheless, in a major spill, or where there is a threat of significant pollution, the Manager of the Offshore Installation informs the Coast Guard, who monitor the progress of the incident as it is being managed at the operator's ECC. The operator also initiates action to set up the Offshore Control Unit (OCU). The approved oil spill contingency plan for the installation must identify the location for the OCU, and it needs to be in close proximity to be operator's Emergency Control Centre. The OCU requires the same support and structure as an SMCU and similar links to their operations units engaged in other tasks, including search and rescue, at sea clean up and shoreline clean up, as appropriate. The administrative support required by the OCU will be provided by MoPNG or any suitable department or organisation designated by the MoPNG.

The members of the OCU are:-

- The Coast Guard Commander;
- The CIC, who acts as a link between Coast Guard and the ECC where is a line to the Offshore Installation Manager;
- The Operator's Representative, who represents the interests of the owner, operator, contractors, and liability underwriters of the offshore installation;
- An Environmental Liaison Officer, nominated by the Environment Group, who advises the Coast Guard on the environmental implications of any proposed actions;
- The DGH, who provides the Coast Guard with advice on the importance of the installation to strategic supplies and other matters of public interest; and

- A specialist or technical advisor to the Coast Guard, either from the operator, the DGH or an independent source, provides advice as required.

6.3.11 Monitoring

Many chemical spills will be difficult or impossible to observe with the naked eye. It is essential that an appropriate monitoring strategy is put in place to ensure the safety of responders and confirm predictions of the spread and dispersion of the slick. The type of monitoring implemented will depend on the specific properties and hazards posed by the substance involved.

6.3.11.1 Monitoring Gases In Air

It is essential to systematically monitor the concentrations of chemicals in the air throughout any incident involving gases or vapours. Key aspects of monitoring include:

- Oxygen concentrations
- Combustible or explosive gas levels
- Toxic substances

6.3.11.2 Monitoring The Water Column

Monitoring the concentration of chemicals in the water column typically involves two main techniques:

a. Collecting water samples – these are then transferred for analysis at fixed or mobile laboratories;
b. Use of towed probes – many monitoring devices can be towed through the water column to establish the extent of a slick and provide real-time data. Typical measurements include pH, light absorption, electrical conductivity.

6.3.11.3 Monitoring Surface Slicks

Thin films on the sea surface can dampen capillary waves. A number of techniques have been developed that make use of the altered properties of the sea surface:

a. Side-Looking Airborne Radar (SLAR) makes use of the reduced intensity of the backscatter, and the surface slick appears as a darker area on the SLAR image;
b. UV scanners can identify changes in the UV reflectivity of the sea surface;
c. IR scanners and Forward-Looking Infrared Imagers (FLIR) identify changes in the radiation temperature of the sea surface.

The effectiveness of these techniques differs depending on the properties of the chemical involved and the environmental conditions. Understanding the available resources and their applicability is a key part of the contingency planning process.

6.3.11.4 Monitoring Sunken Spills

When a pool of liquid chemicals collects on the seabed, there will be a phase boundary between the chemical and the seawater. It may be possible to use echo sounders to locate this phase boundary and hence to identify the area affected by the spill. Monitoring of the concentration of the spilt substance at different depths may also be useful to delineate the area affected.

6.3.12 Improving contingency plan with GIS, Remote sensing, Airborne monitoring and Numerical Modelling

6.3.12.1 GIS (Geographic Information System)

Contingency planners and other response organizations are now using geographic information systems (GIS) to make contingency plans better and easier to use. GIS makes electronic maps that can focus attention on the locations of things that are important to planners and oil spill responders. For example, planners can make maps showing sensitive environments, drinking water intakes, roads, oil storage and production facilities, pipelines, and boat launches. GIS can also provide detailed information about each of the items shown on a map, such as how large an oil storage facility or pipeline is, whether a road is paved, or the times of the year that sensitive species are in the area.

6.3.12.2 Remote sensing

The ability to remotely detect and monitor oil spills at sea is becoming increasingly important due to the constant threat posed to marine wildlife and the ecosystem. As the demand for oil-based products increases, shipping routes will consequently become much busier, and the likelihood of slicks occurring will also increase. If applied correctly, remote sensing can act as a beneficial monitoring tool. It can allow for early detection of slicks, provide size estimates, and help predict the movement of the slick and possibly the nature of the oil. This information will be valuable in aiding clean-up operations and will not only help save wildlife and maintain the balance of the local ecosystem but will also provide damage assessment and help to identify the polluters.

Remote sensing allows for the detection and monitoring of oil spills. Typical platforms are satellites and aircraft.

6.3.12.3 Airborne oil spill monitoring

Airborne oil spill monitoring has become a global concern over the last three decades. Currently, there is a multitude of specialized airborne remote sensing systems all around the world, which are operated for this purpose, especially for the deterrence of potential polluters and the support of oil spill clean-up activities. Recently, more attention has been given to the automated processing of remotely sensed oil spill data acquired by airborne multi-sensor platforms in terms of data analysis and fusion. Using satellite platforms to monitor oil spills is more cost-effective than applying airborne monitoring techniques, but aircraft operation is still the only possible way to perform spatiotemporally flexible surveillance, so airborne monitoring can be seen as complementary to satellite monitoring. Existing users advocate a combined satellite and airborne monitoring service.

6.3.12.4 Numerical Modelling

Oil spill models are numerical tools capable of (a) forecasting the trajectory of a spill, (b) estimating the time needed for the spill to reach specific areas of interest, and (c) assessing its state when it arrives at the modelled locations. The first two issues require accurate data on winds, currents, and waves in the broader area of the oil spill accident, while the third issue requires a deep understanding and reliable algorithms of the oil weathering processes. Authorities may use oil spill models for contingency planning and emergency response to a crisis occurring due to accidental oil releases. In conjunction with an oil spill model, such planning may lead to a deeper understanding of the effects of oil weathering processes on oil spillage, at the surface and within the water column, and thus to improved methods to monitor and clean it up. Generally, to run an oil spill model, the following data are required as a minimum: (a) oil spill scenario details, (b) oil properties, (c) metocean data, and (d) output requirements. The necessary oil spill data to define initial conditions include the oil spill location, time and areal coverage of the spill, rate and duration of spillage, type of oil, and age of the oil spill from initial arrival in the sea.

6.3.12.4.1 Different types of oil spill models

Some of the most widely used oil spill models capable of forecasting the trajectory and fate of surface and/or deep-sea oil spills are: CDOG, OSCAR, OSIS, OILMAP, OILMAPDEEP, SIMAP, TAMOC, BLOSOM, MOTHY, OILTOX, MOHID, POSEIDON OSM, MEDSLIK, GNOME, OILTRANS, OSERIT, MEDSLIK-II, and OpenOil.

6.4 Decommissioning of offshore oil and gas structures

The offshore oil and gas industry had its beginnings in the Gulf of Mexico in 1947 (Day, 2008). The initial design of multiplied steel jackets to support the topside production facilities has since been used extensively. More than 7000 drilling and production platforms are now located on the Continental Shelves of 53 countries (JPT, 1995; Parente et al., 2006; Day, 2008). As the oil and gas fields begin to deplete their reserves, the concern then turns to removing and disposing of these structures (Day, 2008).

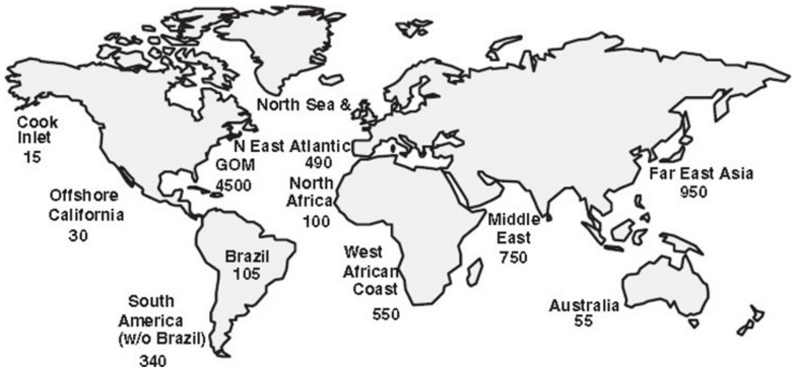

Figure 6. 7 Global Distribution of Platforms. Updated from Ferreira (2003) with numbers compiled from various sources, including government reports, industry reports and academic literature

Decommissioning is the process that the operator of an offshore oil or gas installation and pipeline goes through in order to plan, gain approval for and implement the removal, disposal or re-use of an offshore installation when it is no longer needed for its current purpose.

It has five distinct stages:

- Options are developed, assessed, selected, and put through a detailed planning process that includes engineering and safety preparation.
- The operator has to stop oil or gas production, plug the wells deep below the surface, and make them safe.
- All or part of the installation usually has to be removed from the site.
- Those parts that are removed have to be disposed of or recycled.
- Seabed surveys are carried out and ongoing monitoring if any part of the platform/facility remains in place.

In summary, decommissioning is the process of deciding how best to shut down operations at the end of a field’s life, closing the wells, cleaning up, making the installation safe, removing some or all of the facilities and reusing or disposing of them as appropriate. There are strict international, regional and national guidelines and regulations governing the decommissioning process. Most installations will eventually be reused, recycled or scrapped onshore. Each oil and gas installation is unique, designed and built for a particular location, water depth and environmental conditions, and subject to the technology available at design, construction, and installation. Deciding on the best decommissioning process for each installation and pipeline is a complex, rigorous process demanding the highest degree of responsibility and care to balance the protection of the environment and other sea users with health, safety, and technological and economic considerations during decommissioning activities.

An extensive worldwide regulatory framework governs the removal and disposal of offshore installations. The framework includes global conventions and guidelines, regional conventions and national laws. The prime global authority is the International Maritime Organization (IMO), and in addition, the London Convention is the global convention governing the dumping of waste and material at sea. Under certain circumstances, the London Convention governs the issue of permits for the disposal of installations at sea. Finally, national governments have specific laws governing the operation, including decommissioning.

The sub-sections which follow set out and briefly describe the relevant provisions by way of background

6.4.1 Global regulatory regime

The global regulatory regime, which has evolved over the past forty years, is intended to strike a balance between the need to protect the environment, navigation, fishing and other sea users on the one hand, and to take into account safety, technical feasibility and the cost of decommissioning on the other hand.

The global regulatory regime consists of:

- **Geneva Convention on the Continental Shelf 1958**
  Article 5(5) calls for total removal
- **Convention on the Prevention of Marine Pollution by Dumping of Wastes and other Matter 1972 (London Dumping Convention)**
  Controls dumping at sea

- **UN Convention on the Law of the Seas 1982 (UNCLOS)**
  Article 60(3) permits partial removal provided IMO criteria are met
- **IMO Guidelines and Standards for the Removal of Offshore Installations and Structures on the Continental Shelf 1989**
  Establishes removal criteria

6.4.2 Basic Abandonment Process

The basic process in decommissioning and abandonment of an offshore installation or pipeline is as follows,

- Shut down of production and abandonment of wells
- Decommissioning of the process systems
- Isolation and closing of export/ import pipelines for decommissioning separately
- Shut down and decommissioning of the utility systems
- Phased shut down of the life support and safety systems
- Deconstruction, removal and disposal of the topside facilities
- Removal of the substructure.

Whichever abandonment option is selected, it is a precondition that production is shut-in and the wells abandoned, the risers disconnected after flushing through and cleaning the pipeline, and finally, the processing system is decommissioned, inventory materials removed and the platform left in a safe condition. Options then are what to do with the redundant facility.

6.4.3 Existing Decommission methods in India

All platforms and other facilities must be decommissioned as per the approved Abandonment Plan. All production risers must be flushed with seawater before they are removed.

6.4.3.1 Abandonment Plan for a Platform or other facility

Submit the following information (as relevant) as part of the Abandonment Plan for approval to the OISD:

(a) Identification of the applicant including:

1. Contractor;
2. Address;
3. Contact person and telephone number, email, fax and
4. Shore base.

(b) Identification of the structure that will be decommissioned, including:

1. Platform Name
2. Location (lease, area, block, and block coordinates);
3. Date installed (year);
4. Proposed date of decommissioning (Month/Year); and
5. Water depth.

(c) Description of the structure to be decommissioned, including:

1. Configuration (attach a photograph or a diagram);
2. Size;
3. Number of legs/casings/pilings;
4. Diameter and wall thickness of legs/casings/pilings;
5. Whether piles are grouted;
6. Brief description of soil composition and condition;
7. The sizes and weights of the jacket, topsides (by module), conductors, and pilings; and

(d) Identification of the purpose, including:

1. Lease expiration date; and
2. Reason for removing the structure.

(e) An overview of the removal method,

(f) Plans for transportation and disposal (including as an artificial reef) or salvage of the removed platform.

(g) The results of any recent biological surveys conducted in the vicinity of the structure and recent observations of turtles or marine mammals at the structure site.

(h) Plans to protect archaeological and sensitive biological ecosystem during removal operations, including a brief assessment of the environmental impacts of the removal operations and procedures and mitigation measures to take to minimize such impacts.

(i) A statement of whether or not divers will be used to survey the area after removal to determine any effects on marine life.

6.4.3.2 Information to be submitted once a platform or other facility has been decommissioned

a) Within 90 days after the decommissioning of a platform or other facility, submit a written report to the OISD that includes the following: A summary of the decommissioning operation, including the date it was completed;
b) A description of any mitigation measures taken; and
c) A statement signed by an authorized representative certifies that the types and amount of explosives used in removing the platform or other facility were consistent with those set forth in the approved Abandonment Plan.

6.4.3.3 Decommissioning Pipelines

Pipelines are to be decommissioned and left in-situ to decommission a pipeline in place:

a) Submit the following information as part of the Abandonment Plan for approval to the OISD:
b) Reason for the operation;
c) Proposed decommissioning procedures;
d) Length (meters) of the segment to be decommissioned.
e) Plans for disposal and salvage
f) Stretch of the pipeline passing through eco-sensitive areas like national parks, wildlife sanctuaries, protected areas, etc, at landfall point and plan of their protection.
g) Pig the pipeline, unless pigging is not practical;
h) Flush the pipeline;
i) Fill the pipeline with seawater;

j) Cut and plug each end of the pipeline;
k) Where required, bury each end of the pipeline at least 1 meter below the seafloor or cover each end with sand/ concrete mattress;
l) Remove those pipeline valves and other fittings that could unduly interfere with other uses of the seafloor.

6.4.3.4 Post Pipeline Decommissioning

Within 90 days after the completion of pipeline decommissioning, submit a written report to the OISD that includes the following:

a) A summary of the decommissioning operation, including the date it was completed;
b) A description of any mitigation measures taken; and
c) A statement signed by an authorized representative certifies that the pipeline was decommissioned according to the approved Abandonment Plan.

6.4.4 Environmental effects of Decommissioning

6.4.4.1 Biodiversity

Decommissioning options likely differ considerably in their effects on biodiversity, particularly between partial and complete removal options, the latter of which will result in almost complete loss of associated reef biota (Claisse et al., 2015; Pondella et al., 2015). Structures can enhance taxonomic and functional diversity by adding hard substrate in areas characterised by soft-bottom communities. Complete removal is therefore likely associated with localised biodiversity reductions in areas dominated by soft-bottom habitats. The relative effects of the various partial removal options are more nuanced and depend on the structure and composition of associated communities (Ajemian et al., 2015; Simonsen, 2013). Studies comparing biological communities between natural reefs, operating and reefed platforms highlight the influence of depth, vertical relief and physical characteristics of structures on associated fish assemblages, and suggest that reefing will likely alter assemblage composition (Ajemian et al., 2015; Claisse et al., 2015; Simonsen, 2013). For example, in the Gulf of Mexico, fish assemblages significantly differed in composition and community structure among operating and horizontally reefed platforms but did not differ among operating and topped structures, suggesting that the latter would impact fish assemblages less (Ajemian et al., 2015). Research on fouling and benthic communities has been limited, with no discernible differences among operating and horizontally reefed structures for coral density (Sammarco et al., 2014), or for benthic communities both b0.25 and N1.5 km from platforms in the Gulf of Mexico (Daigle, 2011).

6.4.4.2 Biomass production

O&G structures support significant biomass of sessile invertebrates and fish assemblages (Macreadie et al., 2011), with fouling communities increasing the total weight of structures in the North Sea by up to 30% (Pors et al., 2011). Although these biological communities may, to some extent, represent biomass redistribution, rather than production (Bohnsack, 1989), the fish production potential of the structures was recently demonstrated off California, with structures in this region having the highest secondary fish production per unit area of seafloor of any marine habitats investigated (Claisse et al., 2014). While complete removal of the structures will eliminate most of the existing biomass (Claisse et al., 2015; Pondella et al., 2015), partial removal typically leads to a decline in fish biomass and production for species associated with the shallow portions of the structure that may be removed, such as schooling planktivores and large pelagic predators (Claisse et al., 2015; Simonsen, 2013). Deeper-dwelling demersal species are generally less affected. This suggests that the types of biological communities associated with the structure and their depth stratification influence the site-specific outcomes of decommissioning, and it is plausible that in systems where demersal fishes are dominant (e.g., in California; Claisse et al., 2015), the loss of production caused by partial decommissioning is reduced. For example, in California partial removal would likely retain on average 80% of fish biomass and 86% of secondary fish production (Claisse et al., 2015). Generally, habitat value appears to vary greatly among structures, even when they are in similar ecological settings (Schroeder and Love, 2004) and productivity data from one platform should be used with caution when considering the productivity of other platforms (Fowler et al., 2015).

6.4.4.3 Conservation

O&G structures are considered de facto marine protected areas (Inger et al., 2009; Schroeder and Love, 2004) because they protect biota and habitats from fishing within the safe-working exclusion zones that surround platforms. Decommissioning options that leave the entire or partial structure in place have the potential to act as exclusion zones for specific gear types, particularly trawling, through the risk of entanglement and collision. In addition to conservation benefits, the exclusion of trawling has the potential to enhance fisheries due to the export of fish and larvae to surrounding areas ('the spillover effect'; Russ and Alcala, 2011; Williamson et al., 2016) and the protection of sensitive benthic habitats that act as nursery areas for fish. For example, in Norway, between 30 and 50% of Lophelia pertusa reefs have been damaged or destroyed by bottom trawling, with reports of reduced catch rates of line fishermen in damaged L. pertusa reefs (Fosså et al., 2002). The complete removal of structures will enable trawling in former safety zones, disturbing drill cuttings and resuspending contaminated sediments (Pors et al., 2011). In the North Sea alone, complete removal of all structures would open up ~400 km2 of seabed to trawling.

6.4.4.4 Connectivity

The spatial distribution of structures in the marine environment affects connectivity and consequently biodiversity and ecosystem function at a range of spatial scales (reviewed in Bishop et al., 2017). Ecological communities from artificial and natural habitats interact in complex ways and the removal of structures that have been in place for extended periods may disrupt ecological processes. In regions with sparse natural reef habitat (e.g., North Sea, Gulf of Mexico), structures may facilitate connectivity over large distances for taxa with widely dispersive life stages such as corals (Atchison et al., 2008; Sammarco et al., 2012), and may provide stepping stones for species (Bishop et al., 2017; reviewed in Cordes et al., 2016). A potential risk of decommissioning options that involve transporting structures is the unintended spread of non-native species. For example, a towed rig that became unintentionally stranded on a remote island in Brazil transported 62 non-native sessile species to the new location (Wanless et al., 2010).

