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Geographical Information System for Gulf of Kachchh

Government of India
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Integrated Coastal and Marine Area Management (ICMAM)
Project Directorate, Chennai

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1. Introduction

India is lined with a 7500 km long coastline. Among the Indian maritime states, Gujarat State has the longest coastline extending to 1600 km. Gulf of Kachchh, the fast developing area of Gujarat is the northwestern boundary of the Indian coast, which extends to a length of 170 km covering an area of around 7300 km^2. It is one of the few coastal zones in the world having rich biodiversity. The mangroves of the Gulf are the second largest after Sundarbans in the mainland of India. Gulf of Kachchh is the only place left along the Indian coast after Gulf of Mannar where the live corals occur although dead corals are plenty. Vast intertidal mudflats along with mangroves and corals makes the Gulf of Kachchh a preferred zone for breeding by many marine organisms.

In the past few years, initiation of several coastal developmental activities has led to decline in biodiversity, necessitating introduction of measures for protection. After establishment of Marine National Park and Sanctuary, a visual change is evident in terms of enhanced biodiversity. However, a thorough assessment of present status and adoption of appropriate management solutions is very much essential to ensure healthy developments. In an attempt to achieve this, a Geographical Information System for the Gulf of Kachchh has been developed based on primary and secondary data on various parameters and aspects. The possible threats due to oil spill in this area are also linked to these studies.

2. Site Description

The Gulf of Kachchh (22° 15′ to 23° 40′ N and 68° 20′ to 70° 40′ E) is an east-west oriented indentation between Saurashtra and Kachchh Peninsulas. The Gulf of Kachchh is bordered by Kachchh district in the north and Jamnagar district in the south, with Rajkot district covering a little portion of the Gulf in its eastern side. The Gulf of Kachchh is 170 km long from Okha to inner Gulf and is 75 km wide at its mouth with a water spread area of around 7300 km^2 and a volume of 220,000 million m^3. It narrows down abruptly with a distinct constriction at 70° 20′E at Satsaida Beyt, and divides into a creek system, often called the Little Gulf of Kachchh. The Gulf is characterized by numerous hydrographic irregularities like pinnacles, as much as 10 m high. It is believed that the region of the Gulf of Kachchh was a desert in the Pleistocene period which subsequently changed due to geological subsistence that allowed the Arabian Sea to engulf the land. Its conical structure leads to elevated tidal levels especially in the inner Gulf, the high tidal flux covers vast low-lying areas of about 1500 km^2 comprising a network of creeks, estuaries and mud flats in the interior regions. The creek system consists of three main creeks namely Kandla, Hansthal and Nakti and the little Gulf of Kachchh, inter-connected through many large and small creeks.

The southern part of the Gulf has diverse physical conditions, with 42 islands (Bets) and large marine ecosystem which supports a huge wealth of marine life. The Gulf environment is ecologically very sensitive as it supports vast areas under mangroves, coral reefs, mudflats and their associated ecosystems. The thickest mangrove forest is located in the Kori Creek located northwest of the Gulf. The satellite imagery of Gulf of Kachchh is shown in Figure 1. The marine environment of Gulf of Kachchh is in severe stress in the recent years due to rapid expansion of commercial activities viz. ports and harbours, oil terminals through setting up of Single Point Moorings, industrial cooling and waste disposal, salt production, etc., along its coast.