6.4.4.5 Energy consumption and carbon footprint

All decommissioning options involve fuel consumption and the production of greenhouse gases, with energy use and atmospheric emissions part of the prescribed assessment criteria in certain jurisdictions (e.g., UK). Energy use is typically divided into 'direct energy consumption' for diesel-powered vessel movement (e.g., towing structures to distant recycling locations), dismantling and onshore processing activities, and 'indirect energy consumption': 'recycling energy' (mostly steel) and 'replacement energy', a theoretical amount accounting for the production of new materials that replace materials left at sea. Complete and partial removal options generally involve higher direct energy consumption and emissions s than leave in place options (Pors et al., 2011). For example, the energy consumption to remove and recycle the steel jackets of the Ekofisk platforms in Norway was estimated at 40% of the annual electricity consumption of a city with 100,000 residents (Phillips Petroleum Company Norway, 1999). Nevertheless, energy use and atmospheric emissions need to be evaluated on a case-by-case basis to account for variation in the types and duration of marine operations for different structures (Pors et al., 2011). Moreover, the relative energy performance of decommissioning options might change when replacement energy is considered (e.g., Phillips Petroleum Company Norway, 1999). Emissions calculations add further complexity, with direct energy use generally incurring higher emission factors (a combination of fuel efficiency and engine design) than recycling and material production (Pors et al., 2011).

6.4.4.6 Direct physical disturbance

All decommissioning options involve some physical disturbance to biota and habitats. Leaving structures in place involves the least disturbance because only the wellbore needs to be plugged. Dismantling and severance of structures from the seafloor typically involve diamond wire cutting, abrasive water jetting, hydraulic shears or explosives (NOAA, 2017), which have the potential to damage organisms and habitats. O&G structures made primarily of steel will slowly disintegrate and collapse if left in place, with full corrosion of the structures expected to take over 500 years (Picken et al., 1997). Decommissioning options that involve handling and transport of structures pose safety risks (e.g., collisions, accidents, spills), increase the risk of damage to existing infrastructure and natural habitats, particularly in shallow coastal areas with a high prevalence of sensitive habitats (e.g., coral reefs), but also in the deep sea, where cold-water corals are particularly slow to recover (Roberts and Cairns, 2014).

6.4.4.7 Dispersal of contaminants

Decommissioning can disperse contaminants through the disturbance of drill cuttings located on the seafloor beneath the O&G structures (Breuer et al., 2004; Cordes et al., 2016). Estimates indicate that up to 12 million m3 of drill cuttings lie on the seafloor in the North Sea alone (Breuer et al., 2004). Associated contaminants are likely to remain within the cuttings pile unless they are disturbed (Breuer et al., 2004), which is typically the regulatory direction given to O&G operators. The severance of the structures from the seabed has the potential to resuspend contaminants, with potential disturbance of drill cuttings where topped sections of platforms are placed beside the base of the structure. Decommissioning options that leave components in place contribute to localised contamination by slow degradation of materials, such as anode material commonly used in marine environments to protect structures against corrosion (Picken et al., 1997). To address this, O&G operators are typically required to characterise substances associated with the structures, the extent to which they may be dispersed during and after decommissioning, and the potential exposure of biota to contaminants (e.g., OSPAR Decision 98/3).

6.5 Naturally Occurring Radioactive Materials in Oil and Gas Industry

Naturally Occurring Radioactive Materials (NORM) have been known to be present in varying concentrations in hydrocarbon reservoirs. These NORM under certain reservoir conditions can reach hazardous contamination levels. The recognition of NORM as a potential source of contamination to oil and gas facilities have become widely spread and gained increased momentum from the Industry. Some contamination levels may be sufficiently severe that maintenance and other personnel may be exposed to hazardous concentrations. The naturally occurring radioactivity (NOR) concentrations in well fluids may become enhanced due to extraction processes and subsequently form NOR enriched deposits (produced water, scales, sludge and pigging debris) within production facilities, forming NORM. Uncontrolled work activities involving NORM can lead to unwanted exposure and dispersal, posing a risk to human health and the environment. These risks or doses stemming from the exposure to ionizing radiation emerging from NORM can be reduced by the adoption of appropriate controls to identify if and where NORM is present. The general principles of protection against the hazards of ionizing radiation are primarily implemented by utilizing best working practices. In this respect exposure control and adequate dosimetry are the most critical components of a health and safety programme in the protection of workers. The protection of the environment, and public can be achieved by controlled disposal of NORM waste and the adoption of emission controls.

Sources of NORMs

NOR activity concentrations can vary substantially from one facility to another depending on geological formation and operational conditions and may also change over the lifetime of a single well. All minerals and raw materials contain the primordial radionuclides of natural, terrestrial origin. The ^{238}U and ^{232}Th decay series and ^{40}K are the main radionuclides of interest (Table 6.11). The activity concentrations of these radionuclides in normal rocks and soil are variable but generally low. The activity concentrations in separated produced water streams are routinely many orders of magnitude lower than the concentrations later encountered at a point of accumulative deposition. As the conditions that will lead to their accumulation are fundamentally the same as for conventional wells, it is expected that

NOR activity concentrations will follow Th and U activity concentration trends in the source rocks from which the connate water is extracted. On average NOR activity concentrations in unconventional produced water may be a factor of about 1.5 higher (ratio of Th and U contents in shale and sandstone) than in conventional produced water. Under certain conditions, NOR can become deposited or accumulated inside production or treatment installations as scale or sludge. It is important to stress that NOR occur as impurities within bulk materials and mineral lattices. As Ra (^{226}Ra and ^{228}Ra) is chemically similar to Ba, Sr, Ca and Mg, the use of scale inhibitors plays a key role in the reduction of NORM. Changes in operating conditions that can lead to NORM accumulation include temperature and pressure variations, varying flow (transition between laminar and turbulent), gas expansion due to a pipeline diameter change, pH variation (increase in sulphate concentration due to injection of fluids rich in sulphates, or a mixture of different produced waters) presence of seed crystals on the inner surface of the equipment and rough surfaces. The main types of scale encountered in the oil and gas facilities are sulphate scales such as $BaSO_4$, and carbonate scales such as $CaCO_3$. Ra is chemically similar to Ba and Ca, and co-precipitates are forming incorporated trace impurities within the bulk mineral matrices. There are a number of ways in which normal oil field operations can induce scaling, some of which may contain NORM. For example, mixing seawater, which is rich in sulfate, with formation water, which is rich in brine, increases the scaling tendency. As it is brought to the surface, the sudden change in pressure and temperature or even acidity of the formation water contributes to scaling build-up. This phenomenon has implications for the production of oil and gas; in this case, the capacity of the pipe to transfer oil and gas would be reduced significantly. Scales are rarely homogeneous, and so the abundance of NOR contaminants will vary. Sludge and scrapings may also contain NORs occurring within oil-wet fine mineral grains of sulfates and carbonates that have their origin in the same processes that lead to hard scales. Other NORs such as ^{210}Pbeq may also be found in pipeline scrapings and sludge accumulating in tank bottoms, gas/oil separators, dehydration vessels, NGL storage tanks, waste pits, and in waste pits crude oil pipeline scrapings or pigging debris. Some gas fields may produce

Pb compounds or even almost pure Pb contaminated with ^{210}Pbeq (up to 1,000 Bq/g. The fingerprint of stable Pb isotopes forming this kind of deposit is very typical for gas/oil fields. Produced water discharged to the sea will rapidly dilute, substantially reducing the activity of the overall water body and research has found no evidence of increased accumulation of ^{226}Ra in marine organisms due to produced water inputs.

Table 6. 5 Various NORMs in oil and gas industry

	Radionuclides	Characteristics	Occurrence
Ra scales	^{226}Ra, ^{228}Ra, ^{224}Ra and progeny	Hard deposits of Ca, Sr, Ba sulphates and carbonates	Wet parts of the production installations Well completions
Ra sludge	^{226}Ra, ^{228}Ra, ^{224}Ra	Sand, clay, paraffins, heavy metals	Separators, skimmer tanks
Pb deposits	^{210}Pb and progeny	Stable lead deposits	Wet parts of gas production installations Well completions
Pb films	^{210}Pb and progeny	Very thin films	Oil and gas treatment and transport
Po films	^{210}Po	Very thin films	Condensates treatment facilities
Condensates	^{210}Po	Unsupported	Gas production
Natural gas	^{222}Rn, ^{210}Pb, ^{210}Po	Noble gas Plated on surfaces	Consumers domain Gas treatment and transport systems
Produced water	^{226}Ra, ^{228}Ra, ^{224}Ra and/or ^{210}Pb	More or less saline, large volumes in oil production	Each production facility

NORM Management

A management plan is essential to monitor and control the risk of NORMs appropriately and proportionally complying with relevant national legislation. The process begins with the need to monitor and test for the presence of NORMs routinely. NORMs cannot be directly observed, it has to be measured. This is not always easy and must therefore be factored into operational cycles and maintenance schedules. NORMs accumulation may occur in equipment that is frequently inaccessible. Surfaces may be irregular, making conventional instrumentation hard to use. Self-absorbance can mask the true abundance of NORM or it might be co-mingled with other wastes and hazardous materials. The selection of instrumentation will affect the ability to detect NORM of different types and in different circumstances. Therefore, the monitoring plan must be appropriate for the setting and refreshed regularly, especially when other changes are made to an operation (such as new drilling). NORM management must be planned and carried out with consideration of consultation and engagement of stakeholders. Specifically, the approval of the regulatory authorities may be required. It may be necessary to engage specialized manpower having a high degree of technical knowledge is required due to the contentious nature of radioactivity and radioactive material.

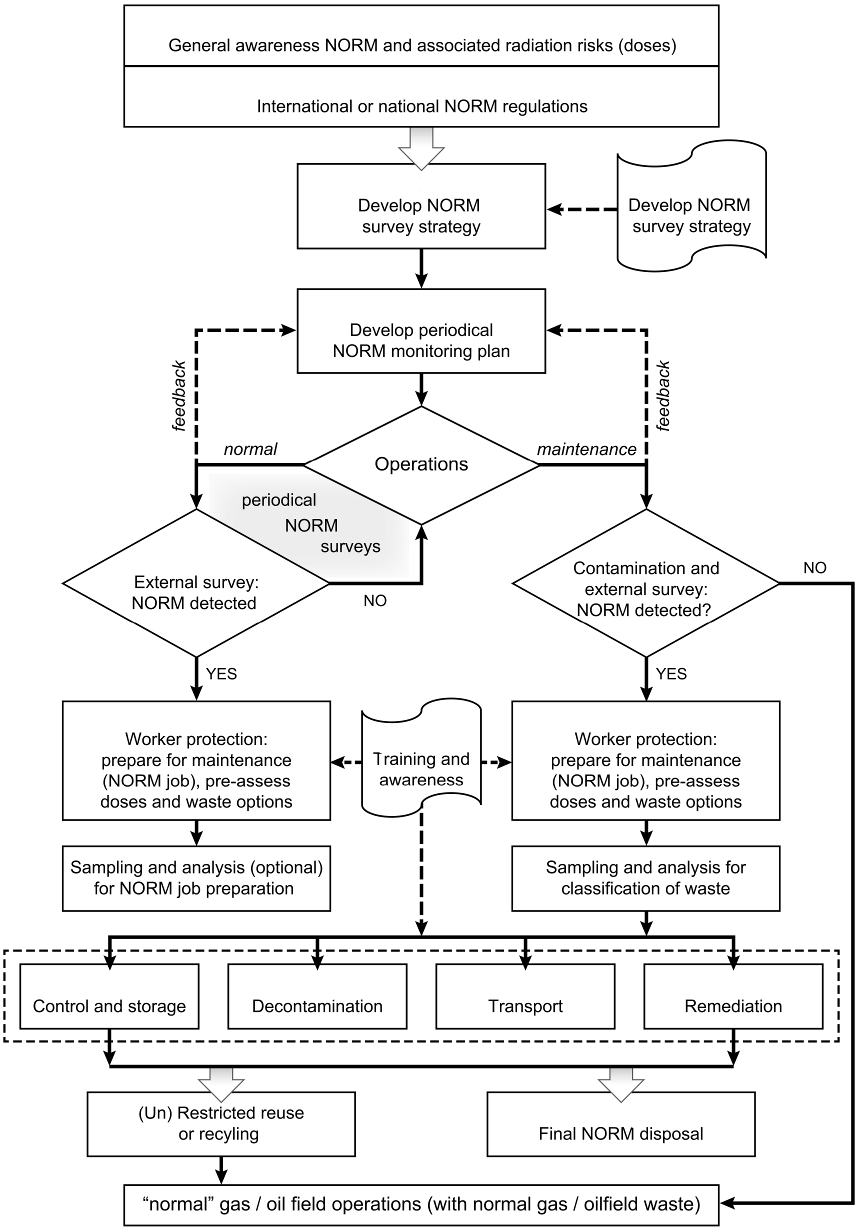

Figure 6. 8 Flowchart showing the management of NORM in oil and gas industry

Norms Emergencies And Contingency Planning

Most accidents involving NORMs that occur are the result of careless handling by individuals. Therefore, many accidents can be avoided by strict adherence to proper procedures and good management of employees. Requirements for documentation of the use of radioactive material will assist in keeping track of radioactive material on site. A good, well-enforced radiation safety programme is the best deterrent to accidents involving radioactive material. Nucleonic gauges used in all activities should be in strict compliance with the licencing and regulations of the Atomic Energy Regulatory Board (AERB), Government of India.

However, even with a well-enforced radiation safety programme, accidents will occur. These accidents can range from small spills to accidents that result in high acute exposures to individuals and spills that require extensive and costly clean-up efforts.

The contingency plan put forward by International Atomic Energy (IAEA) is adopted here. For details, refer to Radiation Protection and the Management of Radioactive Waste in the Oil and Gas Industry, training course series 40, Vienna 2010. Written procedures that the licensee can implement in conjunction with the operator need to be immediately available to deal with an emergency. An emergency would include any event involving the rupture of industrial radiography or well logging source (including the rupture, during recovery attempts, of a well logging source that has become lodged downhole) and procedures should specify:

1. Immediate notification of the regulatory body by the licensee in conjunction with the operator.
2. Securing of the affected area in order to limit the spread of contamination and to prevent anyone from acquiring either an internal or external exposure from the ruptured source.
3. Restrictions on access until a person is authorized (trained and experienced person who can handle NORMs), to assess the problem, including the extent of the contamination, and decide on further actions such as decontamination procedures; in the case of damage occurring while attempting to retrieve a disconnected source from a well, the access restrictions apply to the area around the wellhead and any equipment used in the recovery operations.
4. Accumulation of all contaminated items and storage of them in such a way as to prevent further exposures and the spread of contamination, pending their

decontamination to authorized clearance levels or disposal as radioactive waste in accordance with the requirements of the regulatory body.

5. Monitoring for internal contamination of those persons who were involved in the operations giving rise to the incident or who were in the immediate area when the incident occurred, and assessment of the total committed effective doses resulting from the internal and external exposures of those persons.
6. Retention in the company records of the results of these assessments and copying of them to the companies that employ the workers involved. Site emergency plans will need to include contingencies to deal with the potential radiation exposure of fire fighters and other personnel who need to deal with an incident, accident or other occurrence in an area where radiation sources are present.

A contingency plan has to include standing instructions to specialist service companies to make safe any radiation source for which they are responsible in the event that a site emergency status is announced. The operator ensures that appropriate action will be taken to either make safe a source or implement suitable countermeasures in the event that a radiation worker is incapacitated by the emergency. The contingency planning should recognize the need to advise first responders such as firefighters and traffic control authorities of the presence of radioactive material. The notification of the presence of radioactive material will enable the emergency workers to take the necessary precautions to prevent the further spread of contamination and also for the responders to implement the necessary precautions for their own protection against the radiological health hazards. In the case of transport accidents, the shipping documents will identify the radioactive material by nuclide, quantity and form of the material being transported.

The documents should also identify the individual(s) responsible for assessing the hazards and providing assistance to the emergency workers. The licensee should:

1. Notify the proper fire department or authority when radioactive material is being maintained at a location.
2. Provide 24-hour emergency contact in case a fire occurs.
3. Provide the first responders with relevant information concerning the proper procedures for minimizing the risks to health and for preventing the unnecessary spread of contamination.

In the case of fire, the possibility of volatilization of the radioactive material and consequently the possibility of internal exposure by ingestion exist. The first responders should be made aware of all exposure possibilities and informed as necessary to either stay upwind of the fire or use self-contained breathing apparatus.

6.6 Hydrotest Water

Hydrotest water consists of filtered inhibited seawater containing chemicals, including mono ethylene glycol, triethylene glycol, biocides, corrosion inhibitor, scale inhibitor, dye, and oxygen scavengers. A temporary decline in water quality due to the discharge of oxygen-deficient water and toxic chemicals is noticed in connection with hydro-testing. Hydrostatic testing of equipment and pipelines involves pressure testing with water to detect leaks and verify equipment and pipeline integrity. Chemical additives (corrosion inhibitors, oxygen scavengers, and dyes) may be added to the water to prevent internal corrosion or to identify leaks. Test manifolds installed onto sections of newly constructed pipelines for pipeline testing should be located outside the riparian zones and wetlands. The hydrotest fluid normally contains a dye to aid in the detection of leaks, a biocide, an oxygen scavenger to prevent oxygen pitting of the steel, scale inhibitor and corrosion inhibitor. Fluorescein dye and a combined biocide and oxygen scavenger chemical containing acetic acid (5 to 10%), ammonium bisulfate (oxygen scavenger, 10 to 20%) and polyhexamethylene biguanide hydrochloride (PMBH, corrosion inhibitor and biocide, 10 to 20%) in fresh, brackish or seawater is a commonly used formulation for hydrotest water.

Water sourcing for hydro-testing purposes should not adversely affect a natural water body's water level or flow rate. The test water withdrawal rate (or volume) should not exceed 10% of the water source's stream flow (or volume). Erosion control measures and fish-screening controls should be implemented as necessary during water withdrawals at the intake locations. Following hydro testing, the disposal alternatives for test waters include injection into a disposal well, if available or discharge to surface waters or land surface. If a disposal well is unavailable and discharge to surface waters or land surface is necessary, the following pollution prevention and control measures should be considered:

- Reduce the need for chemicals by minimizing the time that test water remains in the equipment or pipeline
- If chemical use is necessary, carefully select chemical additives in terms of dose concentration, toxicity, biodegradability, bioavailability, and bioaccumulation potential
- Conduct toxicity testing as necessary using recognized test methodologies. A holding pond may be necessary to provide time for the toxicity of the water to decrease
- Holding ponds should meet the standards for surface storage or disposal pits as discussed below
- Use the same hydro test water for multiple tests
- Hydrostatic test water quality should be monitored before use and discharge and should be treated to meet the discharge limits
- If significant quantities of chemically treated hydrostatic test waters are required to be discharged to a surface water body, water receptors both upstream and downstream of the discharge should be monitored. Post-

discharge chemical analysis of receiving water bodies may be necessary to demonstrate that no degradation of environmental quality has occurred

- If discharged into water, the volume and composition of the test water, as well as the streamflow or volume of the receiving waterbody, should be considered in selecting an appropriate discharge site to ensure that water quality will not be adversely affected outside of the defined mixing zone
- Use break tanks or energy dissipators (e.g., protective riprap, sheeting, tarpaulins) for the discharge flow
- Use sediment control methods (e.g., silt fences, sandbags or hay bales) to protect aquatic biota, water quality, and water users from the potential effect of discharge, such as increased sedimentation and reduced water quality
- If discharged to land, the discharge site should be selected to prevent flooding, erosion, or lowered agriculture capability of the receiving land. Direct discharge on cultivated land and land immediately upstream of community/public water intakes should be avoided
- Water discharge during cleaning pig runs and pretest water should be collected in holding tanks and should be discharged only after water-quality testing to ensure that it meets discharge criteria

The biocide PMBH is widely used in a variety of industries, If fully diluted in the line, the maximum concentration of PMBH would be approximately 1000 mg/l. The reported toxicity of PMBH ranges from 0.65 to 0.9 mg/l (96-hour LC50 for bluegill sunfish) to 44 mg/l (96-hour LC50 for brown shrimp). Therefore, if discharged at sea the hydrotest fluid would need to be diluted more than 1000 times within a 96-hour period to avoid the potential for acute toxicity impacts. Given the deep waters and strong currents in the Project's offshore development area, dispersion of hydrotest water from the pipeline is expected to be rapid.

Management of hydrotest water

It is important to note that hydrotesting of flowlines is an important measure for avoiding and minimising the risk associated with potential accidental releases. Hydrodynamic modelling of hydrotest water plumes from the gas export pipeline will be undertaken prior to the commissioning phase in order to predict the dispersion of pollutants into the offshore marine environment. It is expected that upon discharge of the hydrotest water, a plume of water similar in density to seawater will disperse through the water column. Given the current regime in the area and the considerable water depths, the hydrotest fluid is likely to spread and disperse. For minimising the potential for longer- term exposure effects continuous monitoring is required. There are several numerical modelling software packages are available to study the sinking, evaporation, dispersion, and spreading of the discharges (explained in section 6.3.16.4.1 Different types of oil spill models). Any toxicity effects from the discharged pollutants can be assessed using the numerical modelling and also the impact on marine biota that happened to travel in the discharge plume for an extended period. Hydrotest water for subsea or offshore structure can be discharged if it meets toxicity LC50 96 hrs > 30,000 and Biodegradability index A.

6.7 IUCN Red List Marine species in the Indian Ocean Waters

Biodiversity loss is continuing at an unprecedented rate, with many species declining to critical levels and significant numbers going extinct. The IUCN Red List is the most comprehensive information source on the status of wild species and their links to livelihoods. It is the clarion call for fighting the extinction crisis. The overall aim of the Red List is to convey the urgency and scale of conservation problems to the public and policymakers and to motivate the global community to work together to reduce species extinctions. Marine species are poorly represented on the IUCN Red List, largely because of their lack. The status of most of the larger species (marine mammals, seabirds and turtles) has been assessed and many are considered globally threatened. Threatened marine fish are currently being assessed, and many are being added to the Red List, including swordfish, sawfish, all tuna species except yellowfin and skipjack, sharks, groupers, seahorses, manta rays and the coelacanth. Very few marine invertebrates are on the IUCN Red List, with the exception of six species of Giant clam. The main threats currently applicable to each species or group of species are categorised under seven themes (eg overharvest, habitat destruction, limited reproductive output/ slow recovery, limited geographical distribution/endemicity, restricted depth range, susceptibility to climate change and disease and increased predation due to habitat degradation (eg crown-of-thorns starfish on coral). The marine portion of the Red List was checked for those species occurring in the Western Indian Ocean (WIO) region at least for part of their lives. There are 161 species (including two subpopulations) listed as threatened. The great majority of these, 126 species, are listed as Vulnerable (VU), with 27 considered Endangered (EN) and eight species listed as Critically Endangered (CE; a ray, three sharks, two fish and two marine turtle species).

According to IUCN Red List, Eastern Indian Ocean (EIO) found a total of 57 marine animals - 15 bony fish (mainly grouper, tuna and seahorse), 34 cartilaginous fish (sharks, rays, guitarfish and sawfish), 5 reptiles (turtle) and 3 mammals (dolphin and porpoise) inhabiting Bay of Bengal are under different threatened categories. Among the bony fishes, three are data deficient (DD), one is near threatened (NT), eight are vulnerable (VU) and three are endangered (EN). Among the sharks and rays, nineteen are vulnerable (VU), nine are endangered (EN) and six are critically endangered (CR). Three vulnerable (VU), one endangered (EN) and one critically endangered (CR) turtles are found in the Bay of Bengal along with two vulnerable (VU) and one endangered (EN) mammals.

In line with IUCN red list, MINISTRY OF ENVIRONMENT AND FORESTS (MoEF) has brought out the notification of the marine species to be included in scheduled list.

Table 6. 6 IUCN Red List Marine species in the Indian Ocean Waters

Major class	Common English Name (Scientific Name)	Geographical distribution of IUCN Red List Marine species around sedimentary basins in India
Fishes	Sea Horse (All Sygnathidians)	Mainly found in Cauvery, Krishna Godavari and Mahanadi Basin. Tamil Nadu (including Puducherry) emerged as the state with the highest catch where a median of 75% of the annual seahorse catches occurred, followed by Orissa (16.8%) and Andhra Pradesh (3.4%).
	Pointed Sawfish (Anoxypristis Cuspidate)	Found inshore, often in river deltas and estuaries of Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. No robust estimates of historic or current population size exist. However, distribution has been greatly reduced and that the population numbers have declined dramatically in the recent past.
	Porcupine ray (Urogymnus asperrimus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. It favors sand, coral rubble, and seagrass habitats in inshore waters to a depth of 30 m.

	Giant Grouper (Epinephelus lanceolatus)	Krishna Godavari, Mahanadi Basin and Andaman basin. From Indian waters this species is reported from Andaman and Nicobar Islands and from the coasts of Andhra Pradesh and Odisha. inhabits lagoon and seaward reefs at depth of a few to at least 50 m.
	Largetooth sawfish (Pristis microdon)	Kerala Lakshadweep Konkan, Mumbai offshore, Mahanadi basin.
	Giant guitarfish (Rhynchobatus djiddensis)	Historically widely distributed along the entire Indian coastal waters (Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin). Now It is found in the Western Indian Ocean from the Red Sea to the Eastern Cape in South Africa. Which occupies the continental shelf to 70 m (generally shallower than 35 m).
	Longcomb sawfish (Pristis zijsron)	Andaman Basin. A 5.13 m (16 ft. 10 in.) specimen was caught off Port Blair in the Andaman Islands in 1967.
	Ganges shark (Glyphis gangeticus)	Mahanadi Basin. Largely restricted to the rivers of eastern and northeastern India, particularly the Hooghly River of West Bengal, and the Ganges, Brahmaputra, and Mahanadi in Bihar, Assam, and Odisha, respectively.
	Humphead wrasse	Kerala Lakshadweep Konkan, Krishna

	(Cheilinus undulates)	Godavari and Andaman Basin. This species' distribution in India includes Lakshadweep, Gulf of Mannar, the east coast and the Andaman and Nicobar Islands.
	Scalloped hammerhead (Sphyrna lewini)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Black teatfish (Holothuria nobilis)	Kerala Lakshadweep Konkan, Mumbai offshore, Gujarat Basin, Saurashtra Basin. The black teatfish occurs only in the Indian Ocean. Specifically, it can be found off the east coast of Africa, the west coast of India, and around associated islands.
	Golden sandfish (Holothuria scabra)	Andaman Basin
	Prickly redfish (Thelenota ananas)	Kerala Lakshadweep Konkan
	Longheaded eagle ray (Aetobatus flagellum)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Reticulate eagle ray (Aetomylaeus vespertilio)	Very rare in Kerala Lakshadweep Konkan
	Dwarf sawfish (Pristis clavata)	Historically it is found throughout Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery

		basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Redmouth Grouper (Aethaloperca rogaa)	Kerala Lakshadweep Konkan
	Cloudy Grouper (Epinephelus erythrurus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Barred-chest Grouper (Epinephelus faveatus)	Kerala Lakshadweep Konkan, Cauvery basin and Andaman basin. It is found in the Indian Ocean and has been recorded from southern India, Sri Lanka, the Andaman and Nicobar Islands
	Giant Grouper (Epinephelus lanceolatus)	Krishna Godavari, Mahanadi and Andaman basin. From Indian waters this species is reported from Andaman and Nicobar Islands and from the coasts of Andhra Pradesh and Odisha.
	Humpback Grouper (Cromileptes aitivelis)	Kerala Lakshadweep Konkan and Cauvery basin. In India, this species is rare, few specimens have been collected from Kanyakumari, Tamil Nadu and Vizhinjam, Kerala.
	Squaretail Coral Grouper (Plectropomus areolatus)	Kerala Lakshadweep Konkan, Cauvery basin and Andaman Basin.
	Ocean Sunfish (Mola mola)	Several reports showed that this species has found very rare in all sedimentary basins of India. Earlier, landings of

		oceanic sun fish (Mola mola) at Visakhapatnam and West Bengal in the east coast, Bombay, Veraval and Malpe in Karnataka in west coast have been reported.
	Bigeye Tuna (Thunnu sobesus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Madagascar Kob, Southern Meagre (Argyrosomus hololepidotus)	Mahanadi basin. Very rarely found in the north-west coast of India.
	Brick Seamoth (Pegasus laternarius)	Cauvery basin, Krishna Godavari basin, Andaman basin
	Spotted Seahorse (Hippocampus kuda)	Mainly found in Cauvery, Krishna Godavari and Mahanadi Basin.
	Three-spot Seahorse (Hippocampus trimaculatus)	Mainly found in Cauvery, Krishna Godavari and Mahanadi Basin.
	Tawny Nurse Shark (Nebrius ferrugineus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Common Thresher Shark (Alopias vulpinus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin.
	Silky Shark (Carcharhinus falciformis)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari,

		Mahanadi Basin and Andaman basin.
	Pondicherry Shark (Carcharhinus hemiodon)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Oceanic Whitetip Shark (Carcharhinus longimanus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Sharptooth Lemon Shark, Sicklefin Lemon Shark (Negaprion acutidens)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Whale Shark (Rhincodon typus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Great Hammerhead (Sphyrna mokarran)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Winghead Shark (Eusphyra blochii)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Irrawaddy River Shark (Glyphis siamensis)	Mahanadi basin
	Broadfin Shark (Lamiopsis	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan,

	temminckii)	Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Mottled Eagle Ray (Aetomylaeus maculatus)	Mainly found in Cauvery, Krishna Godavari and Mahanadi Basin.
	Banded Eagle Ray (Aetomylaeus nichofii)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Porcupine Ray (Urogymnus asperrimus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Blotched Fantail Ray (Taeniurops meyeni)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Zonetail Butterfly Ray (Gymnura zonura)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
Marine Mammals	Fin Whale (Balaenoptera physalus)	Reports showed that it is found in Mumbai offshore basin, Kerala Lakshadweep Konkan, Cauvery basin, Mahanadi basin.
	Blue whale (Balaenoptera musculus)	Mumbai offshore, Kerala Lakshadweep Konkan
	Sei whale	Mumbai offshore, Kerala Lakshadweep

	(Balaenoptera borealis)	Konkan
	Common Dolphin (Delphinus delphis)	Gujarat basin, Saurashtra basin, Kerala Lakshadweep Konkan, Cauvery basin
	Bottlenose Dolphin (Tursiops truncatus)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Striped Dolphin (Stenella coeruleoalba)	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Irrawaddy Dolphin (Orcaella brevirostris)	Mahanadi basin
	Rissos Dolphin (Grampus griseus)	Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin
	Finless Porpoise (Neophocaena phocaenoides)	Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin
	Cuviers Beaked whale (Ziphius cavirostis)	Kerala Lakshadweep Konkan
Coelenterates	Reef Building Coral (All Scleractinians)	Kerala Lakshadweep Konkan, Gujarat basin, Cauvery basin and Andaman basin.
	Black Coral (All Antipatharians)	Andaman basin
	Sea Fan (All Gorgonians)	Andaman basin
Echinodermata	Sea Cucumber (All Holothurians)	Gujrat basin, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari and Andaman basin

Turtles	Loggerhead Turtle (Caretta caretta)	Kerala Lakshadweep Konkan, Cauvery basin, Mahanadi basin and Andaman basin
	Green turtle (Chelonia mydas)	Gujarat basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. It occurs in the west and east coasts of India, Lakshadweep and Andaman and Nicobar Islands.
	Leatherback turtle (sub-pop) (Dermochelys coriacea)	Gujarat basin, Saurashtra basin, Mumbai offshore, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.
	Hawksbill turtle (Eretmochelys imbricate)	Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. In India, hawksbills are mainly found in the Lakshadweep islands, Andaman islands, and few beaches in the Nicobar islands such as Indira Point at the southern tip of Great Nicobar (here turtles often have to crawl over reefs and rocks to reach the nesting beach).
		Olive Ridley (Lepidochelys olivacea)
Molluscs		Cypraea lamacina
	Cypraea mappa	Gujarat basin, Cauvery basin, Andaman basin. Mainly found in Andaman & Nicobar, Pondicherry, Gujarat, Tamil Nadu, and Lakshadweep.

	Cypraea talpa	Gujarat basin, Cauvery basin, Andaman basin. Mainly found in Andaman & Nicobar, Pondicherry, Gujarat, Tamil Nadu, and Lakshadweep.
	Placenta placenta	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Lakshadweep, East and West coast of India and Andaman and Nicobar islands.
	Lambis truncate	Kerala Lakshadweep Konkan, Cauvery basin and Andaman basin. Mainly found in Lakshadweep, Tamil Nadu and Andaman & Nicobar
	Turbo marmoratus	Andaman basin
	Strombus plicatus sibbaldi	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Lakshadweep, East and West coast of India and Andaman and Nicobar islands.
	Fasciolaria trapezium	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Andaman & Nicobar, Pondicherry, Gujarat, Lakshadweep, East and West coasts of India

	Harpulina arausiaca	Kerala Lakshadweep Konkan, Cauvery basin. Mainly found in Pondicherry, Lakshadweep, South East Coast of India
	Trochus niloticus	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Andaman & Nicobar and East and West coasts of India.
	Lambis scorpius	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Tamil Nadu, Andaman & Nicobar and Lakshadweep
	Lambis crocea	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Lakshadweep, Tamil Nadu and Andaman & Nicobar.
	Lambis chiragra arthritica	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Tamil Nadu, Pondicherry, Andaman & Nicobar and Lakshadweep.
	Lambis millepeda	Andaman basin
	Lambis chiragra	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Tamil Nadu, Pondicherry, Andaman & Nicobar and Lakshadweep
	Cassis cornuta	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin.

		Mainly found in Lakshadweep, Andaman & Nicobar and East and west coasts of India.
	Cypracasis rufa	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Lakshadweep, Andaman & Nicobar and Tamil Nadu.
	Hippopus hippopus	Andaman basin
	Tridacna squamosal	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Lakshadweep, Tamil Nadu and Andaman and Nicobar islands.
	Tudicla spiralis	Kerala Lakshadweep Konkan, Cauvery basin. Mainly found in Lakshadweep and Tamil Nadu.
	Cassis cornuta	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Lakshadweep, Andaman & Nicobar and East and west coasts of India.
	Nautilus pompilius	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Lakshadweep, Andaman & Nicobar and East and west coasts of India.

	Tridacna maxima	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Lakshadweep, Tamil Nadu and Andaman and Nicobar islands.
	Charonia tritonis	Kerala Lakshadweep Konkan, Cauvery basin, Andaman basin. Mainly found in Lakshadweep, Tamil Nadu and Andaman and Nicobar islands.
	Conus malneedwards	Gujarat basin, Saurashtra basin, Mumbai offshore, Kerala Lakshadweep Konkan, Cauvery basin, Krishna Godavari, Mahanadi Basin and Andaman basin. Mainly found in Lakshadweep, Andaman & Nicobar and East and west coasts of India.

Chapter 7: Environmental Management Plan Offshore Oil and Gas sector

7.1 Environmental Management Plan

Environmental management within the oil and gas industry draws principally from the E&P Forum **Guidelines for the Development and Application of Health, Safety and Environmental Management Systems** (HSE-MS). Effective management system implementation requires a precise analysis of current practice and total commitment from all staff, which implies good communication within organisations; timely and relevant training (see UNEP/ICC/FIDIC Environmental Management Systems Training Resource Kit). Commitment to and demonstration of continual performance improvement is vital in ensuring that management is effective and maintained. Under the HSE-MS, standards, procedures, programmes, practices, guidelines, goals, and targets must be established, and where necessary, agreed with regulators and other stakeholders. Monitoring and auditing will show how well an operation performs and provide a measure of effectiveness. Figure 7.1 defines the operational activities' structure by using different tools under the company management system.

Activity	Environmental management requirement
Desk study: identifies area with favourable geological conditions	Establish environmental management system Environmental profile
Aerial survey: if favourable features revealed, then	Environmental profile
Seismic survey: provides detailed information on geology	Preliminary environmental assessment/review Environmental training Operational procedures*
Exploratory drilling: verifies the presence or absence of a hydrocarbon reservoir and quantifies the reserves	Preliminary environmental assessment/review or Environmental impact assessment Environmental training Environmental monitoring Operational procedures*
Appraisal: determines if the reservoir is economically feasible to develop	Preliminary environmental assessment/review or Environmental impact assessment Environmental training Environmental monitoring Operational procedures*
Development and production: produces oil and gas from the reservoir through formation pressure, artificial lift, and possibly advanced recovery techniques, until economic reserves are depleted	Environmental impact assessment Environmental training Environmental monitoring Environmental audit Waste management Operational procedures*
Decommissioning and rehabilitation may occur for each of above phases.	Site assessment Implementation of site restoration plan Environmental monitoring Operational procedures*

*Operational procedures included in the risk assessments

Figure 7. 1 Activity and Environment management requirement

A typical EMP shall be composed of the following:

1. Summary of the potential impacts of the proposal ;
2. Description of the recommended mitigation measures ;
3. Statement of their compliance with relevant standards ;
4. Allocation of resources and responsibilities for plan implementation ;
5. Schedule of the actions to be taken ;
6. Programme for surveillance, monitoring and auditing; and
7. Contingency plan when impacts are greater than expected each of the above components are precisely discussed below:

Summary of impacts: The predicted adverse environmental and social impacts for which mitigation measures are identified in the earlier sections to be briefly summarised with cross-referencing to the corresponding sections in the EIA report.

Description of mitigation measures: Each mitigation measure should be briefly described with reference to the impact to which it relates and the conditions under which it is required. These should be accompanied by, or referenced to, project design and operating procedures which elaborate on the technical aspects of implementing the various measures.

Description of monitoring programme: Environmental monitoring refers to compliance monitoring and residual impact monitoring. Compliance monitoring refers to meeting the industry-specific statutory compliance requirements.

Residual impact monitoring refers to monitoring identified sensitive locations with an adequate number of samples and frequency. The monitoring programme should indicate the linkages between impacts identified in the EIA report, measurement indicators, detection limits (where appropriate), and the definition of thresholds that will signal the need for corrective actions.