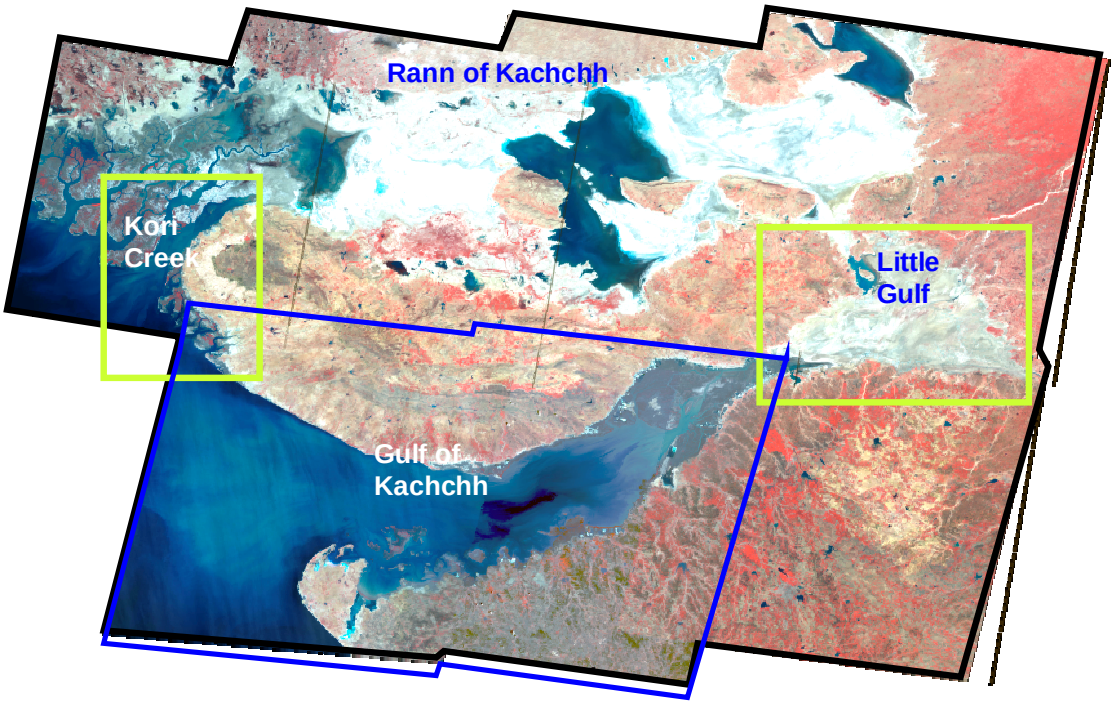


Fig. 1 - Satellite image of the Gulf of Kachchh

2.1 Marine National Park and Sanctuary

Gulf of Kachchh was the first Marine National Park and Sanctuary (MNPS) established in the year 1982 under the Wildlife (Protection) Act, 1972. The areas covering the Marine National Park and Sanctuary are shown in Figure 2. Southern part of the Gulf has diverse physical conditions with many islands and marine ecosystems. More than 40 islands of southern part are full of live corals requiring protection. The islands and coast are characterised by dense mangrove forests.

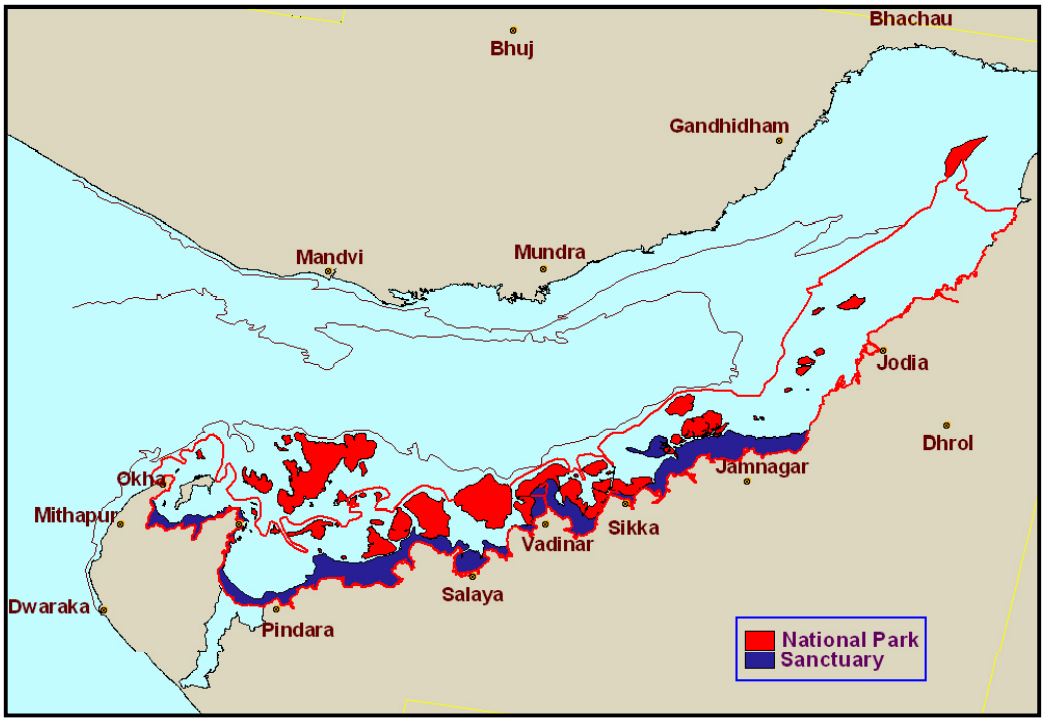


Fig. 2 - Marine National Park & Sanctuary area

The estimated mangrove coverage in the MNP area is 5722 ha. These mangroves help the Gulf ecosystem by contributing to the oxygen budget and in soil conservation. Mangroves and corals are the nursing grounds for a variety of economically important fishes, exotic coral fishes and innumerable flora and fauna. The Gulf also abounds in more than 210 species of marine algae. These marine algae, in combination with the corals and mangroves, provide a very healthy, useful and conducive ecosystem for the diverse flora and fauna existing in the Gulf. Protection, therefore, of these corals, mangroves and such basic constituents of the Gulf ecosystem becomes necessary. It was only to save such diverse life from further human interference and to protect, conserve and restore them back to their original levels, the Gulf area was declared as a Sanctuary and Marine National Park in 1982. An area of 457.92 km^2 was declared as Marine Sanctuary and 162.89 km^2 was notified as Marine National Park. National Park and Sanctuary zone include reserve forests, unclassified forests (Notified under Sec.4 of IFA, 1927) and non-forest areas. Area mentioned under National Park, Sanctuary, Reserve Forests and unclassified Forests are scattered and mostly having no proper specific boundary. Apart from its natural beauty, it can also prosper into a balanced and controlled tourism centre and provide facilities for ocean education and research and also diversify into related fields.

A large area of inter-tidal zone has been leased out by the Government to salt industries. These areas in the coastal zone were once supporting immense growth of mangroves, but have been destroyed due to various reasons and reduced to patches. This zone is traditionally used by people for various purposes.