Institutional arrangements: Responsibilities for mitigation and monitoring should be clearly defined, including arrangements for coordination between the various actors responsible for mitigation. Details should be provided w.r.t the deployment of staff (detailed organogram), monitoring network design, parameters to be monitored, analysis methods, associated equipments *etc.*

Implementation schedule and reporting procedures: The timing, frequency and duration of mitigation measures should be specified in an implementation schedule, showing links with overall project implementation. Procedures to provide information on the progress and results of mitigation and monitoring measures should also be clearly specified.

Cost estimates and sources of funds: These should be specified for both the initial investment and recurring expenses for implementing all measures contained in the EMP, integrated into the total project costs, and factored into loan negotiation.

The EMP should contain commitments that are binding on the proponent in different phases of project implementation, *i.e.* pre-construction or site clearance, construction, operation, decommissioning.

8.2 Check List/SOP for E&P operators engaging E&P activities beyond 12 NM

A) Seismic Operations:

S No	Activities	Prerequisites	Checks/Permissible Limits
1	Identification of sites	Sites may avoid protected areas and local sensitivities, if feasible	Readings to be captured through an environmental assessment study
2	Scheduling of upstream E&P activities	Least sensitive period of the year (As per the order: Ministry of Fisheries, Animal Husbandry and Dairying; Department of Fisheries)	Operators may avoid the most sensitive periods in the respective areas: The Bay of Bengal from 15th April to 14th June The Arabian Sea from 1st June to 31st July
3	Imaging of the target structures	Lowest possible source levels	From ambient sea noise, 80 dB
4	Acoustic activity	To be started at the lowest practicable level	Measurement & Self Certification
5	30/60-minute Pre-shooting Search	60-min shooting search for deeper waters than 200 m	Measurement & Self Certification

B) Exploration and Appraisal Drilling:

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Site selection and design stage	Least sensitive marine habitats and consideration of lifecycle periods for relevant species	• Benthic habitat surveys • A detailed Biodiversity plan has to be prepared if any red-listed IUCN organism is identified as listed in Annexure-4 (Table 6.12 of the report). • Directional drilling to access beneath sensitive areas • Cluster well drilling to be encouraged • Assessment and monitoring of local conditions • Exclusion zones to be developed for key stakeholders like fisheries • Adequate lighting infrastructure	• Operator to comply • Self-Certification
2	Information to the mariners	Notice to Mariners detailing the area of operations	• DG of Shipping • Concerned Port authorities • Concerned State authorities	• Operator to comply • Self-Certification
3	Protection of project vessels	Implement Collision Risk Management Plans	• Adherence to COLREGS • Dynamic placement of drill rigs to reduce the requirement of anchors to reduce the impact on benthic flora and fauna, operators may avoid anchoring of drill ships.	• Operator to comply • Self-Certification
4	Dredging/Trenching & Rock Dumping	Delineation of dredging zones to be made considering the sensitive marine habitats and lifecycle times of relevant species	• Benthic habitat surveys • The utilisation of state-of-the-art technologies • Formulation and Implementation of a Dredge Management Plan	• Operator to comply • Self-Certification
5	Vessel Operations	• Optimizing the ship's position • Planned survey track to be followed • Proper handling & maintenance of cabling equipment • Optimized handling of explosives according to procedures and	• Ensuring a gradual start-up of engines, allowing the species to take evasive actions. • Disposal of wastes and oily water in accordance with international regulations (as per MARPOL) • Contingency plans for lost equipment & oil spillage • Timely reporting of all	• Operator to comply • Self-Certification

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
		locations • Clear labelling of towed equipment	unplanned interactions	
6	Site Operations	• Engineering measures to minimise operational noise emissions • Minimise external lighting	• Requirements in the planning process to be met	• Operator to comply • Self-Certification
7	Aqueous Discharges	• Treatment of oily water prior to discharge • Treatment of sewage in accordance with international standards • Proper storage of oils and chemicals • Oil for well test operations to be stored separately	• Contingency plans for oil spillage • Control documentation for storage and disposal • Treatment & discharge of effluents as per MARPOL and GSR 546(E) in accordance with CPCB guidelines • Produced water discharge as per GSR 546(E) in accordance with CPCB guidelines	• Operator to comply • Self-Certification
8	Solid Wastes Disposal	Proper management of solid waste onboard	• Onshore disposal of non-biodegradable domestic waste • Ensuring waste segregation at source for different waste types • No overboard debris/waste discard by closing all containers • Materials to be supplied in bulk to reduce the generation of packaging wastes	• Operator to comply • Self-Certification on non-hazardous waste • Proof of Submission of compliance to Hazardous Rules (Manifest copies) to State/Central Government.
9	Muds & Cuttings	Proper management of Muds & Cuttings during drilling	• Non-disposal of OBM in sea • Downhole disposal of OBM wastes • Usage of low-toxicity water-based drilling muds • Adherence to the plan initially outlined	• Operator to comply • Self-Certification • Segregation of Hazardous OBM/SBM and Non-Hazardous wastes like WBM may be done
10	Atmospheric emission/ noise/light	To reduce Atmospheric emission/ noise/light	• Efficient well-test burners • Effective control of H_2S emissions with safety measures	• Operator to comply • Self-Certification

C) **Development and Production**

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	General	• Long-term occupation of sites • All aspects identified for exploration drilling should be applied to permanent sites	• Detailed assessment of environmental implications • Site & Route selection plan for flowlines and pipelines • All checklists mentioned in Exploration & Appraisal drilling (Check list-3.2) are to be followed	• Operator to comply • Self-Certification
2	Site Operations	• Evaluation of constriction & drilling activities • Use of central processing facility, satellite & cluster wells to be minimized • Avoiding gas venting by adopting best engineering practices; This is applicable for new platforms • Waste stream monitoring	• Impact assessment of operational activities, including EMP • Assessment of full implications of well treatment and workover, process, storage, power generation & other support facilities • Incorporation of an oily treatment system for both produced & contaminated water treatment • An onboard sewage treatment system • Assessment of waste gases emissions and effluent limit • A proper plan for treatment and disposal of solid, toxic & hazardous wastes onshore • A detailed waste management plan • Detailed contingency plans	• Operator to comply • Self-Certification
3	Environment Monitoring plan	A proper monitoring plan needs to be established for assessing the status of the marine environment, particularly for a long duration of E&P activities	• To adopt a proper monitoring strategy • Frequency of Monitoring • Environment parameters to be studied • Evaluation of environment parameters	• AS per OSPAR guidelines • Once in a year • As per mentioned in the Table 5.3 of the report - Guidance for the assessment of baseline components and attributes • AS per the permissible limit mentioned in the Table 5.2b of the report • Operators to comply as above

D) Decommissioning of Offshore Oil and Gas Structures

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Decommissioning & abandonment of offshore installations/pipelines	Site restoration guidelines (SRG) 2018 and its amendments need to be followed by the operators		• Operator to comply with OISD approval

E) Post Decommissioning:

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Assessment of decommissioning phases and status of the site environment	• Decommissioning & abandonment of offshore installations/pipelines as per guidelines	• Submission of the written report to OISD comprising: • Summary of decommissioning operation • Description of mitigation measures • Signed statement by authorised representatives in accordance with the Abandonment Plan • Environmental Survey Report with video graphics evidence	• Operator to comply • Self-Certification

F) Discharge of Gaseous Emissions:

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Gaseous Emissions	As per MARPOL/CPCB guidelines		• Operator to comply • Self-Certification

G) Naturally Occurring Radioactive Materials in Oil & Gas (NORM):

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Wells in production	If any radioactivity is found, follow AERB guidelines		• Operator to comply • Self-Certification

H) Oil Spill Response Plan:

S No	Activities	Prerequisites	Checks	Permissible Limits/Compliance (if any)
1	Spilling of oil has occurred	As per NOS-DCP 2015 and amendments		• Operator to comply • Self-Certification

7.3 Guidelines for Oil and Gas fields beyond 12 nautical miles

Drilling and processing of oil can be considered the most harmful stage of oil E&P because it is a permanent phase, unlike other possible accidents that could occasionally happen, such as oil spills. During the E&P phase, oil rigs release oil waste and produce water that forms 98% of the total waste. It consists of hydrocarbons that cause water toxicity and, eventually, aquatic toxicity. Drilling fluids (drilling muds) are discharged during the drilling process. They may contain toxic substances like benzene, zinc, arsenic, chromium, iron, mercury, barium, and other contaminants used to lubricate drill bits and maintain pressure, e.g., barium acts as a lubricant. Other main polluter factors are greenhouse gases such as carbon dioxide, carbon monoxide, methane, volatile organic carbons, and nitrogen oxides generated directly by offshore rigs and DG sets. These gases are the major concern of climate change by global warming, melting ice at the poles, and ocean acidification. Thus, a set of guidelines has been prepared to minimise the impact of Oil and Gas exploration activities beyond 12 NM on the marine environment and thereby foreseen a healthy ecosystem.

7.3.1 Guidelines for Seismic operations

- Use environmental assessment to identify protected areas and local sensitivities.
- For a seismic survey, avoid sensitive locations and times of year for critical activities such as migration, breeding, calving and pupping, as well as fishing areas (Operation avoidance periods: Bay of Bengal 15th April to 14th June; The Arabian Sea from 1st June to 31st July).
- Schedule operations during the least sensitive period.
- Use the lowest possible source levels to image the target structures.
- Start acoustic activity at the lowest practicable level (80 dB) and gradually increase it to the required level to allow marine life to move away from the source.
- Undertake a 30-minute pre-shooting search (60 minutes in waters deeper than 200 m due to deeper diving mammals).

7.3.2 Guidelines for Exploration and appraisal drilling

- Consider sensitive marine habitats and lifecycle periods for relevant species and communities during the site selection and design stage (Operation avoidance periods: Bay of Bengal 15th April to 14th June; The Arabian Sea from 1st June to 31st July)
- Undertake benthic habitat surveys to identify sensitive habitats and biota and, where feasible, avoid these areas
- If any red-listed organism is found during the baseline survey as listed in Table 6.12 of the report, preparing a biodiversity action plan for the concerned is mandatory.
- Minimise physical footprint, where feasible.
- Consider directional drilling to access targets beneath sensitive areas.
- Consider cluster well drilling.
- Local conditions must be fully assessed, such as waves, wind and currents; similarly, the history of cyclones and earthquakes at the site.
- Develop exclusion zones for various key stakeholders, including local fishing communities, and promote awareness of exclusion zones with all stakeholders
- Ensure all facilities/infrastructure have the appropriate navigation lighting, and all facilities/infrastructure and subsea infrastructure are gazetted and included on nautical charts
- Issue a 'Notice to Mariners' through the relevant government agencies, detailing the area of operations
- Develop and implement Collison Risk Management Plans for project vessels
- Ensure all vessels adhere to Class certification of the vessel as per Indian Regulation or International Regulations for Preventing Collisions at Sea (COLREGS), which set out the navigation rules to be followed to prevent collisions between two or more vessels
- Consider potential impacts from offshore structures, both positive and negative. In some cases, restoration may be needed to assist the recovery of damaged or

destroyed habitat or offsets considered. Consider dynamic positioning on drill rigs to avoid or minimise the need for anchors

Dredging/Trenching and Rock Dumping

- The site selection, design & demarcation, placement and timing of dredging zones should be selected by considering sensitive marine habitats and lifecycle periods for relevant species identified during the detailed baseline environmental monitoring.
- Use state of the art dredging technology that minimises the disturbance, reduces footprint, duration and volume of dredging, rock dumping and dredge disposal to the minimum required.
- Formulate and implement a dredge management plan describing measures to minimise impacts and deploy suitable management techniques when critical values for marine water quality are exceeded.

Vessel operations

- For ships, ensure gradual start-up of engines and thrusters where possible to allow species to take evasive action.
- Assess whether anchoring or the use of DP would be more appropriate for maintaining a ship’s position. Anchoring will lead to seabed disturbance, while DP will result in noise disturbance.
- Remain on the planned survey track to avoid unwanted interaction.
- Dispose of all waste materials and oily water properly to meet national and international regulations. i.e., the oil content of the discharged effluent cannot exceed that specified under CPCB/MARPOL guidelines.
- Apply proper procedures for handling and maintenance of cable equipment, particularly cable oil.
- Label all towed equipment.
- All towed equipment must be highly visible.
- Make adequate allowance for deviation of towed equipment when turning.
- Prepare contingency plans for lost equipment and oil spillage.

- Attach active acoustic location devices to auxiliary equipment to aid location and recovery.
- Store and handle explosives according to operators' procedures and regulations.
- Consider using a guard boat in busy areas.
- Report all unplanned interactions with other resource users or marine life to the authorities.

Site Operations

- Offshore facilities/infrastructure should consider engineering measures to minimise operational noise emissions.
- Minimise external lighting as much as possible to that required for navigation, for the safety of deck operations, except in the case of an emergency and limit the occurrence and duration of flaring, where possible.
- Requirements specified in the planning process must be met, including supply vessel operations.

Aqueous discharges.

- Oily water from deck washing, drainage systems, bilges etc., should be treated prior to discharge to meet national and international consents.
- Sewage must be adequately treated prior to discharge to meet international standards. Treatment must be adequate to prevent discolouration and visible floating matter.
- Most spills and leakages occur during transfer operations, ensuring adequate preventative measures and spill contingency plan requirements are in place.
- Store oils and chemicals properly in contained areas.
- Limited quantities are to be stored to a minimum level required for operational purposes. Ensure proper control documentation and manifesting and disposal. Do not dispose of waste chemicals overboard.
- Preferentially, separate and store oil from well test operations.

Solid wastes

- Collect all non-biodegradable domestic waste and compact it for onshore disposal.

- Ensure requirements specified in the planning process are met with regard to waste treatment and disposal.
- Ensure proper documentation and manifesting.
- Consider waste segregation at the source for different waste types such as biodegradable, non-biodegradable, plastic etc.,
- No debris or waste to be discarded overboard from rigs or supply vessels.
- Waste containers must be closed to prevent loss overboard.
- Spent oils and lubes should be containerised and returned to shore.
- Consider the bulk supply of materials to minimise packaging wastes.

Muds and cuttings.

- Mud make-up and mud cuttings disposal requirements must be addressed in the planning process
- Preferentially, use low toxicity water-based drilling muds.
- Do not dispose OBM to sea.
- Consider downhole disposal of OBM wastes.

Atmospheric emission/noise/light

- Well-test burners must be efficient, maintained, and burn gas and oil effectively.
- Ensure requirements addressed in the planning phase are met with regard to emissions, noise and light.
- H_2S emissions must be effectively controlled. Appropriate safety measures have to be taken if any such emissions are noticed.

7.3.3 Guidelines Development and Production

- Long-term occupation of sites, including supply and support, will require a detailed assessment of environmental implications, particularly where resource use conflicts arise and commercially important fish species may be affected.
- All aspects identified for exploration drilling should be applied to permanent sites.
- Consider site and route selection for flowlines and pipelines.

Site Operations

- Evaluate construction and drilling activities and impacts separately from operational activities.
- Maximise use of central processing facility, and use satellite and cluster wells to minimise footprint.
- In terms of long-term disturbance and impact, assess full implications of well treatment and workover, process, storage, power generation, and other support and accommodation facilities.
- Incorporate an oily water treatment system for both produced and contaminated water treatment to meet national and international discharge limits.
- Onboard sewerage treatment system.
- Assess treatment of waste gases and emission limits, particularly where gas is flared.
- Avoid gas venting by adopting best engineering practice
- Onshore treatment and disposal of solid, toxic and hazardous wastes will require proper planning, particularly if local infrastructure is limited in capacity and capability.
- A detailed waste management plan will be required.
- Prepare detailed contingency plans, personnel training, and regular response exercise, considering storage and export systems.
- Monitor waste streams in order to meet compliance requirements.

7.3.4 Guideline to the Decommissioning of offshore oil and gas structures

The basic process of decommissioning and abandonment of an offshore installation or pipeline is prepared in compliance with MoPNG Notification No. O-32011/75/2013-ONG-I. Dated 2018 and as follows,

- The operator has to shut down oil or gas production, plug the wells deep below the surface, and make them safe.
- Deconstruction, removal and disposal of the topside facilities

- Removal of the substructure.
- Removal of facilities should consider potential impacts on the site, including noise (from explosives), physical disturbance of communities established during the life of the facility and demobilisation routes.
- All debris must be removed from the seabed.
- Identifying, labelling, maintaining, storing, and disposing of equipment contaminated with Naturally Occurring Radioactive Material (NORM) shall follow the Department of Atomic Energy (DAE) guidelines if any.
- Any facilities and infrastructure handed over to the authorities must include proper instructions for use, maintenance, and proper training procedures.
- Decommissioning offshore structures are subject to international and national laws (MoPNG Notification No. O-32011/75/2013-ONG-I. dated 2018) and should be dealt with on a case-by-case basis.
- Seabed surveys are carried out, as well as ongoing monitoring, if any part of the platform/facility remains in place.
- Record and monitor site as required after appropriate decommissioning activities.
- The development of a trust fund that can be used to decommission the infrastructure when its production life is over should be considered

Post Decommissioning

Within 90 days after the completion of decommissioning, submit a written report to the OISD that includes the following:

- A summary of the decommissioning operation, including the date it was completed;
- An environmental survey report with description of any mitigation measures taken, if any.
- A statement signed by an authorised representative certifies that the site was decommissioned according to the Abandonment Plan.
- Environmental Survey Report on the post decommission with video graphic evidence on the status of the site in good condition.

7.3.5 Guidelines for Environmental Monitoring Programme

Offshore environmental monitoring aims to overview the environmental status and trends over time. Monitoring is intended to indicate whether the environmental quality of the offshore oceanic environment is stable, deteriorating or improving due to operators' activities. Oil & gas projects differ in size, complexity and environmental sensitivity, and factors should be considered when deciding on a monitoring programme. Evaluate the adequacy of mitigation and pollution control measures implemented to reduce the adverse impacts caused during the operation stage; if the environmental quality is not at the anticipated level, further modification is required in the mitigation plans.

Guidelines for Environmental monitoring applied to offshore Oil & Gas platforms are as follows:

- Develop a sampling strategy that includes site selection, the number of locations to be surveyed, samples to be collected, methods, samples storage, preservation, analysis and report writing.
- Site selection for sampling: The plan identifies the location and number of stations, sampling methodologies and analytes to be measured as per OSPAR guidelines. The location and number of stations should also be related to the project objective, activity, and development size, as shown below.

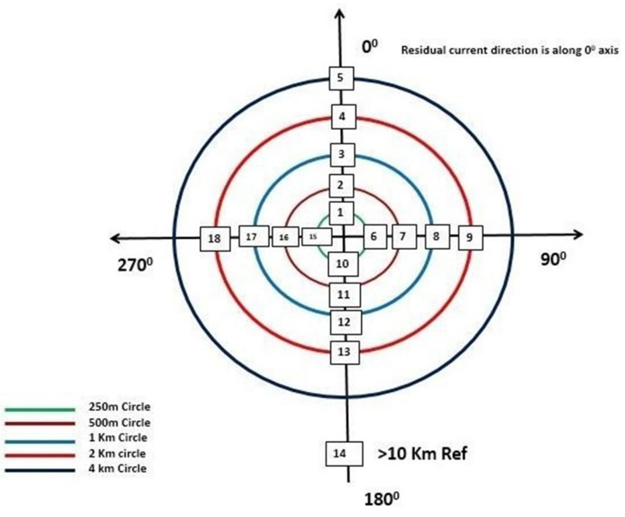

Figure: Sampling Strategy

- Dispersion modelling may also be useful in selecting sampling sites by predicting the deposition of constituents. Attention should be given to understanding previous and current activities in and around the study area and how these activities influence the obtained results.
- Guidance for measuring baseline components and attributes is listed in Annexure-3 (Table 5.3 of the report), which must comply with the limits given in Annexure-2 (Table 5.2 of the report).

Meteorological conditions

One station at the project site

Hourly observations - continuous records during the monitoring period

- Wind speed and direction
- Dry bulb and wet bulb temperature
- Barometric pressure
- Relative humidity
- Solar radiation
- Rainfall

Noise

Noise and vibration measurements should be conducted at least one day continuously on a working and non-working day at one location in the project site during the monitoring period.

Water column sampling

One sample from the surface mid and bottom at each station, process-wise or activity-wise, once in a year (pre or post-monsoon)

- Temperature & Salinity
- Turbidity
- Currents

- Dissolved Oxygen
- pH
- Nutrients (NO3-, NO2-, SiO4- and PO43-) and Ammonia
- Petroleum hydrocarbon
- Heavy Metals

Solid Waste – Sediment Quality

Process-wise or activity-wise, once in a year

- Munsell Soil Colour Chart System and smell
- Particle size distribution
- Organic Carbon
- Heavy metal
- PHC

Biological Parameters

Process-wise or activity-wise, once in a year

- Primary productivity
- Aquatic weeds
- Bacteria, phytoplankton, zooplankton, and benthos (macro and meiofauna)
- Fisheries
- Heavy metals and PHC in mixed plankton and fish
- Diversity indices
- Trophic levels
- Rare and endangered species
- Avifauna

- Sample storage and preservation: Sampling plans should specify the type of container, storage conditions, and maximum holding times for each type of analysis. Sample containers should be clean and properly stored to avoid contamination.

- Quality assurance and quality control (QA/QC): Documentation of the steps taken to ensure that the desired data quality is achieved is necessary to provide initial users with confidence in the reliability of the results.

- Data statistics and analysis: The data analyses to be conducted are dictated by the objectives of the environmental monitoring program. Major statistical data analysis methods are 1) Frequency Distribution Analysis; 2) Analysis of Variance; 3) Analysis of Covariance; 4) Cluster Analysis; 5) Abundance and Biomass Curve; 6) Diversity Index; 7) Multiple Regression Analysis; 8) Time-Series Analysis; 9) Application of Statistical Models.

- Subsea monitoring: An advanced measurement strategy using Landers and ROVs may be used to allow a large number of assessments to be made over a wide temporal and spatial area and track natural seasonal and global changes possibility for real-time measurements.

- Preparation of secondary data: All the relevant secondary data available for different environmental components should be collated and analyzed.

- Reporting: A detailed report should be prepared, including an introduction, methods, results & discussion, overall evaluation and conclusions, recommendations, summary and application of the results. This report should provide guidance to offshore operators on when and how to conduct an environmental monitoring programme.

7.3.6 Guidelines for discharge of gaseous emissions

General

Air emissions associated with oil and gas exploration and production activities can be generally categorized as arising from three activities: (1) the combustion of fuels for power generation; (2) emissions arising directly from the production, treatment, storage or transportation of produced oil and gas, and (3) flaring of gas.

Best Available Techniques (BAT)

All large combustion plants offshore (both existing and new) may proactively apply integrated prevention and reduction of pollution. This implies the application of Best Available Techniques (BAT). Regulators should refer to BAT when discharge limits are set in the discharge permits and reflect what reduction levels can be achieved without a definite resolution on what technology to use.

When making plans for the development of new fields, it is important to consider the need to reduce emissions to the air. Operators must inform the regulators on BAT considerations at an early stage in the development.

DG sets

DG sets at the production station should conform with the norms notified under the Environment (Protection) Act, 1986.

These trace gas concentrations must be within the ambient quality guidelines and standards as per the national legislated standards

- Use of high-efficiency equipment to minimise power requirement
- Use of low sulphur diesel (15 ppm)
- Power generation plants incorporating low emissions technology
- Renewable energy sources into developments
- Regular plant maintenance
- Regular maintenance and emission control devices on vehicles and machinery

Combustion

- Use of appropriate valves, flanges, fittings, seals, and packings, considering safety and suitability requirements as well as their capacity to reduce gas leaks and fugitive emission.
- Implementation of effective and regular leak detection and maintenance
- Ensuring new systems/processes do not use ozone-depleting chemicals or chemicals that cause global warming.

Venting

- The adoption of measures consistent with the Global Gas Flaring and Venting Reduction Voluntary Standard (part of the Global Gas Flaring Reduction Public-Private Partnership),
- Tightly controlled and managed flow of gas and a preferential flare rather than vent,
- Vapour recovery units may be installed for hydrocarbon loading and unloading operations
- Excess gas should not be vented in an emergency or equipment failure but sent to an efficient flare gas system.

Flaring

- Reducing the amount of gas flared from an offshore installation is beneficial both from an environmental point of view and can help avoid the potential waste of resources and reservoir energy.
- Some gas may be utilised for power production at the installation, but if a large amount of gas is produced, possible solutions may be an injection into the reservoir or export through pipelines. Every effort should be made to flare only where necessary for safety purposes.
- The planning and execution of activities regarding flaring reduction are extremely time-consuming and cost-intensive, hence technologies that could be used for reducing emissions from flaring may be closed flare technology and/or flare gas recovery systems.

- Ensuring a tightly controlled and managed flow of gas
- Careful flow tip design, implementation of state-of-the-art technology, reduction of levels of nitrogen oxides, particulate matter and carbon dioxide emissions to the atmosphere during flaring
- Adoption of measures consistent with the Global Gas Flaring and Venting Reduction Voluntary Standard (part of the Global Gas Flaring Reduction Public-Private Partnership) when considering flaring options for offshore activities
- Design of flare gas metering and tip design to minimise the need for flaring through recirculation, off-gas recovery, and/or flare gas recovery process design
- Maximise flare combustion efficiency by controlling and optimising flare fuel, air, and streamflow rates to ensure the correct ratio of assist stream to flare stream
- Strictly adhering to safety regulations, minimise flaring from purges and pilots through the adoption of various measures (installation of purge gas reduction devices, vapour recovery units, inert purge gas, soft seat valve technology, and installation of conservation pilots)
- Minimise the risk of pilot blowout by ensuring sufficient exit velocity and providing wind guards
- In the event of emergency or equipment breakdown, or during facility upset conditions, excess gas should be flared, not vented if possible

7.3.7 Guidelines to the Management Techniques for Drilling Wastes and Production Effluents

Offshore oil and gas activities produce a variety of wastes in the form of aqueous and solid discharges and atmospheric emissions that need to be managed to avoid air and water pollution to the marine environment especially smothering of benthic communities and contamination of materials and food sources. Waste management should be included in the planning from the beginning and combined with pollution prevention measures. Prevention and elimination of these discharges and emissions, which pose pollution threats to the environment, should be a targeted goal of regulatory activity. New technology makes this goal achievable in some situations.

- The operator should do the extent possible to avoid the generation of waste. Any waste generated should be handled in an environmentally and hygienically adequate manner. Solid waste should not be discharged into the sea.
- The operator should prepare a plan connected to waste, including possibilities for waste
- Reduction, waste segregation, reuse, recycling, energy recovery or treatment.
- Transfer of pollutants from one media to another should be avoided based on risk assessment.

Recommended Preventative Management Techniques:

Considering no discharge of the main waste streams at the planning and construction stage, in particular drilling waste and produced water; the following recommendations may be adopted:

(i) reduce waste at the source by process modification, material elimination, material substitution, inventory control and management, (ii) improved housekeeping, and water recovery; (iii) reuse of materials or products such as chemical containers, and oil-based or synthetic-based drilling fluids; (iv) recycle/recovery by the conversion of wastes into usable materials and/or extraction of energy or materials from wastes such as recycling scrap metal, recovery of hydrocarbons from tank bottoms and other oily sludge, burning waste oil for energy, and the use of produced water for enhanced recovery; (v) reduce the toxicity of effluents through the careful selection of drilling fluids and chemical products used in separation equipment and wastewater treatment systems; (vi) perform radiation surveys of equipment and sites to prevent or minimise the spread of Naturally Occurring Radioactive Materials (NORM), which may be carry out on a central basin in prospecting sedimentary basin; and where NORM-scale formation is anticipated, use scale inhibitors to minimise or prevent the buildup of radioactive scale in tubular.

For offshore discharge of effluents, the oil content of the treated effluent without dilution shall not exceed 40 mg/l for 95% of the observation and shall never exceed 100 mg/l. Three 8-hourly grab samples are required to be collected for a day, and the average value of soil and grease content of the three samples should comply with these standards.

Major Discharges

Disposal of drill cuttings & drilling fluids for offshore installations in compliance with The Environment (Protection) Rules, 1986:

- The chemical additives used for DF preparation should have low toxicity, i.e. 96 hr LC50 > 30,000 mg/l as per mysid toxicity test conducted on locally available sensitive sea species.
- The chemicals used (mainly organic constituents) should be biodegradable.
- Barite used in preparation of DF shall not contain Hg> 1 mg/kg & Cd > 3 mg/kg. Total material acquired for the preparation of the drill site must be restored after the drilling operation, leaving no waste material at the site.

Waste from Drilling Activities

- Drilling wastes in the form of residual drilling fluids and cuttings comprise the principal waste generated during well drilling. Initially, a determination needs to be made on whether or not to prohibit discharge based on its nature/volume and effect on the environment. In certain areas, due to the identification of environmentally sensitive areas, drilling fluids and cuttings may need to be managed to prevent discharge. In areas where discharge is permitted, the disposal method should be based upon careful consideration of drilling fluid formulation and specific environmental conditions at the site.

- Where water-based drilling fluids are employed, additives containing oil, heavy metals, or other substances with negative ecotoxicological properties should be avoided or removed prior to discharge.
- Persistent and toxic substances should be avoided.
- Criteria for the maximum allowable concentration of harmful or hazardous substances should be established.
- If the option of land disposal is used, both the properties of the drilling fluid and the environmental conditions at the proposed disposal site should be carefully considered to determine the acceptability of the disposal site. This is particularly important in offshore, where the creation of a disposal site on land may lead to environmental damage.
- Environmental considerations favour the use of non-oil-based drilling fluids for drilling.
- In shallow portions of a well, saltwater and saltwater with clay are often used as the primary drilling fluid, and the cuttings and residual fluids can generally be safely discharged into the marine environment.
- Discharge to the marine environment should be considered only where zero discharge technologies or re-injection are not feasible. Based upon site-specific biological, oceanographic and sea conditions, risk assessment methods and dispersal modelling studies should be used to determine whether the discharges should be at or near the seafloor or at a suitable depth in the water columns to keep the impact on marine life as low as possible. These discharges should be considered on a case-by-case basis.
- Where non-aqueous fluids are required, for example, in highly deviated wells or certain geological formations, operators should ensure that harmful or hazardous components are as low as possible and that fluids are recycled as far as practicable.

Disposal of cuttings contaminated with such fluids should be assessed on the basis of a comparative assessment of alternatives, including reuse of the material, injection into geological formations and discharge onto the sea bed, taking into account possible impacts on the sea and other environmental compartments.

- Spent oil-based or synthetic-based drilling fluids can often be reconditioned and recycled. Injection into disposal wells or encapsulation of reserve fluid pits containing drilling fluids and cuttings, including those with acceptable levels of NORMs, and other pumpable wastes, are potential disposal techniques. Where geological conditions permit, the re-injection of wastes into the reservoir significantly reduces discharges of cuttings and drilling fluids to the marine environment. Management of down-hole disposal will require diligence to ensure that wastes do not migrate into unsealed or undesirable stratigraphic zones and that well integrity is maintained. Stabilized burial at approved onshore disposal sites is another alternative.

Production Waste Discharges

- During production, produced water can be properly treated and discharged or may be reinjected.
- Other fluids, which are brought to the surface in connection with completion, workover, well treatment or production, may be mixed with wastewaters unless those waters are identified as hazardous waste at the time of injection. They can be commingled with produced water for treatment and discharged within acceptable limits or reinjected in most cases.
- Produced water treatment should be taken into account in the design phase and when significant modifications in operations are carried out.
- As characteristics of production water differ from one platform to another, no single system can be applied successfully to all offshore platforms. Therefore, a site-specific combination of technologies should be employed based on the characteristics of produced water such as droplet size, stability of the emulsion, the ratio of droplets/dissolved hydrocarbons, and the presence of other substances such as corrosion inhibitors, solids, and naturally occurring substances.

- Regulators and the industry should consider the options for reduction and possible elimination of produced water discharged to the sea through the application of BAT, for example, injection, downhole separation or water shut-off. The focus should be on reducing the volume of produced water discharges with the highest loads of oil and other substances.
- Regulators and industry should ensure that BAT and BEP are implemented on each platform and regularly review BAT and BEP. In addition, regulators and the industry should ensure that new offshore platforms or major modifications to existing platforms should consider design changes that minimise discharges.
- Produced sand containing elevated levels of naturally occurring radioactive material should be reinjected, encapsulated, or removed from the site and stored in a safe and environmentally sound manner that is carefully controlled and whose risks and circumstances have been adequately evaluated. Management of these wastes will require diligence to ensure that radioactive wastes taken to shore are handled and disposed of in accordance with applicable international law and in an appropriate and approved manner. Radioactive materials should be transported in approved containers with proper labelling, which identify the substance and its special transport and handling requirements. Appropriate record-keeping and proper notification for shippers should be maintained (For details, pl. see NORMS under Additional Studies).
- Deck wash and chemical/fluid releases are another concern to the marine environment, especially where oil-based drilling fluids are in use. A facility plan should be developed to address these potential conditions and methods of spill control, and leak minimisation should be incorporated into facility design and maintenance procedures. These plans, minimisation efforts and controls shall be applied to, but not limited to, material storage areas, loading and unloading operations, oil/water separation equipment, wastewater treatment, waste storage areas, and facility runoff management systems.
- All washdown waters, hydrocarbon-contaminated rainwater and deck wash, and machinery drainage space fluids should be either processed through an oil-water

separator prior to overboard discharge should meet Industry-specific standards issued by CPCB under EPA Rules 1986.

Fluid Waste from Well-Testing

- Oil or water containing oil may not be completely incinerated when flaring during well testing. The regulators must determine whether this may be discharged into the sea and, if so, the quality of the fluid which is allowed to be discharged. One possibility is to allow discharge after treatment if the quality of the water is similar to the discharges from produced water or drainage water.

Deck Drainage and Bilge Water

- The use of vessels/ships with a valid International Oil Pollution Prevention Certificate,
- Chemicals storage areas are to be free from residues/spills,
- Vessels to maintain an Oil Record Book, including the discharge of dirty ballast or cleaning water;
- Discharge into the sea of oil or oily mixtures is prohibited except when the oil in water content of the discharge without dilution does not exceed 40 ppm;
- Contaminated deck drainage and bilge water to be contained and treated prior to discharge in accordance with the prevailing norms. Suppose treatment to this standard is not possible. In that case, these waters should be contained and shipped to shore for disposal, and extracted hydrocarbons from oil-in-water separator systems to be stored in suitable containers and transported to shore for treatment and/or disposal by a certified waste oil disposal contractor.

Cooling Water and Brine

- Detailed dispersion and modelling studies are needed to identify appropriate coolant water and brine disposal locations.
- A minimum dosage of biocides and other chemicals and the generation of minimum freshwater for the operational requirement is the major mitigation measures to be adopted in this regard.

Hydrotest Water

The operators shall ensure that the chemicals used for hydro testing should be "environmentally friendly". When concluding a chemical as environmentally friendly, the following criteria (any one) shall be taken into consideration.

- ✓ The chemical cocktail should be easily biodegradable (results in more than 60% biodegradable within 28 days), and Toxicity (96 hr LC50 > 30,000 mg/l for most abundant biota and IUCN red list organism as in the Annexure-4, if any) should be minimum as per the criteria, which can be discharged offshore intermittently with an average rate of 50 bbl/hr/well from a platform so as to have proper dilution & dispersion without any adverse impact on the marine environment. OR
- ✓ Chemical cocktails or individual constituent chemicals should be in Gold or Silver classification as per Chemical Hazard And Risk Management (CHARM) prepared by the Centre for Environment, Fisheries, and Aquaculture Science (CEFAS). OR
- ✓ Part of OSPAR-PLONOR List (OSPAR List of Substances/Preparations used and discharged offshore which are considered to Pose Little Or No Risk to the Environment -PLONOR)

Produced Water

- ➢ Adopt methods to minimise the quantity of produced water
- ➢ Recycle and reuse produced water
- ➢ Evaluate options for treatment and disposal, including ship to shore, re-injection or discharge offshore
- ➢ When disposal/re-injection should be done without the leakage of the disposed water
- ➢ Where disposal to the sea is necessary, all means to reduce the volume of produced water should be considered
- ➢ The produced water discharge outfall should be designed to maximise dispersion of produced water in the sea to reduce the concentration of constituents that have the potential for environmental impact

- Production chemicals should be selected carefully by taking into account their application rate, toxicity, bioavailability, and bioaccumulation potential.
- Periodic comprehensive assessment of the marine environment should be undertaken, and various management strategies should be employed depending on the levels of pollution due to the project activities.

Ballast Water

- Strict compliance with local regulatory-authority guidelines should be ensured, and all the ships in international traffic are required to manage their ballast water and sediments in ballast tanks to minimise the risk of invasive marine species.

Produced Sand and Scale

- The management strategies include transporting produced sand, removed from process equipment to shore for treatment and disposal or routed to offshore injection disposal well, if available.
- If discharge to the sea is the only feasible option, the discharge should meet the guideline stipulated for marine disposal after a sediment dispersion modelling study.
- Any oily water generated from the treatment of produced sand should be recovered and treated to meet the guideline values for produced water.

Drilling Discharges

- Reduce the number of drilling wells and also reduce the generation of drill cuttings and drill fluids
- Drilling discharges should be as per GSR 546(E)
- Use of appropriate drilling fluid components with biodegradable (mainly organic constituents) and minimum toxicity of 96 hr LC 50 Value > 30,000 mg /l as per toxicity test conducted on locally available sensitive sea species.
- WBM/OBM /SBM should be recycled to a maximum extent. The unusable portion of OBM should not be discharged into the sea and shall be brought on-shore for treatment & disposal in an impervious waste disposal pit.

- Thoroughly washed DC, separated from WBM/SBM & an unusable portion of WBM/SBM having toxicity of 96 hr LC50 > 30,000 mg/l, shall be discharged off-shore into sea intermittently, at an average rate of 50 bbl/hr/well from a platform so as to have proper dilution & dispersion without any adverse impact on marine environment.
- Solids control equipment should be available onboard the drill rig to reduce the amount of residual drill fluids on cuttings prior to discharge
- The following guideline should be adopted if the sea disposal is unavoidable: The depth of water below the discharge outlet should be sufficient to allow acceptable dispersion of the cuttings to occur, bulk cement and additives discharge to be regulated.