2.2 Physiography

Gulf of Kachchh is a shallow water body, with depth extending from 20 m at the head of the Gulf to 60 m at the mouth. While the average depth is 30 m, the minimum is 3 m above chart datum (GTS) in the inner creeks (Nair et al., 1982). The residence/turnover time of the Gulf water ranges from 8-51 days, decreasing upstream. The Gulf is surrounded by arid to semi-arid landmass. The relative humidity is the highest in August (82%) and the lowest in December-January (60%). Atmospheric temperature varies from 10°C in January to 35°C in May-June. River runoff is negligible, as the streams, which drain into the Gulf carry only a small quantity of freshwater, except during the brief spell of monsoon in July-September and have dams across most of them converting the Gulf to a negative water balance body. Cyclonic storms periodically strike North Gujarat, particularly the Kachchh and Saurashtra regions. Cyclones produce large tidal waves inundating coastal stretches temporarily and also cause appreciable damage to coastal/ nearshore structures. Tides in the Gulf are mixed, predominantly semi-diurnal type with a large diurnal inequality. The tidal front enters the Gulf from the west and due to narrowing cross-section and resonance, the tidal amplitude increases considerably, upstream of Vadinar. The tidal elevations along the Gulf are illustrated in Table 1.

Table 1 - Tidal elevations (m) along the Gulf of Kachchh

Location	MHWS	MHWN	MLWN	MLWS	MSL
Okha	3.47	2.96	1.20	0.41	2.04
Sikka	5.38	4.35	1.74	0.71	3.04
Rozi	5.87	5.40	1.89	1.00	3.60
Kandla	6.66	5.17	1.81	0.78	3.88
Navlakhi	7.21	6.16	2.14	0.78	4.15

MHWS - Mean High Water Spring; MHWN - Mean High Water Neap; MLWN - Mean Low Water Neap; MLWS - Mean Low Water Spring; MSL - Mean Sea Level

The phase-lag between Okha and Kandla is 2 hrs to 2 hrs 45 min, while that between Okha and Navlakhi is 3 hrs to 3 hrs 30 min. Due to high tidal ranges in the inner Gulf, vast mudflats and coastal low lands, particularly of the Little Rann of Kachchh (Little Gulf) which

get submerged during high tide are fully exposed during low tide with innumerable tidal pools confined to shallow depressions. Commensurate with the increasing tidal amplitude, the inter-tidal expanse along the shores of the Gulf increases upstream from 0.5 to 2 km from Jakhau to Kandla along the northern coast and from about 1 km at Okha to over 5 km at Jodiya along southern coast. Storm and high tidal waves hit the coral reefs on the northern and western sides thereby reducing their energies by orders of magnitude, before breaking against the northern shores of Saurashtra.

Circulation in the Gulf is mainly controlled by tidal flows and bathymetry, though wind effect also prevails to some extent. Strong currents normally occur during mid-tide, i.e. 2-3 hrs before and after low and high tides. The spring currents are 60 to 65% stronger than the neap currents. The surface currents are moderate (0.7 - 1.2 $m.s^{-1}$), but increase considerably (2.0 - 2.5 $m.s^{-1}$) in the central portion of the Gulf. The bottom currents are periodically strong with bimodel directions generally parallel to the uneven bottom contour. The associated tidal currents are fairly strong and bimodel in nature having two dominant directions – upstream during flood and downstream during ebb in all-encompassing oscillatory motions. Such motions cannot flush the Gulf completely, leaving behind pockets of perennially undulating water.

The circulation in the central portion of the middle Gulf (Vadinar-Bedi segment) evolved based on drogue trajectories indicates an elliptical displacement over a tidal cycle with the major axis of the ellipse varying between 5 and 20 km depending on the tidal state and location in the Gulf. The circulation pattern in the nearshore areas, however is modified considerably due to the presence of creeks and islets.

2.3 Gulf Ecology

The southern coast from Okha in the outer Gulf to innermost Gulf can be classified into ecologically sensitive zone as is being occupied with mangroves, corals, intertidal and high tidal mudflats (Fig. 3). Some areas of mud flats have potential for mangrove afforestation. The innermost Gulf is mainly occupied with salt pans along the coast and mudflats which were in the past covered with mangrove forest. Along the northern coast, the sites between Kandla creek and Mandvi are also occupied with sparse mangroves and rich intertidal mudflats. Recently, Scientists have discovered patches of live corals near Mundra. In the northwestern coast, the thickest mangrove vegetation was noticed between Jakhau and Kori creek.

Fig. 3 - Ecologically sensitive zone of the Gulf of Kachchh

2.3.1 Mangroves

The area under mangrove cover along the Gujarat coast is the second largest (next to the Sunderbans) along the Indian coast (Untawale and Wafar, 1988) and Gulf of Kachchh accounts to 93% of Gujarat mangroves. Several locations along the coastline in the Gulf of Kachchh are fringed with the growth of mangroves. At present, the mangrove coverage is in the form of a discontinuous and patchy vegetation. All the islands of Southern coast are intersected by creeks fringed with mangroves. The coast between Okhamandal and Dhani and Jamnagar to Jodiya is having fringing mangroves and the rest of the coasts, islands and creeks are characterized by healthy and thick mangrove vegetation (RSAM,1992). Although Kachchh region has the maximum forest cover, it displays the least mangrove diversity with Avicennia marina var. acutissima as the dominant species (Fig.4) forming almost pure stand at many places due to its adaptability to higher salinities of ∫ 35.0 PSU prevalent throughout the year. The other mangrove species found commonly are A.officinalis and A.alba while Rhizophora mucronata, Ceriops tagal (Fig.5) and Bruguiera gymnorrhiza are vulnerable species. Aegiceros corniculata has become endangered.

Fig. 4 – Stunted growth of Avicennia marina at Karumbhar Island

Fig. 5 – Ceriops tagal and Rhizopora mucronata at Pirotan Island

Due to high salinity, grazing and cutting pressure on the Kachchh mangroves, they have stunted growth (up to 1 m tall). However, the trees in some untouched patches gain the height of about 5 m in the Pirotan Island and more than 10 m in the Kori creek, with good girth of the trunk (Untawale and Jagatap, 1998). The mangrove ecosystem is associated with a good growth and a variety of flora (Fig.6) and fauna.