Process and Production Chemicals

- Usage of low toxicity and water-soluble control fluid, collect the waste fluid in closed systems and send to the onshore facility of treatment and disposal.
- Design of equipment to reduce the volume of fluid and acids should be neutralised before disposal.
- Use chemical systems in relation to their concentration, toxicity, bioavailability, and bioaccumulation potential.
- The use and discharge of chemicals from the oil and gas industry should be strictly regulated to avoid or reduce possible negative effects on the marine environment.
- The amounts of chemicals used and discharged should be as low as possible.
- All major substances in chemical preparations should meet GSR 546 (E) standard.
- The tests should be performed by laboratories that are approved in accordance with established international standards, for example, OECD’s principles for Good Laboratory Practice (GLP) or equivalent.

Biodegradability

- If possible, the substance should be tested in accordance with established standards, for example, the seawater test OECD 306 “Biodegradability in Seawater” or equivalent.

Bioaccumulation

- Chemicals that consist of several substances should be tested for the individual organic substance's bioaccumulation potential.
- The substances should be tested according to established standards, for example, OECD standards or equivalent.
- For substances where standardised tests are not applicable, as for surfactants, a calculation or a scientific evaluation of the bioaccumulation potential may be performed.

Acute toxicity

- Inorganic and organic chemicals should be tested for acute toxicity.
- Toxicity tests specified in the OSPAR Protocols on methods for testing of chemicals used in the offshore industry should be used.

Assessing chemical risk

- The operators should ensure that risk evaluations are done based on the chemicals' intrinsic properties, time, place and amounts of discharge, and also other conditions of significance for the risk. According to environmental risk evaluations, the operator should choose the chemicals that pose the lowest risk of harming the marine environment.
- The operator should have plans to ensure that hazardous chemicals are substituted with substances that pose less risk of environmental harm. The plans shall describe which chemicals are prioritised to replace and when this can take place.
- Chemicals should be stored safely and prudently.

Hazardous Waste

- The most effective way of protecting human health and the environment from the dangers posed by hazardous wastes is to ensure the reduction of their generation to a minimum in terms of quantity and/or hazard potential. Minimising the generation of hazardous waste requires the implementation of environmentally sound low-waste technologies, recycling options, good housekeeping and management systems.

- The availability of adequate disposal facilities should be ensured prior to allowing an activity to generate hazardous wastes.
- Hazardous wastes requiring transport to a disposal site should be packaged, labelled, and transported in conformity with generally accepted and recognised international rules and standards in the field of packaging, labelling, and transport.
- Due account should be taken of relevant internationally recognised practices. Transported hazardous wastes should be accompanied by a movement document from the point at which movement commences to the point of disposal.
- Segregation of hazardous waste in hazardous drums or tanks prior to disposal and hazardous waste should be managed, handled, and stored according to their Safety Data Sheet.

Non-hazardous Solid Waste

- Proper segregation of wastes (recyclable and non-recyclable) and offshore disposal strictly adhering to the regulatory guidelines should be adopted.
- Disposal of solid and domestic wastes should conform to international law, such as MARPOL 73/78, and national legislation.
- Sanitary wastes such as sewage and grey waters should be processed according to international or local government standards prior to discharge into the marine environment. Processing in an acceptable sanitary waste treatment unit will properly treat waste streams prior to discharge.
- Discharge water from showers, toilets, and the kitchen should be treated on-site in an appropriate effluent treatment plant.

Unplanned Events

Accidental Release of Chemicals

- Chemical spill containment and recovery equipment will be available near chemical inventories,

- Chemical transfers should be undertaken only in suitable weather conditions, and the vessels/drilling units have a valid International Oil Pollution Prevention Certificate.

Spills – Collision/Tank/Pipeline Rupture

- Vessels should maintain suitable lighting, shapes, and navigation, at all times to inform other users of the position and intentions of the vessel, hydro testing to ensure leaks are free in pipelines, protection of pipelines by trenching and burial are recommended.

Spills during Refueling and Bunkering

- Refuelling to be conducted in port, where spill risk factors are more easily controlled
- Refuelling at sea to be undertaken by trained personnel using defined procedures, during daylight hours except where safety considerations take priority and when sea conditions are sufficiently calm
- Regular inspection of transfer hose integrity, limiting volumes of fuel held in the transfer hose and the use of fail-safe valves to ensure rapid shutdown of fuel pumps
- Continuously monitor tank levels to prevent overflow

Spills from Exploration and Production Facilities

- Oil spill modelling or dispersion modelling should be undertaken to determine the potential impact on the surrounding environment
- Blowout prevention measures to focus on maintaining wellbore hydrostatic pressure by effectively estimating fluid formation pressures and the strength of subsurface formations
- Well integrity testing should be performed in-par with Well Operations Management Plan (WOMP) and Well Control Contingency Plan (WCCP) should be in place.
- If well workover/intervention is required, well isolation barriers and well intervention procedures should be in place.

- Contingency plans should be prepared for well operations and should include identification of provisions for well capping, relief well drilling and other response measures, including plans for the mobilisation of resources, in the event of an uncontrolled blowout; Spill preparedness measures and emergency response procedures in place; Implementation of ongoing maintenance and inspection procedures to maintain facility integrity.

Collision with Marine Fauna and Introduction of Invasive Marine Species

- Monitor for presence and movements of large cetaceans, pinnipeds, and turtles so that avoidance actions can be taken where marine fauna is observed on a collision course with vessels and the application of species-specific management actions to minimise adverse interactions;
- Reduce the potential for entanglement of marine animals in the seismic equipment and rescue and release of entangled animals to the sea.
- Development of Invasive Marine Species Management Plan and Comply with the International Convention on the Control of Harmful Anti-Fouling Systems on Ships.
- Ensure vessels have a valid Class certification of vessel as per Indian Regulation/International Anti-Fouling System Certificate and regular inspections of the hull, including niche areas, cleaning, dry-docking, and regular renewal of anti-fouling coatings, should be adopted in this regard.

7.3.8 Guideline for Oil Spill Response Plan

Oil spill response plan needs to be prepared at par with the National Oil Spill Disaster Contingency Plan 2015 (NOS-DCP). Operators should be required to have site-specific or operator-specific plans. An oil spill response plan addresses an oil spill volume based on relevant well data, catastrophic loss of a tank ship or barge, or damage to a pipeline. The plan should be supplemented by resource sensitivity maps arranged sequentially by month for those identified by spill trajectories as potentially exposed to oil pollution. The plan should also describe the process for its development, which should include involvement by response entities, both government and private, health officials, scientists, local populations that may be affected, wildlife experts, trustees of resources, and anyone else who may be affected or who may have a role in the response. Operators should allow the opportunity for public review and comment on the plan.

The oil spill response plan should include, in addition to the items described above, the following:

- A brief description of the operation
- Awareness of remote sensing imagery analysis concerning oil spills detection and monitoring on a spatial-temporal scale.
- Description of the site, water depth, seasonal constraints, and logistical support
- References to all environmental support material that would be relevant to establishing clean-up priorities
- Details of the operator's capability in using real-time wind and current data to implement an oil spill trajectory model both for the open sea and for ice-infested areas
- A map depicting sensitive areas to be protected
- Description of clean-up and containment strategies required for shoreline and ice-covered areas
- Description of alternative clean-up strategies such as the use of dispersants, in situ burning, and no response
- Strategy to respond to small spills from the installation, shore base or loading operations
- Provisions for transport, storage, and disposal of recovered oil and oil-contaminated materials
- Spill response crew relief & logistics
- List or inventory of spill response equipment and their measured efficiency when used as expected in the plan.
- Operators should have access to oil spill countermeasures equipment. The oil spill response plan should itemise equipment on-site for immediate containment purposes.

- The plan should also provide details of oil spill equipment and resources that are not on-site but will be mobilised in the event of a spill; the details should include the type of equipment, required resources, logistics and timing of mobilising the equipment to the site.
- The oil spill response plan should include the qualifications and training of personnel responsible for managing oil spill responses. It should clearly define their authority to take action to respond to such emergencies.
- A national preparedness and response system should be developed to protect the nation's citizens health and safety, the environment, and socio-economic interests.

Exercises and Drills

- To enhance response capabilities, response organisations should conduct regular safety and emergency response drills during which trained workers and emergency responders carry out regular exercises.
- Drills include desk-top exercises and actual equipment and operational deployment exercises.

7.4 Recommendations for future course of action:

Limitation to access the region and expensive/unavailability of state-of-the-art equipment and sampling platforms are major reasons for the paucity of environmental data in the Indian EEZ beyond 12 NM. From the compilation of various reports/studies to prepare baseline data for the sedimentary basins in India, the least studied basins are Kerala-Konkan, Mahanadi and Andaman basins. Hence, it is recommended that studies should be undertaken to generate adequate baseline environmental data for these basins to facilitate the preparation of the EIA report.

NIO recommends following actionable items for all the blocks beyond 12 NM for following E&P activities.

A) ***Exploratory Surveys***: Operators may avoid explorative surveys during breeding periods of fish in the respective areas, such as 15th April to 14th June in the Bay of Bengal and from 1st June to 31st July in the Arabian Sea.

B) ***Exploratory / Appraisal Drilling***: In line with MOEF&CC notifications dt 16th Jan 2020, it is recommended that the operator needs to prepare the Environmental Management Plan as per the best industry practice for blocks beyond 12 NM for the exploratory/appraisal drilling campaign. The report may be prepared by national R&D organisations / MoEF&CC approved/NABET accredited consultants for offshore Oil & Gas operations. The operator is required to submit the EMP report to DGH prior to commencement of drilling activity and also submit the yearly compliance report to DGH till the drilling campaign completes.

C) ***Development / Production Phase***: For the development facilities beyond 12 NM, the operator would be required to prepare and submit the EIA report to DGH, and DGH may approve the report after due diligence. The operator would be required to submit the yearly compliance reports to DGH for all the recommendations mentioned in the EIA report. The operator would also be required to conduct baseline studies through MoEFCC approved / NABET accredited consultants/ nationally reputed R&D organizations.

For the development facilities beyond 12 NM, the operator would be required to prepare and submit the EIA report to DGH, and DGH may approve the report after due diligence. The operator would also be required to submit the yearly compliance reports to DGH for all the recommendations mentioned in the EIA report, including baseline studies through MoEFCC approved / NABET accredited consultants/ nationally reputed R&D organizations-

D) ***Operation Phase***: Prior to the commencement of the operation phase, the operator is required to prepare the Environmental Management Plan and submit the same to DGH for consideration. It would be mandatory for the operator to submit a compliance report of the EMP document to the DGH for consideration on a yearly basis.

E) ***Decommissioning Phase***: The EIA report for the selected decommissioning methodology as per the SRG' 2018 guidelines should consider environmental protection methods, and the EIA report for the selected concepts will be submitted by the operator to OISD along with the site restoration plan for approval.

Chapter 8: Summary and conclusion

India has an estimated sedimentary area of 3.36 million sq km, comprising of 26 sedimentary basins, out of which, 1.63 million sq km area is in the land, shallow offshore up to 400 m isobaths with an aerial extent of 0.41 million sq km and deep water beyond 400 m isobaths with the sedimentary area of 1.32 million sq km as per renewed categorisation of sedimentary basins. Over the last few years, there has been a significant forward leap in exploring the hydrocarbon potential of the sedimentary basins of India. The unexplored area has come down significantly due to the surveys carried out by DGH, while unexplored/poorly explored areas of the country are mainly in the Deep waters. Office of the Directorate General of Hydrocarbon, Ministry of Petroleum & Natural Gas, Government of India, requested CSIR NIO to carry out the Study of Environmental Impact of Petroleum Exploration and Developmental projects in offshore areas beyond 12 nautical miles and suggest means for protecting marine ecology and prevention of marine pollution through a proper monitoring and mitigation plan become the genesis of this work

Chapter 2 broadly explains the national and international regulations and frameworks in the oil and gas exploration industries. This chapter looks into the Environment Impact Assessment Notification of 2006, which has decentralized the environmental clearance projects by categorizing the developmental projects in two categories, i.e., **Category A (national level appraisal)** and **Category B (state-level appraisal)**. In the original EIA Notification, 2006, "offshore and onshore oil & gas **exploration**, development and production" has been covered under schedule 1(b) and being category A projects, it requires preparation of an Environment Impact Assessment (EIA) report, the conduct of public hearing and clearance from the Union MoEF&CC. Vide notification **dated 16 January 2020 categorizes onshore and offshore oil and gas exploration activities as B2 category** for seeking prior Environmental Clearance(EC). As exploration activities in the hydrocarbon sector have been moved from Category A to Category B2, they will now require environmental clearance only from the States concerned and will not require preparation of an EIA report or conduct of Public Hearing. However, both on offshore

/onshore fields as hydrocarbon blocks, development, or production will continue to merit assessment as"category A". ToR has been prepared to comply with environmental standards to sustain a good ecosystem by negating adverse impact related Oil and Gas fields beyond 12 nautical miles.

Chapter 3 deals with Baseline data of the marine environment prepared by comprehensive analysis of Marine EIA/ monitoring work carried out in the oil fields within the EEZ of India in shallow and deep offshore blocks; we have compiled most of the available reports related to the oil field along with the western and eastern offshore blocks, books, journal papers, thesis and other documents. For each basin, Meteorological parameters (wind speed, relative humidity barometric pressure, air temperature, solar radiation), physical parameters (currents, wave, temperature, salinity, density, turbidity/TSM), chemical parameters (Dissolved oxygen (DO), BOD, Nutrients (nitrate- NO_3^-, silicate - SiO_4^- and phosphate – PO_4^{3-}), Dissolved petroleum hydrocarbon, Dissolved heavy metals), sediment parameters, heavy metals, phytoplankton, zooplankton, benthos, the abundance of fish etc. were prepared through the compilation of the documents. Apart from that, we have referred and verified meteorological and physical datasets from several websites, such as NCEP, ECMWF, GIOVANNI, APDRC and NIO web database, for supporting the baseline data collected from available reports. All basin Cyclone data were taken from India Meteorological Department (IMD). Ultimately for each basin, we have tabulated the minimum, maximum, with average values of each parameter, which can be further used as the baseline data to study the impact of Oil and Gas project on the marine environment.

The Marine Protected Areas is a network in India that has been used to manage natural marine resources for biodiversity conservation and the well-being of the people dependent on them. India has designated four legal categories of protected areas: National Park, Wildlife Sanctuary, Conservation Reserve and Community Reserve. India has created a network of PAs representing all its 10 biogeographic regions. A total of 690 protected areas have been established in India as of 1 April

2014, including 102 national parks, 527 wildlife sanctuaries, 57 conservation reserves and 4 community reserves. Besides, 26 wetlands have been designated as Ramsar sites. India has a coastline of nearly 8129 km, but the reef formation is restricted to four major centres. Gulf of Kutch. Gulf of Mannar, Lakshadweep and Andaman and the Nicobar Islands. The total area of coral reefs in India is estimated to be 2,375 sq. km.

Chapter 4 deals with the Environmental Impact Assessment and Mitigation measures related to the Offshore Oil and Gas Sector. Potential impacts are generally assessed at the project level through some formal process, termed an environmental impact assessment (EIA). These typically involve identifying, predicting, evaluating, and mitigating impacts before starting a project. Various activities during Seismic survey, vessel operations, Exploratory & appraisal drilling, Development & Production and Decommissioning stages were identified, and the impact on the marine environment has been assessed. Together with baseline information and anticipated impact, mitigation measures to negate the adverse effect on the environment has been discussed.

The primary aim of chapter 5 is the environmental monitoring program, and it is a systematic, site-specific plan for monitoring the environmental parameters within the impact area, during and after commissioning of the project, which would aid in assessing the effectiveness of mitigation and environmental protection measures implemented for the proposed project based on the existing ecological scenario and the probable environmental impacts appraisal. The offshore environmental monitoring provides an overview of the environmental status combined with baseline data that trends over time due to offshore oil and gas activities. Sampling location, parameters, frequency and strategies were discussed to monitor the environment during the various stages of the project activity, intending whether the environmental status of the offshore oceanic environment is stable, deteriorating or improving, due to operators' activities. Overall, the environmental monitoring contributes to describing to what degree a station or a wider area around an installation or in a region is impacted because of discharges from oil and gas activities. It is important that results from the environmental monitoring offshore can be used to verify predictions and conclusions of the environmental impact assessment study for the respective field or the region.

Chapter 6 Additional studies deal with Risk Assessment by identifying, analysing, assessing, and communicating risk and accepting, avoiding, transferring or controlling it to an acceptable level by considering associated costs and benefits of any actions taken. We also prepared a disaster management plan related to the offshore Oil and Gas projects to set out the appropriate course of action to mitigate the impact of an emergency event. This is to respond immediately to an emergency event to prevent its escalation to a disaster and the response in such an escalation. Natural hazards like Cyclone, Tsunami, earthquakes and Oil Spill has been discussed, and an action plan has been formulated for early response to such events. Improving contingency plans with GIS, Remote sensing, Airborne monitoring, and Numerical Modelling has been discussed in this section. Various stages in the decommissioning offshore oil and Gas project and related environmental impact have been identified. The best minimum footage on the environment has been suggested. The possibility of Naturally Occurring Radioactive Materials (NORM) during the project activity has been identified, and its mitigation measured were suggested; similarly, the management of Hydrotest water was also discussed. IUCN Red List Marine species in the Indian Ocean Waters has been listed; if any of these organisms were identified in the project domain during the survey, a detailed biodiversity action should be prepared to conserve the organism and its habitat.

Chapter 7 deals with Environmental management within the oil and gas industry draws principally from the E&P Forum Guidelines for the Development and Application of Health, Safety and Environmental Management Systems (HSE-MS) point of view. Commitment to and demonstration of continual performance improvement is vital in ensuring that management is effective and maintained. Under the HSE-MS, standards, procedures, programmes, practices, guidelines, goals, and targets must be established, and where necessary, agreed with regulators and other stakeholders. Monitoring and auditing will show how well an operation performs and provide a measure of effectiveness.

Checklist/SOP and Guidelines for the operators engaging E&P activities beyond 12 nm have been prepared to adopt better environmental management to negate adverse impact due to project activity.

- Guidelines for Seismic operations
- Guidelines Exploration and appraisal drilling
- Guidelines Development and Production
- Guidelines to the Decommissioning of offshore oil and gas structures
- Guidelines for Environmental monitoring programme
- Guidelines for discharge of gaseous emissions
- Guidelines to the Management Techniques for Drilling Wastes and Production Effluents
- Guidelines for Naturally Occurring Radioactive Materials in Oil and Gas Industry
- Guideline for Oil Spill Response Plan

Chapter 9: Disclosure of Consultant

CSIR-National Institute of Oceanography, Government of India, is one of the 37 constituent laboratories of the Council of Scientific & Industrial Research (CSIR), New Delhi.

Our Mission: To continuously improve our understanding of the seas around us and to translate this knowledge to benefit all.