Fig. 6 - Salicornia brachiata at Karumbhar Island

2.3.1.1 Causes for degradation

- Usage of mangrove plants as fodder and fuel and hypersalinity of the soil are the main reasons. The maximum cutting (22.6%) and lopping (4.1%) of trees are recorded at Mundra and Jakhau, respectively (GUIDE, 1999).
- Release of bittern from salt pans damages the respiratory roots while bunding for salt pans obstruct the salt water intrusion into the mangrove areas.
- Ecocatastrophe, the phenomenon of biodeterioration of mangrove vegetation due to the marine boring and fouling organisms. Along the northern coast, the attacks of borers and foulers were found to be more in Kori creek (14.81 and 32.1%) and least in Jakhau area (2.26 and 0.72%) (GUIDE, 1999).
- Some of the mudflats having good mangroves in the past, for example near Mundra and east of Kandla creek, are devoid of vegetation or have scrubby sparse mangroves mainly due to their rise and stabilisation and the change in salinity level.
- Natural calamities like cyclone of 1998, have uprooted many mangrove plants and much more were dead.

- ☛ Conversion of mangrove areas to commercial activities viz. salt pans, jetties, ports, laying pipelines, etc.
- ☛ Chemical and oil pollution - Petroleum products cause leaf and root damage, growth retardation, mechanical clogging of lenticals, air hole of prop roots and pneumatophores, defoliation and ultimately leading to the death of growing seedling and plants (Zingde, 1999).

A comparison of the changes in the wetland areas between 1975 and 1982 as reported by Nayak et al. (1987), is illustrated in Table 2.

Table 2 - Change in wetland area in the Gulf of Kachchh between 1975 and 1982

S.No.	Classification	Area in km^2		Change
		1975	1982	
1	Mangroves	733.53	177.31	-76%
2	Mudflats	148.18	549.68	+271%
3	Salt affected area	--	118.17	--
4	Salt Pan	4.81	49.13	+921%
5	Submerged area	84.54	157.15	+86%
6	Water bodies	428.64	361.59	-16%
7	Coastal plain (cropland + scrubland)	183.24	194.58	+6%
8	Unclassified	53.00	27.43	-48%
	Total	1635.94	1635.04	

It is inferred from the above table that increase in the mudflat and salt pan areas have witnessed the reduction in mangrove area.

2.3.1.1 Afforestation

In order to regain its density, Gujarat Forest Department has undertaken afforestation of the mangroves in Kachchh and Jamnagar districts from 1983. Seed sowing and plantation of polypot seedling mostly for Avicennia sp. were done for propagation in Cher forest and in other muddy and marshy areas. Conservation effort along with plantation resulted in consistent recovery of tidal forest cover from 397 km^2 in 1991 to 419 km^2 in 1993, 689 km^2 in 1995 and 991 km^2 in 1997. There is further increase of about 45 km^2 in 1999. The plantation areas in the Marine National Park of Jamnagar and Kachchh districts are 24.03 and 1.5 km^2, respectively. However, some of the attempts to afforest certain elevated mudflats in the Jamnagar area have failed due to increased soil salinity. Success of plantation before 1991-92 was very low, but success rate improved during the last six years due to

improvement in regeneration techniques. Strict protection along with plantation in Pirotan has improved the density of Cher forests.

2.3.2 Corals/Coral Reefs

Stony corals of Gulf of Kachchh form the coral area in the North-West coast of Arabian Sea. The coral formations of the Gulf of Kachchh are found between 22° 20′ and 22° 40′N and 69° and 70°E along the coast of Jamnagar district. 34 islands out of 42 in the Marine National Park bordering the southern shore of the Gulf support coral and coral reefs. The age of these reefs varies from 5240 years at Salaya to 45,000±105 years before present at Okha (Gupta, 1972). Pirotan island represents the northern limit of the coral growth with living corals confined to small areas along the northern side of the island where the currents are the strongest. Coral growth is scarce at present and perhaps not termed more as patch than fringing. Growth at present is confined to intertidal sandstones or wave cut eroded, shallow banks, etc. The eastern side exhibits vast areas of dead corals giving a clear indication of mass mortality.

Based on the classification of reefs by Davies (1972), the reefs of the Gulf are classified as Fringing, Platform Reefs and Patch Reefs & Coral Pinnacles. The most northerly reefs or coral patches are found at Munde reef and Pirotan Island, but solitary corals are found as far as Dwaraka on the Saurashtra coast. Recently in 1999 live coral polyps and a few stony corals and their associate fauna such as bryozoa, gorgonians and sea anemone have been observed off Mundra on the Kachchh coast (near Mundra Port at a water depth of about 25 m) for the first time by GES Scientists.

Patel and Bhaskaran (1978) quantified about 28,100 tons of live corals and 6,09,000 tons of dead corals from 25 islands of Gulf of Kachchh. The beach coral boulders are collected by agents of merchants to feed the local markets of Okha, Beyt Dwaraka, Harsad and Somnath where thousands of pilgrims visit every year. Approximately 20 tonnes of dead corals are sold annually.

Diversity of living corals in the Gulf of Kachchh is poor with 39 species under 24 genera (Gopinadha Pillai, 1983). This is in agreement with the findings of NIO, which recorded 37 species under 24 genera. Among these, 33 species under 20 genera are hermatypes and 4 species under 4 genera are ahermatypes. Soft corals are confined to 12 species, belonging to 8 families and 11 genera. The low diversity is due to combination of several factors including geographical isolation and extreme environmental conditions prevalent in this zone. In a subsequent study Patel (1985) has reported 44 species of

scleractinian corals (hard) and 12 species of soft corals, whereas Wafar (1986) has recorded only 26 species under 20 genera from the Gulf of Kachchh. Coral species such as Turbinaria, Montipora, Favia, Leptoria, Symphyllia, Porites, Leptastrea, Hydrophora, Goniopora, Goniastrea, etc., are found predominantly in the Gulf. Huge quantities of the dead horns of Acropora sp. found in this area suggest that there could have been a luxuriant growth of branched corals in the past (Patel, 1978 and Pillai and Rajagopalan, 1979).

2.3.2.1 Causes for degradation

It is evinced from literature and satellite data that vast areas of coral reefs are dead. Even in areas normally referred to as coral reefs or patches, live coral cover rarely exceeds 20 – 30% (NIO, 1992). The total reef area in the Gulf declined from 217 km^2 in 1975 to 118 km^2 in 1985 and 123 km^2 in 1986, with a net loss of 94 km^2 of coral cover equivalent to 43%. Some of the coral species in the Gulf of Kachchh are extinct. The degrading/dead corals at intertidal zone of Pirotan Island are depicted in Figure 7. The causes for degradation of corals are:

- Prolonged exposure, heavy siltation/deposition of silt, commercial exploitation of coral sands by Cement Company at Sikka, mining operations, etc.
- Chronic oil pollution due to shipping activities, discharge of oil derived chemicals, bilge water, oil spillage, leakage from SPMs, etc., add to the damage.
- Excessive growth of algae on reefs reduces availability of light and the algal blades spreading over corals trap the sediments which are detrimental to coral's survival.
- Fishing, walking on coral reefs, collecting of corals, fishing with poisonous material and explosives.

Degrading Favites sp.

Dead corals encroached by sponges and fouling organisms

Fig.7 - Coral degradation at intertidal region of Pirotan Island

2.3.2.2 Regeneration

The remote sensing data supported by ground truth data collected revealed that between 1985 and 1991, after declaration of Marine National Park a net improvement in coral cover from 53 to 85 km^2 within the core area has taken place (Bahuguna and Nayak, 1998). Underwater photography and videography of GES (1999) in some of the sub-tidal coral reefs (Pirotan Island, Karumbhar island, Boria reef and Beyt Shankhodar) revealed that different stages of live corals (both soft and stony) were abundant. The reefs are generally restricted to areas exposed to the strongest tidal currents and live corals are generally confined to northern and western sides of the islands.

3. Geographical Information System

In order to facilitate planners to manage and protect the health and wealth of the Gulf of Kachchh, a Geographical Information System has been developed by integrating the ecology and biodiversity of this region to land use, bathymetry, and various environmental conditions on developmental projects. It is more of a scientific database presenting the collected data in new ways so as to be accessible for scientific enquiry and long term monitoring of the environment. It was built by integrating the primary and secondary data with remote sensing digital data using the tool Geographical Information System (GIS). The Resource Information System incorporates the following:

- Spatial distribution of corals, mangroves, salt pans and mudflats with their quantitative estimations (except for corals).
- Present status of phytoplankton, zooplankton, benthos, algae and fishes.
- Information on the various commercial activities and their environmental implications on the Gulf.
- Integration of oil spill model outputs generated using MIKE 21 software with resource information to find out possible zones of threat.
- Selection and environmental assessment of sites available for future development along the Gulf coast.

3.1 Methodology adopted for development of Information System

The architecture of GIS has been utilised in developing Geographical Information System for the Gulf of Kachchh. The Information System comprises the linking of externally stored primary and secondary data in a relational database and oil spill model outputs to the processed satellite data in GIS environment.

Primary data on phytoplankton, zooplankton, benthos and algae were collected by Gujarat Ecological Commission (GEC), Vadodara. Water quality data was extracted from COMAPS reports. The methodologies for samples collection and analysis varies with respect to parameters studied. An RDBMS (Relational Database Management System) has been generated with the above data using Visual Basic and Oracle as front and back ends. The data on fisheries were collected from Department of Fisheries, Rajkot. Underwater videography through SCUBA diving for coral ecosystem of selected areas was done by National Institute of Oceanography, Goa during February 1999 and was analysed by Gujarat Ecological Society, Vadodara. Information on various ports and industries have been collected personally from the respective organisations.

The details of Satellite data used in developing Resource Information System are depicted in Table 3.

Table 3 - Details of Remote Sensing Data used

S.No.	Satellite / Sensor	Row/Path	Period	Area Description
1	IRS 1-D / LISS III	88/55	January, 1999	Kori Creek
2	IRS 1-D / LISS III	89/56	January, 2001	Outer Gulf
3	IRS 1-D / LISS III	90/56	February, 2001	Inner Gulf
4	IRS 1-D / LISS III	90/55	January, 1998	Little Gulf

Digital image processing was carried out using ERDAS-IMAGINE 8.4 software. The above Satellite Data sets were geo-referenced using the respective Survey of India Toposheets of 50,000 and 250,000 scale and were mosaiced. The satellite images of the Gulf proper (89/56 and 90/56) have chosen to match the lowest low tide period thus exposing a maximum cover of intertidal mudflats. The base map is digitised onscreen from the satellite image. All the marine features like mangroves (dense and sparse), mud flats, salt affected mud flats, inshore sandy areas, etc., and terrestrial features like land use pattern have been attempted from supervised classification to the best of visual identification with an accuracy of around 80%. While geomorphological and salt pan features have been digitised onscreen, no ground truth could be done to validate it. All these processed satellite outputs were projected, analysed and displayed in GIS using ARCVIEW 3.2 software linking the attributes of Relational Database Management Systems (RDBMS) to spatial units that are represented in a wide variety of ways.