CSIR-NIO was established on 1 January 1966 following the International Indian Ocean Expedition (IIOE) in the 1960s. The institute has since grown into a multi-disciplinary oceanographic research institute of international repute. The principal focus of research has been on observing and understanding special oceanographic characteristics of the Indian Ocean. The results have been reported in more than 5000 research articles so far. The National Institute of Oceanography (NIO) with its headquarters at Dona Paula, Goa, and regional centres at Kochi, Mumbai and Visakhapatnam. The institute has a sanctioned strength of 200 scientists and 100 technical support staff. The major research areas include the four traditional branches of oceanography - biological, chemical, geological/geophysical, and physical – as well as ocean engineering, marine instrumentation and marine archaeology. With the largest collection of ocean scientists in the country and equipped with suitable ocean research infrastructure, CSIR-NIO serves as an advanced centre of education in ocean sciences

In addition to basic research, the institute also carries out applied research sponsored by the industry. These studies include oceanographic data collection, environmental impact assessment, and modelling to predict environmental impact. The institute also provides consultancy on a number of issues, including marine environmental protection and coastal zone regulations.

Institute has the necessary expertise supported by equipment and infrastructural facilities to carry out the marine survey and EIA studies. EIA consultants are the regular staff of CSIR-NIO and are listed below.

Department	Name of Consultant	Specialization
Physical Oceanography	Dr. Muraleedharan K R	Coastal Processes, Hydrography, Large-Scale Ocean Processes, Numerical modelling, Marine EIA
	Dr. Dinesh Kumar P.K	Coastal Processes, Climate Change, Marine EIA
	Dr. Revichandran C	Coastal Processes, Hydrography, Beach Erosion & Coastal Protection
Chemical Oceanography	Dr. Gireesh Kumar TR	Nutrient Cycling & Biogeochemistry, Chemical processes at the benthic boundary layer, Marine Pollution, Marine EIA
	Dr. Maheswari Nair	Nutrient Cycling & Biogeochemistry, Marine Pollution
Biological Oceanography	Dr. Madhu NV	Productivity & Trophic Dynamics, Ecology & Ecosystem Functioning, Marine Biodiversity
	Dr. Jyothibabu R	Ecology & Ecosystem Functioning, Productivity & Trophic Dynamics, Marine Biodiversity
	Dr. Anas Abdulaziz	Ecology & Ecosystem Functioning, Biotechnology & Molecular Biology, Biogeochemistry & climate change
	Dr. Abdul Jaleel KU	Ecology & Ecosystem Functioning, Productivity & Trophic Dynamics, Marine Biodiversity

Mandate

- To disseminate knowledge on the waters around India.
- To develop knowledge on physical, chemical, biological, geological, geophysical, engineering and pollution aspects of the waters around India.
- To provide support to various industries, government and non-government organisations through consultancy and contract research.

Industrial Consultancy

Industrial units dealing Port and Harbour development, Oil and Gas exploration, ship breaking yards, fertilizers, pharmaceuticals, paper, chemical, petroleum and cement are being set up along the coast. Most of these industries need guidance and advice for identifying suitable areas and modes to discharge their treated effluent into the sea such that the impact on the environment is minimal. Power plants look for appropriate sites in their vicinity to draw large quantities of seawater to serve as a coolant. Other developmental activities such as the expansion of ports and harbours, deepening of navigational channels and construction of offshore facilities require an assessment of their potential environmental impact.

Apart from carrying out the research work, NIO provides services to various organizations in solving ocean-related problems and assists in carrying out the work in the marine environment through sponsored or consultancy projects. As per the project requirement, NIO scientists collect data on physical, chemical, biological, geological and engineering aspects through field measurements using moored/drifting buoys and research vessels. We also utilize the data transmitted by a number of satellites equipped with oceanographic sensors. These data are analysed and interpreted along with outputs of numerical models to understand various coastal and oceanic processes and their roles on the marine environment due to industrial activities.

Bathymetry, seabed Engineering, CRZ demarcation

NIO conducts Bathymetry, Seabed Engineering and CRZ demarcation surveys for offshore industry developmental projects with international standards. Surveys for

CRZ demarcation for coastal stretches of the sea, bays, estuaries, creeks, rivers and backwaters, which are influenced by tidal action, are carried out as per MoEF guidelines.

Environmental Impact Assessment and environmental monitoring

NIO carries out Environmental Impact Assessment for developmental projects in the marine area as per MoEF notification dated September 2006.

Oil spill risk analysis and preparation of contingency plan

The facilities where crude oil and products are stored and handled have the potential for the oil spills.

Our consultancy is in the following areas:

- Environmental Impact Assessment and environmental monitoring
- Bathymetry, seabed Engineering, CRZ demarcation
- Evaluation of design parameters for coastal & offshore facilities
- Site selection for marine outfall, sea water intake, jetty, SPM and submarine pipelines
- Numerical modelling
- Oil spill risk analysis and preparation of contingency plan
- Biofouling and corrosion
- Underwater Surveys

Numerical modelling

- Simulation of tides and tidal currents
- Storm surge estimation
- Coastal circulation
- Thermal plume mapping
- Pollutant transport in creeks, estuaries and coastal ocean

- Prediction of near shore and deepwater wave statistics and wave spectra
- Sediment transport
- Beach changes
- Water quality
- Offshore and nearshore spectral wave modelling
- Ecological modelling
- Oil spill modelling

MoEF Certificate

Ministry of Environment Forest and Climate Change identified CSIR-National Institute of Oceanography as an expert organisation to carryout Marine Environmental Impact Assessment and Environmental Monitoring studies.

मनोज कुमार सिंह
Manoj Kumar Singh

सत्यमेव जयते

संयुक्त सचिव
भारत सरकार
पर्यावरण, वन एवं जलवायु परिवर्तन मंत्रालय
Joint Secretary
Government of India
Ministry of Environment, Forest & Climate Change

No. J-11013/77/2014-IA-I

Dated: 18th January, 2017

Dear Dr. Kumar,

This is with reference to my earlier letter of even no. dated 26th October, 2016 wherein you were requested to give your consent for working as Environmental Consultant Organizations for preparation and presentation of Environment Impact Assessment (EIA) report and Environment Management Plan (EMP). You have provided consent for your organization to work as Environmental Consultant Organizations.

2 Environment Impact Assessment Notification, 2006 provided for 39 sectors for which the project proponent is required to obtain prior environmental clearance. The EIA Notification, 2006 can be seen at the Ministry's website: http://environmentclearance.nic.in. You are requested to provide the sector(s) in which your organization will be taking up the projects for preparing EIA/EMP based on the sectoral expertise in the organization, as the accreditation granted for working as Environmental Consultant Organization is sector(s) specific.

with Regards!,

Yours Sincerely

Encls: As above

18.1.17
(Manoj Kumar Singh)

Dr. Prasanna Kumar,
Director
CSIR –National Institute of Oceanography,
Dona Paula, Goa

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स्वर्ण जयंती वर्ष

सी एस आई आर - राष्ट्रीय समुद्र विज्ञान संस्थान
(वैज्ञानिक एवं औद्योगिक अनुसंधान परिषद)
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(Council of Scientific & Industrial Research)
DONA PAULA, GOA - 403 004, India

75 Years of CSIR Touching Lives

डॉ. एस. प्रसन्न कुमार
कार्यकारी निदेशक

Dr. S. Prasanna Kumar
Acting Director

NIO/BDG/Gen-2017/1
23 January 2017

Ref: No. J-11013/77/2004-IA-I dated 18 January 2017

Dear Shri Manoj Kumar Singh,

CSIR-National Institute of Oceanography has the required expertise for preparing the Environment Impact Assessment (EIA)/Environment Management Plan (EMP) of projects in below mentioned sectors.

i) Offshore oil and gas exploration, development and production
ii) Oil & gas transportation pipeline (crude and refinery/petrochemical products) passing through national parks/sanctuaries/coral reefs/ecologically sensitive areas including LNG Terminal
iii) all ship breaking yards including ship breaking units
iv) Ports, Harbours
v) common effluent treatment plants (CETPs).

We give our consent to work as Environmental Consultant Organisation for above mentioned Sectors listed in EIA notification, 2006.

With best regards,

Yours sincerely,

(Prasanna Kumar)

Shri Manoj Kumar Singh,
Joint Secretary,
Ministry of Environment, Forests and Climate Change,
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References

"Coast Guard: Striving for Excellence', Sainik Samachar, February 1-15, 1997, p.15.

"Deep Sea Fishing Policy Scrapped," Maritime International, March 1997, p. 35.

"Ocean Policy Statement", Department of Ocean Development, November 1982.

"Report of the Expert Committee on Ocean Part of the. Coastal Zone," Department of Ocean Development, February 1996, pp. 1-15.

"Search and Rescue Organisations: India," paper prepared by the Society of Indian Ocean Studies (SIOS), New Delhi, for an international workshop on The Mitigation of Maritime Natural Hazards in the Indian Ocean, Mt. Macedon, Australia, October 8-11, 1996.

"Voices for the Oceans: A Report of the Independent World Commission on the Oceans," The International Ocean Institute (India) (1996), p. 58.

A Field Guide to Coastal Oil Spill Control and Cleanup Techniques. CONCAWE (1981). Report No. 9/81.

A Field Guide to Inland Oil Spill Clean-up Techniques. CONCAWE (1983). Report No. 10/83.

A Guide to Contingency Planning for Oil Spills on Water. IPIECA 1991.

A Guide to Risk Assessment and Risk Management for Environmental Protection. HMSO. London. (1995).

Agenda 21. Conference document from the UN Conference on Environment and Development, Rio de Janero, 1992.

Ajemian, M. J., Wetz, J. J., Shipley-Lozano, B., Shively, J. D., & Stunz, G. W. (2015). An analysis of artificial reef fish community structure along the northwestern Gulf of Mexico shelf: potential impacts of "Rigs-to-Reefs" programs. PloS One, 10(5), e0126354.

American Petroleum Institute. Safety and Environmental Management Programs (SEMP) in the offshore oil industry. RP75.

An Overview of Monitoring Results in the United Kingdom, the Netherlands and Norway, OSPAR Commission, 2007

Annual Report 2019–20, Ministry of Petroleum and Natural Gas, Government of India, page 30, available at http://petroleum.nic.in/sites/default/AR_2019-20E.pdf

Anticipating the Environmental Effects of Technology—A Primer and Workbook. 1996, 216 pp.

APELL Awareness and Preparedness for Emergencies at Local Level. A Process for Responding to Technological Accidents. UNEP/IE. Paris. (1988).

APELL—Awareness and Preparedness for Emergencies at Local Level: a Process for Responding to Technological Accidents. 1988, 63 pp. article9724778.ece.

Artiola, J.F., Pepper, I.L., Brusseau, M. (Eds.). (2004). Environmental Monitoring and Characterization. Burlington, MA: Elsevier Academic Press.

Atchison, A. D., Sammarco, P. W., & Brazeau, D. A. (2008). Genetic connectivity in corals on the Flower Garden Banks and surrounding oil/gas platforms, Gulf of Mexico. Journal of Experimental Marine Biology and Ecology, 365(1), 1–12.

Atmospheric Emissions from the Offshore Oil and Gas Industry in Western Europe. E&P Forum (December 1994). Report No. 2. 66/216.

Audit and Reduction Manual for Industrial Emissions and Wastes (TR 7). UNEP/UNIDO, 1991, 127 pp.

Azaino, E. U. (2012). International Decommissioning Obligations: Are There Lessons Nigeria Can Acquire from the UK's Legal and Regulatory Framework. University of Dundee.

Beanlands, G. E., and Duinker, P. N. (1984). Lessons from a decade of offshore environmental impact assessment. Ocean Manag. 9, 157–175. doi: 10.1016/302-184X(84)90001-5

Biological Impacts of Oil Pollution: Coral Reefs. IPIECA 1992.

Biological Impacts of Oil Pollution: Mangroves. IPIECA 1993.

Biological Impacts of Oil Pollution: Rocky Shores. IPIECA 1995.

Bishop, M. J., Mayer-Pinto, M., Airoldi, L., Firth, L. B., Morris, R. L., Loke, L. H. L., … others. (2017). Effects of ocean sprawl on ecological connectivity: impacts and solutions. Journal of Experimental Marine Biology and Ecology, 492, 7–30.

Blueprint for Green Management—creating your company's own environmental action plan G. Winter, McGraw-Hill, 1995.

Bohnsack, J. A. (1989). Are high densities of fishes at artificial reefs the result of habitat limitation or behavioral preference? Bulletin of Marine Science, 44(2), 631–645.

BP Statistical Review of World Energy 2020 (69th ed.), page 8, available at https://www.bp.com/content/dam/bp/businesssites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2020-full-report.pdf.

Breuer, E., Stevenson, A. G., Howe, J. A., Carroll, J., & Shimmield, G. B. (2004). Drill cutting accumulations in the Northern and Central North Sea: a review of environmental interactions and chemical fate. Marine Pollution Bulletin, 48(1–2), 12–25.

Bullock, R., Ralph, G.M., Stump, E., Al Abdali, F., Al Asfoor, J., Al Buwaiqi, B., Al Kindi, A., Ambuali, A., Birge, T., Borsa, P. and Di Dario, F., 2021. Conservation status of marine biodiversity of the Western Indian Ocean.

Cabinet approves 'Natural Gas Marketing Reforms', Press Information Bureau, Cabinet Committee on Economic Affairs (7 October 2020), https://pib.gov.in/PressReleasePage.aspx?PRID=1662325.

Cabinet approves 'Natural Gas Marketing Reforms', Press Information Bureau, Cabinet Committee on Economic Affairs (7 October 2020), https://pib.gov.in/PressReleasePage.aspx?PRID=1662325.

'Cabinet approves Policy Framework for exploration and exploitation of Unconventional Hydrocarbons', Press Information Bureau, Government of India, Cabinet, (August 2018), http://pib.nic.in/newsite/PrintRelease.aspx?relid=181361.

Cameron, P. D. (1998). Decommissioning of Oil & Gas Installations: A Comparative Approach to the Legal & Contractual Issues. Barrows Company.

Case Studies Illustrating Environmental Practices in Mining and Metallurgical Processes. UNEP/ICME, 1996, 61 pp.

CBM Policy approved by the Government of India 19th July, 1997, http://petroleum.nic.in/sites/default/files/cbmpolicy_0.pdf.

Changing Course—a Global Business Perspective on Development and the Environment. S. Schmidheiny, MIT Press, 1992.

Chemical Pollution, a global overview. UNEP, 1992

Chemical Treatments and Usage in Offshore Oil and Gas Production Systems. API, Offshore Effluent Guidelines Steering Committee. October 1989. Ed. C.M. Hudgins

Chemical Usage in North Sea Oil and Gas Production and Exploration Operations. OLF. (February 1991) (4) Exploration and Production (E&P) Waste Management Guidelines. E&P Forum. September 1993. Report No. 2.58/196.

Claisse, J. T., Pondella, D. J., Love, M., Zahn, L. A., Williams, C. M., & Bull, A. S. (2015). Impacts from partial removal of decommissioned oil and gas platforms on fish biomass and production on the remaining platform structure and surrounding shell mounds. PloS One, 10(9), e0135812.

Claisse, J. T., Pondella, D. J., Love, M., Zahn, L. A., Williams, C. M., Williams, J. P., & Bull, A. S. (2014). Oil platforms off California are among the most productive marine fish habitats globally. Proceedings of the National Academy of Sciences, 111(43), 15462–15467.

Climate Change and Energy Efficiency in Industry. UNEP IE/IPIECA, 1991, 64 pp.

Company Environmental Reporting: A Measure of the Progress of Business and Industry Towards Sustainable Development (TR 24). 1994, 118 pp.

'Consolidated FDI Policy (effective from 28 August 2017)', D/o IPP F. No. 5(1)/2017-FC-1, Department of Industrial Policy and Promotion Ministry of Commerce and Industry, Government of India.

Contracts signed under Open Acreage Licensing Policy Bid Round-I, Press Information Bureau, Government of India, Ministry of Petroleum and Natural Gas (1 October 2018), https://pib.gov.in/PressReleaseIframePage.aspx?PRID=1548095;

Cordes, E. E., Jones, D. O. B., Schlacher, T. A., Amon, D. J., Bernardino, A. F., Brooke, S., … others. (2016). Environmental impacts of the deep-water oil and gas industry: a review to guide management strategies. Frontiers in Environmental Science, 4, 58.

Cordes, E. E., Jones, D. O. B., Schlacher, T. A., Amon, D. J., Bernardino, A. F., Brooke, S., … others. (2016). Environmental impacts of the deep-water oil and gas industry: a review to guide management strategies. Frontiers in Environmental Science, 4, 58.

Daigle, S. T. (2011). What is the importance of oil and gas platforms in the community structure and diet of benthic and demersal communities in the Gulf of Mexico?

De Blij, H.J., Muller, P.O., Williams, R.S., Conrad, C., Long, P. (2005). Physical Geography: the Global Environment. Don Mills, ONT: Oxford University Press.

Decommissioning Offshore Oil and Gas Installations: Finding the Right Balance. A discussion paper. E&P Forum. 1995

Decommissioning, Remediation and Reclamation Guidelines for Onshore E&P Sites. E&P Forum (October 1996). Report No. 2.70/242.

Department of Ocean Development Annual Report 1996-97 (1997), p. 22.

Department of Ocean Development, Draft Notification 1996, pp. 1-9.

DGH Report (2019–20), Key Highlights of the Indian E&P Sector 2019–20.

DGH Report, Key Highlights of the Indian E&P Sector: 2019–20.

Directorate General of Hydrocarbons, Website/ About DGH, http://dghindia.gov.in.

Dispersants and their Role in Oil Spill Response. IPIECA 1993.

E&P Forum Guidelines for the Planning of Downhole Injection Programmes for Oil-Based Mud Wastes and Associated Cuttings from Offshore Wells. E&P Forum (October 1993). Report No. 2. 56/87.

E&P Forum Workshop on Data in Oil and Gas Quantitative Risk Assessments, 15 December 1993. Report No 11.7/205. January 1994.

Eco-efficiency and Cleaner Production—Charting the Course to Sustainability. UNEP—Paris, World Business Council for Sustainable Development—Geneva. 1996.

Energy Statistics (2020), Ministry of Statistics and Programme Implementation, Government of India, page 52, available at www.mospi.gov.in/sites/default/files/publication_reports/ ES_2020_240420m.pdf.

Environmental and Safety Incidents Concerning Tailings Dams at Mines. UNEP/DHA, 1996, 129 pp. 20

Environmental Aspects of Selected Non-Ferrous Metals (Cu, Ni, Pb, Zn, Au) Ore Mining (TR 5). UNEP/ILO, 1992, 116 pp.

Environmental Assessment. A Guide to the Procedures. HMSO. London. (1989).

Environmental Auditing. International Chamber of Commerce Paris. June 1989.

Environmental Auditing. UNEP/IEO Technical Report No 2. 1990.

Environmental Business Management—an introduction. Klaus North, ILO, 1992.

Environmental Guidelines for World Industry, International Chamber of Commerce, Paris, 1990.

Environmental Guidelines. UKOOA (1991)

Environmental Management of Mine Sites—A Training Manual (TR 30), UNDDSMS/UNEP, 1994, 311 pp.

Environmental Management Practices in Oil Refineries and Terminals—An Overview. 1988, 103 pp.

Environmental Management Tools—Sustainable Industrial Development. Industry and Environment. UNEP IE. Paris. Volume 18, No 2–3. April–September 1995

Environmental Principles. EUROPIA/E&P Forum (1991).