4. Description of Geographical Information System

4.1 Physical Environment

4.1.1 Geomorphology

The northern coast between the segments Jakhau-Mundra and Mundra-Kandla have irregular and dissected configuration. The western half, overlooking the open Arabian Sea, trends NW-SE and is dominantly sandy and silty with narrow beaches. The east-west trending coast, that lies inside the Gulf between Mundra and Kandla is made up of extensive tidal flats and merges with Rann of Kachchh to the east.

The southern coast, Navlakhi-Jamnagar-Okha-Dwaraka trending east-west, overlooks the Gulf and shows a crenulated rocky shoreline with extensive mudflats and the subtidal zone consisting of channels, shoals, submerged islands, sand bars, coral reefs and mangroves (Fig. 8).

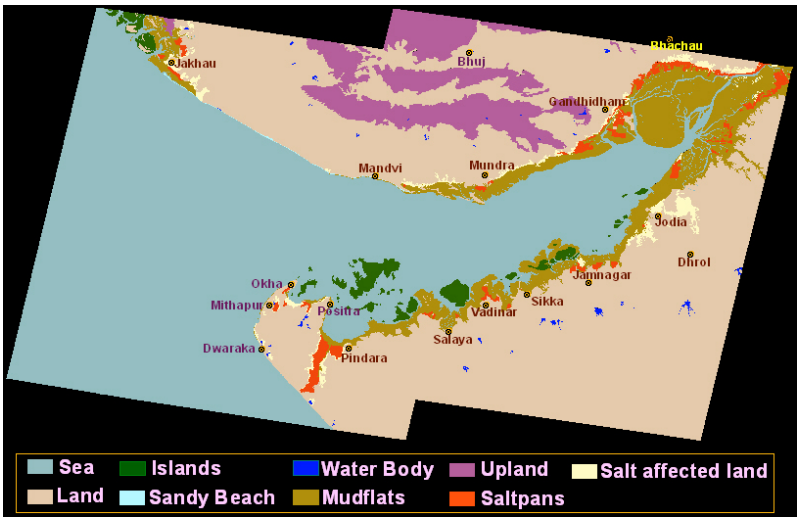


Fig. 8 - Geomorphology of the Gulf of Kachchh

4.1.2 Geology

Quaternary sediments occupied almost the entire southern coast and also Rann of Kachchh with tertiary sedimentary rocks embeded in between. Okhamandal and Kalyanpur taluks bear tertiary sedimentary rocks while cretaceous deccan traps covered the other taluks of the southern coast (Fig.9).

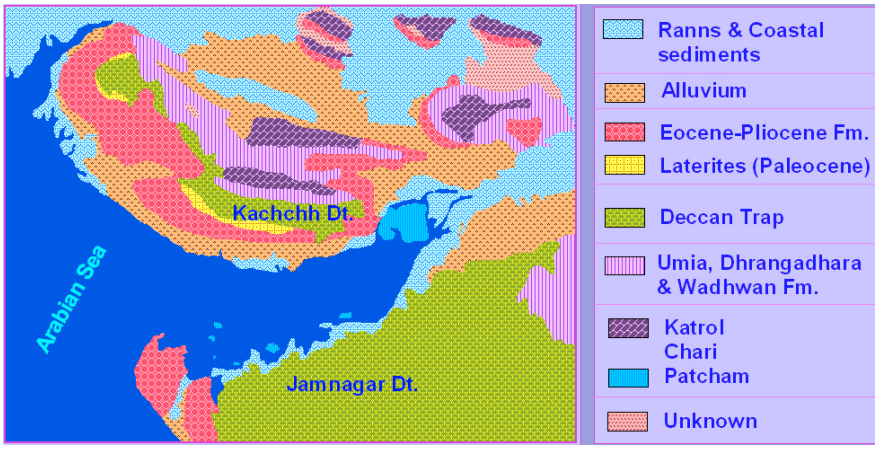


Fig. 9 - Geology Map of the Gulf of Kachchh

4.1.3 Soil

The soils of Kachchh district are mostly sandy to sandy-loam, silty clay-loam and are salt affected and that of the northern portion is composed of Rann sediments. While most of the near coastal soils of Jamnagar district are calcareous in nature with grain-size varying from silty-loam to clay, the soils beyond this place are calcareous and alkaline in nature (Fig.10).