Environmental Problems of Petroleum Production in the Amazon Lowlands of Ecuador. Hettler, J; Lehmann, B; Le Marie, L. (1996). Berliner geowiss.Abh. (A). 183. 71pp. Berlin 1996.

Environmental Source Book Volume III: Guidelines for Environmental Assessment of Energy and Industry Projects. World Bank Technical Paper Number 154. 1991. ISSN 0153-7494.

Ferreira, D. F., & others. (2003). Anticipating impacts of financial assurance requirements for offshore decommissioning: a decision model for the oil industry.

Fowler, A. M., Macreadie, P. I., & Booth, D. J. (2015). Should we “reef” obsolete oil platforms? Proceedings of the National Academy of Sciences, 112(2), E102--E102.

Fowler, A. M., Macreadie, P. I., Jones, D. O. B., & Booth, D. J. (2014). A multi-criteria decision approach to decommissioning of offshore oil and gas infrastructure. Ocean & Coastal Management, 87, 20–29.

From Regulations to Industry Compliance: Building Institutional Capabilities (TR 11). 1992, 62 pp.

Government Drives Big Bang Reforms in Oil & Gas Sector, Press Information Bureau, Government of India, Niti Aayog (20 February 2019), https://pib.gov.in/PressReleseDetail.aspx?PRID=1565604#:~:text=The%20Union%20Cabinet%20chaired%20by,production%20of%20oil%20and%20gas.

Government Strategies and Policies for Cleaner Production. 1994, 32 pp.

Government Strategies and Policies for Cleaner Production. UNEP/IE. Paris. (1994).

'Govt of India categorizes onshore and offshore oil and gas exploration activities as Category B2 for green clearance', Notification No. S.O. 236(E), 16 January 2020,http://dghindia.gov.in/assets/downloads/5e26b9dacbb53Gazette_Notification.pdf.

GST credit will be available only on value-added crude oil products', The Hindu Business Line (21 August 2017), www.thehindubusinessline.com/economy/gst-credit-will-be-available-only-on-valueadded-crude-oil products/article9825371.ece.

Guidelines for Early Monetization of Hydrocarbon discoveries under Production Sharing Contracts (PSCs) and Revenue Sharing Contracts (RSCs), File Ref: DGH/PSC-RSC/EM/20-21 (25 June 2020), http://dghindia.gov.in/assets/downloads/5ef4a5fe1a7a2EarlyMonetisationGuidelines.pdf.

Guidelines on Biological Impacts of Oil Pollution. IPIECA 1991.

Hartman, S. E., Lampitt, R. S., Larkin, K. E., Pagnani, M., Campbell, J., Lankester, T., et al. (2012). The Porcupine Abyssal Plain fixed-point sustained observatory (PAP-SO): variations and trends from the Northeast Atlantic fixed-point time series. ICES J. Mar. Sci. 69, 776–783. doi: 10.1093/icesjms/fss077

Hazard Identification and Evaluation in a Local Community (TR 12). 1992, 86 pp.

Hazard Identification and Evaluation in a Local Community. UNEP/IE Technical Report No. 12. Paris. (1992).

http://documents.worldbank.org/curated/en/101091468153885418/IFCperformance-standards-on-environmental-and-social-sustainability https://www.ndrdgh.gov.in/NDR/pdf/PETROLEUM_TAX_GUIDE.pdf.

Hydrocarbon Exploration and Licensing Policy, Resolution No. O-32011/4/2013-ONG-I, 30 March 2016, Ministry of Petroleum & Natural Gas, Government of India, http://petroleum.nic.in/sites/default/files/HELP.pdf.

India to trade partners: Sign new bilateral investment treaties, March 2018, https://www.thehindubusinessline.com/economy/indias-bilateral-investment-pacts-under-cloud/article9625580.ece.

India's Hydrocarbon Outlook: 2019–20, Directorate General of Hydrocarbons, Ministry of Petroleum and Natural Gas, Government of India, Key Highlights of the Indian E&P Sector: 2019–20 available at http://dghindia.gov. in/assets/downloads/ ar/2019-20.pdf (DGH Report).

Industrial Ecology. T.E. Graedel and B.R. Allenby, AT&T, Prentice Hall Publ. 1995.

Inger, R., Attrill, M. J., Bearhop, S., Broderick, A. C., James Grecian, W., Hodgson, D. J., … others. (2009). Marine renewable energy: potential benefits to biodiversity? An urgent call for research. Journal of Applied Ecology, 46(6), 1145–1153.

International Association of Geophysical Contractors, (1992). Environmental Guidelines for World-wide Geophysical Operations. IAGC, Houston, USA.

International Tanker Owners Pollution Federation Technical Papers 1–12 (1981–86).

Investment policy hub, http://investmentpolicyhub.unctad.org/ISDS/ FilterByCountry. Jane's Defence Weekly, March 26, 1997.

Iversen, P. E., Green, A. M. V., Lind, M. J., Petersen, M. R. H., Bakke, T., Jay, S. (2010). Strategic environmental assessment for energy production. Energy Policy 38, 3489–3497. doi: 10.1016/j.enpol.2010.02.022

K Ravichandran, 'How will the new tax rates impact the oil and gas sector?', Economic Times, Energy World (22 May 2017), http://energy.economictimes.indiatimes.com/news/oil-and-gas/-how-will-the-new-tax-

L.R. Brown, H.Kane, D.M. Roodman, Worldwatch Institute, 1994. Landfill of Hazardous Industrial Wastes—A Training Manual (TR 17). 1994, 315 pp.

Lichtenhaler, R., et al. (2011). Guidelines for Offshore Environmental Monitoring on the Norwegian Continental Shelf. Oslo: Norwegian Climate and Pollution Agency

M. Sudhakar and B.V. Kumar, "A New International Order on Oceans-Indian Perspective," Current Science, September 1996, p. 437.

Macreadie, P. I., Fowler, A. M., & Booth, D. J. (2011). Rigs-to-reefs: will the deep sea benefit from artificial habitat? Frontiers in Ecology and the Environment, 9(8), 455–461.

Management of Industrial Accident Prevention and Preparedness. Training Resource Package, 1996, 110 pp.

'Marginal field policy', Resolution No. O- 19018/22-95-ONG.III, Press Information Bureau, Government of India, Ministry of Petroleum and Natural Gas (15 October 2015, 05:20 PM), http://pib.nic.in/newsite/printrelease.aspx?relid=128772.

Ministry of Defence Annual Report 1996-97 (1997), p. 38.

Ministry of Petroleum and Natural Gas signs contracts for 32 blocks awarded under Open Acreage Licensing Programme (OALP) Bid Rounds – II & III, Press Information Bureau, Government of India, Ministry of Petroleum and Natural Gas (16 July 2019), https://pib.gov.in/Pressreleaseshare.aspx?PRID=1579035;

Ministry of Petroleum and Natural Gas signs Contracts for 7 Blocks Awarded under Open Acreage Licensing Programme (OALP) Bid Round – IV; 2020 Will Witness More Investment in Country's Energy Infrastructure, Says Shri Dharmendra Pradhan, Press Information Bureau, Government of India, Ministry of Petroleum and Natural Gas (2 January 2020), https://pib.gov.in/PressReleseDetailm.PRID=1598294.

Mitchell, B. (2002). Resource and Environmental Management (2nd ed.). Harlow: Pearson

Modalities for making CTE and EC a one-step process, F. No. 3-3/2019-1A.III, Government of India, Ministry of Environment, Forest and Climate Change, Impact Assessment Division, 5 February 2020, http://dghindia.gov.in/assets/downloads/5e3d16a2a665eonestepencte.pdf.

Model Text for the Indian Bilateral Investment Treaty', Press Information Bureau, Government of India, Ministry of Finance, (16 December 2015, 08:10 PM), http://pib.nic.in/newsite/PrintRelease.aspx?relid=133411.

Monitoring Industrial Emissions and Wastes (TR 27). UNEP/UNIDO, 1996, 131 pp.

Mostafa A R Hossain M. Enamul Hoq, 2018. Threatened fishes and other aquatic animals of the Bay of Bengal

New Exploration Licensing Policy, Resolution No. N-O-19018/22/95-ONG-DO-VI, February 1999, Ministry of Petroleum & Natural Gas, Government of India, http://petroleum.nic.in/sites/default/files/circulars-notifications60.pdf.

Noble, B. F. (2000). Strategic environmental assessment: what is it? & what makes it strategic? J. Environ. Assess. Policy Manage 2, 203–224. doi: 10.1016/S1464-3332(00)00014-X

Noble, B., Ketilson, S., Aitken, A., and Poelzer, G. (2013). Strategic environmental assessment opportunities and risks for Arctic offshore energy planning and development. Mar. Policy 39, 296–302. doi: 10.1016/j.marpol.2012.12.011

North Sea Produced Water: Fate and Effects in the Marine Environment. E&P Forum. May 1994. Report No. 2. 62/204.

OALP Bid Round – V Part-I Opening Summary of Bids received against offered blocks,http://online.dghindia.org/Files/pdf/OALP_V_Part_I_Bid_Opening_Result.pdf.

Oil and Gas Exploration and Production in Arctic and sub-Arctic Offshore Regions. E&P Forum. In preparation.

Oil and Gas Exploration and Production in Arctic and sub-Arctic Regions. IUCN/E&P Forum (1993). Report No. 2. 55/184.

Oil and Gas Exploration and Production in Mangrove Areas (IUCN/E&P Forum 1993). Report No. 2. 54/184. Guidelines for the Development and Application of Health, Safety and Environmental Management Systems. E&P Forum (1994). Report No. 6. 36/210.

Oil Exploration in the Tropics: Guidelines for Environmental Protection. IUCN (1991).

Oil Exploration, Development and Production in Coastal Waters: Best Environmental Practice. Countryside Council for Wales (January 1994). FSCRC Report No. FSC/RC/19/93.

Oil Industry Operating Guideline for Tropical Rainforests. E&P Forum (1991). Report No. 2. 49/170.

Oil-based Drilling Muds. Status Report. E&P Forum (November 1985). Report No. 2.37/124.

Oil-based Muds—Some Developments Influencing Cuttings Discharges and their Environmental Implications—a progress report. E&P Forum (1985). Report No. 2.41/136.

OLF Environmental Programme, Report Phase 1, Part A—Emissions to Air. OLF. December 1991.

Our Common Future. Report by the UN Commission on Environment and Development, 1987.

Overview of Rules Regulations and Recommended Practice for Operational Discharges from Offshore Oil and Gas Exploration and Exploitation Activities.

Parente, V., Ferreira, D., dos Santos, E. M., & Luczynski, E. (2006). Offshore decommissioning issues: Deductibility and transferability. Energy Policy, 34(15), 1992–2001.

Partnerships for Sustainable Development. The Role of Business and Industry. UNEP/PWBLF/Tufts University. London. (1994).

Partnerships for Sustainable Development: the Role of Business and Industry. a joint Prince of Wales Business Leaders Forum.

Petroconsultants (UK) Ltd. Report for Netherlands government. Society of Petroleum Engineers Conference, New Orleans, June 1996.

Picken, G., Curtis, T., & Elliott, A. (1997). An estimate of the cumulative environmental effects of the disposal in the deep sea of bulky wastes from the offshore oil and gas industry. SPE Offshore Europe.

Pondella, D. J., Zahn, L. A., Love, M. S., Siegel, D., & Bernstein, B. B. (2015). Modeling fish production for southern California's petroleum platforms. Integrated Environmental Assessment and Management, 11(4), 584–593.

Quantitative Risk Assessment Data Directory. E&P Forum. (October 1996). Report No. 11.8/250.

Quantitative Risk Assessment. A Position Paper issued by the E&P Forum May 1989. Report 11.2/150.

R.C. Sharma and P.C. Sinha, India's Ocean Policy (1994), p. 195. Also see, Vivian Forbes, "India's Maritime Jurisdictional Claims," The Indian Ocean Review, December 1996, pp. 12-15.

Rahul Bedi, "Not-so-Friendly Neighbourhood," Indian Express, May 15,1997.

Rahul Roy-Chaudhury, "The Indian Coast Guard in the 1990s," Indian Defence Review, October 1993, p. 64.

Rahul Roy-Chaudhury, Sea Power and Indian Security (1995), pp. 88-89.

Recommended Measurements to Improve the Availability and Quality of High Priority Quantitative Risk Assessment Data. E&P Forum. April 1991. Report No 11.3/174.

Richa Mishra & Twesh Mishra, 'GST: Fitment blues worry oil and gas industry', www.thehindubusinessline.com/economy/policy/gst-oil-and-gas-industry/

Richa Mishra, 'What kept foreign players off OALP-I', Business Line, May 7, 2018, available at https://www.thehindubusinessline.com/economy/what-kept-foreign-players-off-oalp-1/article23805274.ece.

Richmond, M.D., 2015. Threatened marine species. Regional state of the coast report Western Indian Ocean, pp.129-153.

Risk Management of Contaminated Industrial Land. Training Resource Package, 1996, 110 pp.

Roberts, J. M., & Cairns, S. D. (2014). Cold-water corals in a changing ocean. Current Opinion in Environmental Sustainability, 7, 118–126.

Russ, G. R., & Alcala, A. C. (2011). Enhanced biodiversity beyond marine reserve boundaries: The cup spillith over. Ecological Applications, 21(1), 241–250.

Sammarco, P. W., Atchison, A. D., Boland, G. S., Sinclair, J., & Lirette, A. (2012). Geographic expansion of hermatypic and ahermatypic corals in the Gulf of Mexico, and implications for dispersal and recruitment. Journal of Experimental Marine Biology and Ecology, 436, 36–49.

Sammarco, P. W., Lirette, A., Tung, U. F., Genazzio, M., & Sinclair, J. (2014). Coral community development on “rigs-to-reefs” vs standing oil/gas platforms: artificial reefs in the Gulf of Mexico. ICES J Mar Sci, 71, 417–426.

Schroeder, D. M., & Love, M. S. (2004). Ecological and political issues surrounding decommissioning of offshore oil facilities in the Southern California Bight. Ocean & Coastal Management, 47(1–2), 21–48.

Sensitivity Mapping for Oil Spill Response. IMO/IPIECA. 1996.

'Shale Oil and Gas', Directorate General of Hydrocarbons, Ministry of Petroleum & Natural Gas, Government of India, www.dghindia.org/index.php/ page?pageId=37.

Short bibliography on environment Global Environment Outlook. UNEP, 1997. Encyclopaedia of the Environment. R. Eblen & W.R. Eblen eds., Rene Dubois Center for Human Environments, Houghton Kifflin, 1994.

Simonsen, K. A. (2013). Reef fish demographics on Louisiana artificial reefs: the effects of reef size on biomass distribution and foraging dynamics.

Site Restoration and Abandonment Guidelines for Petroleum Operations (April 2018).

State of the World 1995. L.R. Brown, Worldwatch Institute. Earthscan Publ. 1995

Storage of Hazardous Materials: A Technical Guide for Safe Warehousing of Hazardous Materials (TR 3). 1990, 80 pp.

Technologies for Handling Produced Water in the Offshore Environment. E&P Forum (Sept 1996). Report No. 2. 71/247.

Territorial Waters, Continental Shelf, Exclusive Economic Zone and Other Maritime Zones Act, 1976, No. 80, Acts of Parliament, 1976, Section 6(4), Section 7(5).

The BIT with Belarus was signed on 24 September 2018. Bilateral Investment Treaties (BITs)/ Agreements, Department of Economic Affairs, Ministry of Finance, Government of India, https://dea.gov.in/bipa?page=7

The BIT with the Kyrgyz Republic was signed on 14 June 2019, Bilateral Investment Treaties (BITs)/ Agreements, Department of Economic Affairs, Ministry of Finance, Government of India, https://dea.gov.in/bipa?page=10.

The Community-Based Environmental Monitoring Network (CBEMN). (2010). The Environmental Stewardship Equipment Bank.

The Gazette of India, Extraordinary Part II-Section 2, No. 49, May 28, 1976, and Notification by India of the Exclusive Economic Zone, January 15, 1977.

The Gazette of India, Extraordinary Part II-Section 3, No. 397, December 9, 1981; and updates from 1982.

The Impact of Water-Based Drilling Mud Discharges on the Environment. Industry and Environment Overview Series. UNEP Paris (1985).

The Impact of Water-Based Drilling Mud Discharges on the Environment—An Overview. 1985, 50 pp.

The Investment Cooperation and Facilitation treaty between India and Brazil was signed on 25 January 2020, https://dea.gov.in/bipa?page=10.

The Joint Interpretative Declaration with Colombia came into force on 4October 2018.

The Joint Interpretative Note with Bangladesh came into force on 7 October 2017.

The Oil Industry Experience. Technology Cooperation and Capacity Building. Contribution to Agenda 21. UNEP/IPIECA. London. (1995).

The Oil Industry Experience: Technology Cooperation and Capacity Building. Contribution to Agenda 21, UNEP/IPIECA, 1995, 65 pp.

The Oilfields (Regulation and Development) Act, 1948, No. 53, Acts of Parliament, 1948 (India).

The Physical and Biological Effects of Processed Oily Drill Cuttings (Summary Report). E&P Forum. April 1996. Report No. 2.61/202.

The removal of offshore installations: a compilation of International Rules, Guidelines and Standards. E&P Forum. Report No. 10.11/193. June 1993.

The World Environment 1972–1992—two decades of challenge. UNEP, M.K. Tolba & O. El-Kholy eds., Chapman & Hall, London, 1992. Environmental Data Report, 1993–1994. UNEP, Blackwell Publ.

Thomas, S., 2013. Conservation criteria and Red listed marine resources of India.

Treatment of Production Water—A Review of Current Performance. E&P Forum (July 1989). Report No. 2. 29/111.

Under the profit-sharing model, the management committee (which includes the Indian government representatives)

UNEP/ICC/FIDIC Environmental Management System Training Resource Kit. UNEP/ICC/FIDIC, 1995, 400 pp.

USEPA (United States Environmental Protection Agency). 2000. Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan. United States Environmental Protection Agency, 13p.

USEPA (United States Environmental Protection Agency). 2008. Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan. United States Environmental Protection Agency, 13p.

van der Stap, T., Coolen, J. W. P., & Lindeboom, H. J. (2016). Marine fouling assemblages on offshore gas platforms in the southern North Sea: effects of depth and distance from shore on biodiversity. PLoS One, 11(1), e0146324.

Vital Signs 1994—the trends that are shaping our future.

Wanless, R. M., Scott, S., Sauer, W. H. H., Andrew, T. G., Glass, J. P., Godfrey, B., … Yeld, E. (2010). Semi-submersible rigs: a vector transporting entire marine communities around the world. Biological Invasions, 12(8), 2573–2583.

Wiens, J. A., and Parker, K. R. (1995). Analyzing the effects of accidental environmental impacts: approaches and assumptions. Ecol. Appl. 5, 1069–1083

Wiersma, G.B. (Ed.) (2004). Environmental Monitoring. Boca Raton, FLA: CRC Press.

Williamson, D. H., Harrison, H. B., Almany, G. R., Berumen, M. L., Bode, M., Bonin, M. C., … others. (2016). Large-scale, multidirectional larval connectivity among coral reef fish populations in the Great Barrier Reef Marine Park. Molecular Ecology, 25(24), 6039–6054.

World Bank (2012). IFC Performance Standards on Environmental and Social Sustainability. Washington, DC: World Bank.