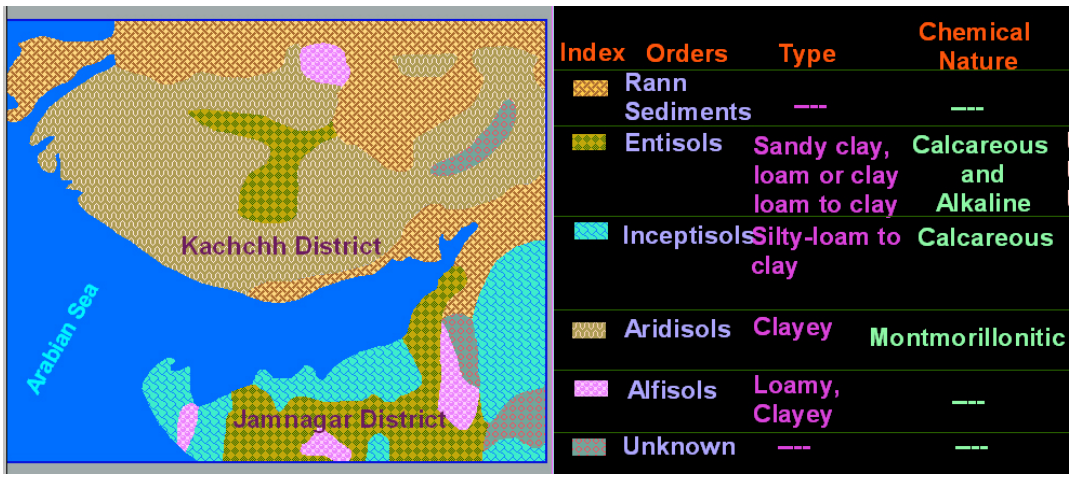


Fig. 10 - Soil Map of the Gulf of Kachchh

4.1.4 Land Use / Land Cover

The land use pattern in the 3 districts around the Gulf reveals that an overwhelming portion of about 85% forest cover of the coastal region falls in the Kachchh district. The coastal region of the Jamnagar district, adjoining an ecologically sensitive Marine National Park and Sanctuary, accounts only for 14% of the total forest cover of the region as a whole.

The details of land use cover are illustrated in Table 4 and Figure 11. The irrigated land of Jamnagar district alone accounts for 60% of the region which is equivalent to 16% of the cultivable coastal land of the district. 90% of total irrigation is through ground water. These conditions not only help accelerate salinity ingress, but will also affect ground water balance disturbing intertidal ecology. Conditions in the Kachchh district do not reveal any rosy picture either, as ground water irrigation accounts for 72% of the irrigated land due to lack of adequate surface water. As of 1996, such water harvesting practice has resulted in Mandvi and Bhachau taluks to be classified as 'dark' in the Kachchh district, whereas Abdasa and Mundra taluks of Kachchh district and Okhamandal and Jodia taluks of Jamnagar district are classified in the 'grey' category. The coastal region of Rajkot district has negligible irrigated land. In the Kachchh region, the proportion of unirrigated land still remains as high as 60% and culturable wasteland 66% of the regional total in each category. Scrub and fallow land has dominated the Jamnagar district while Kachchh district is mainly rocky and dry land with little vegetative cover.

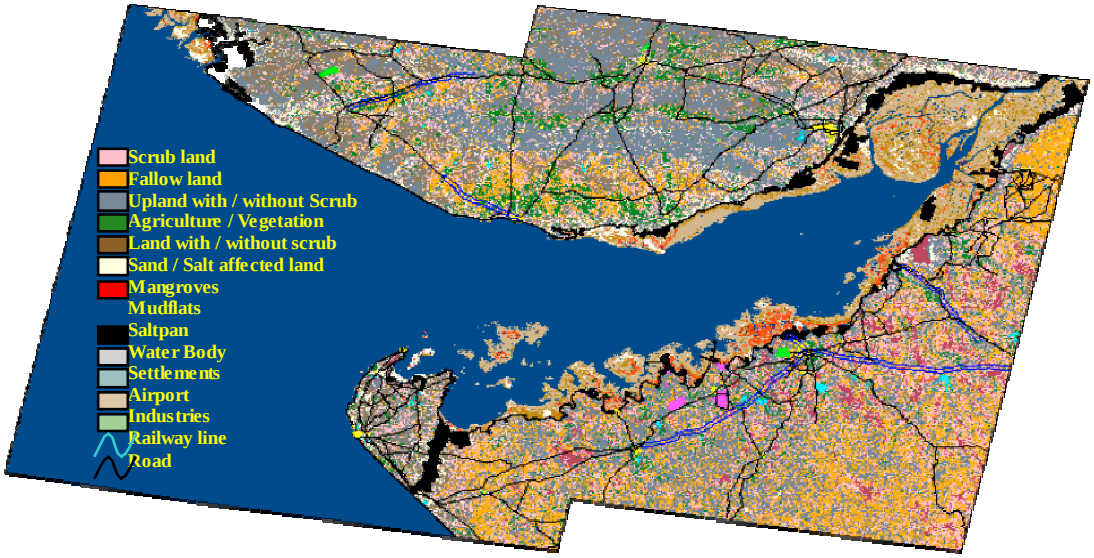


Fig. 11 - Land use map of the Gulf

Table 4 - Area details of Land Use / Cover

(Area in km^2)

DISTRICT/ Taluk	Upland with/ Without Scrub	Land with/ without Scrub	Scrub Land	Vege-tation	Fallow Land	Water body / Wetland	Sand/ Salt affected Land	Tank/ Reservoir	Settlement	Air Port / Industries	Total
KACHCHH*	1987.6	1056.2	856.5	489.4	807.7	14.1	425.5	13.64	50.22	9.24	5710.1
Abdasa#	516.9	523.4	221.5	90.8	174.1	5.0	132.4	5.43	--	8.45	1678.0
Mundra	473.2	206.8	220.1	200.0	221.9	1.0	65.9	2.28	12.63	--	1403.8
Mandvi	319.3	68.1	139.9	116.0	141.7	1.2	69.0	0.83	6.33	--	862.4
Anjar	487.6	185.5	162.8	68.8	120.0	1.7	75.5	5.05	23.82	0.79	1131.6
Bhachau#	76.1	71.1	36.9	6.3	21.0	0.6	71.1	--	0.50	--	283.6
RAJKOT*/ Maliya#	114.5	1.3	75.3	7.5	129.0	4.6	11.6	0.05	6.94	--	350.8
JAMNAGAR*	2415.7	261.4	1125.4	180.7	1151.3	403.6	57.4	25.87	40.34	38.97	5700.7
Jodia	313.7	1.1	219.8	26.3	189.6	110.7	15.6	--	2.78	--	879.6
Jamnagar	568.3	0.2	283.2	15.6	222.1	165.6	2.5	13.08	20.84	26.67	1318.1
Lalpur	581.1	1.0	163.4	16.9	239.6	41.0	2.1	1.06	1.26	12.30	1059.7
Khambalia#	557.8	0.5	221.6	22.1	264.3	75.5	1.51	3.40	5.60	--	1152.3
Kalyanpur#	229.2	76.1	129.8	72.8	177.5	7.3	8.0	0.59	1.20	--	702.5
Okhamandal	165.6	182.5	107.6	27.0	58.2	3.5	27.7	7.74	8.66	--	588.5

* - District area as covered in satellite image.

\# - Partially covered Taluks (areas covered only to the extent available in the satellite image).

4.2 Marine Environment

Ecologically the southern side of the Gulf has rich biodiversity in terms of mangroves and corals along with their associated flora and fauna as compared to the northern coast.

4.2.1 Ecology

4.2.1.1 Mangroves

It was not possible to distinguish various species of mangroves and also from the other vegetation. Hence, the term mangroves referred in this Information System can be read as mangroves with its associated flora. The mangroves of Kori and adjoining creeks, located extreme northwest of Gulf of Kachchh, accounts for about 75% of total mangrove cover of the Gulf. Two cyclones which crossed Gulf of Kachchh during June, 1998 and May, 1999 resulted in a devastating effect on mangrove cover of the Gulf especially in the Kori creek zone. Also, there is a reduction in mangrove area due to several commercial activities in the core zone of the Gulf. These pockets have been identified and the results are summarised. However, as a whole, the image of the Gulf proper for the period 2001 has been evaluated for talukwise mangrove cover and is illustrated in Table 5. The estimated dense and sparse mangrove area almost matches with the previous estimation of 115.30 and 91.44 km^2, respectively, for the period November, 1998 (Singh, 2000).

Table 5 - Talukwise Mangrove and Mudflat cover* in the Gulf of Kachchh

District	Taluk	Dense Mangroves	Sparse Mangroves	Lowtidal Mudflats	Hightidal Mudflats
Kachchh	Lakhpat	2.73	0.68	30.13	13.75
	Abdasa	3.40	1.86	18.25	11.97
	Mundra	0.07	0.20	5.22	2.91
	Mandvi	2.57	7.34	126.69	42.63
	Anjar	1.18	5.04	119.81	37.91
	Bhachau	0.94	0.82	115.07	27.96
Rajkot	Maliya	1.62	4.47	229.64	93.03
Jamnagar	Bets & Islands#	47.87	39.74	506.58	178.53
	Jodia	15.34	13.37	172.96	72.69
	Jamnagar	12.03	23.91	83.53	33.15
	Lalpur	1.96	3.95	50.50	8.50
	Khambalia	3.86	11.48	101.94	56.91
	Kalyanpur	0.04	0.01	0.78	1.36
	Okhamandal	1.73	1.84	28.54	5.02
Total		95.34	114.71	1589.64	586.32

* - Area in km^2 # - excluding islands of Kori area.

4.2.1.1.1 Kori and adjoining Creeks

Kori and adjoining creeks form the northwestern part of the Gulf where thickest patch of mangroves exists (Fig. 12). Much of interior mudflats were affected with salt as a result of June, 1998 cyclone. Some of the mangroves were uprooted owing to the cyclone. The area of mangroves and other features of this zone are as follows:

Dense Mangroves	-	52.96 km^2
Sparse Mangroves	-	273.74 km^2
Mudflats	-	1099.88 km^2
Salt affected Mud	-	180.68 km^2
Rocky Land	-	43.95 km^2

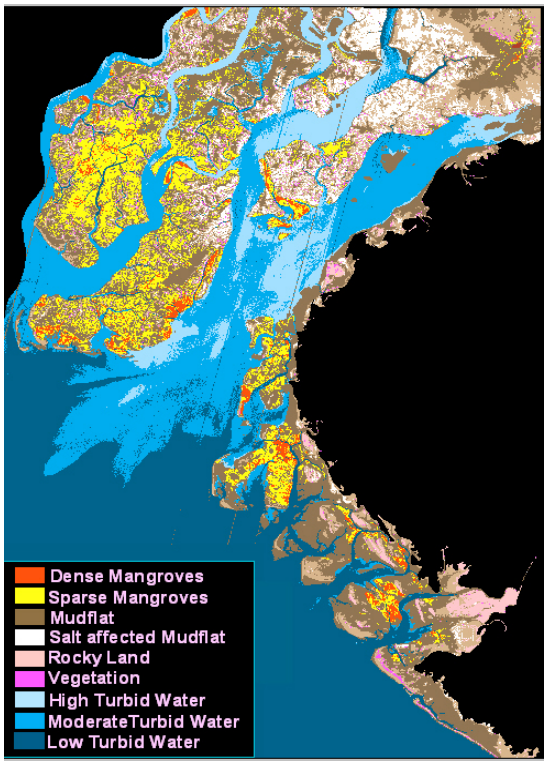


Fig. 12 - Mangroves of Kori and adjoining Creeks

4.2.1.1.2 Outer Gulf

The area coverage of the island ecosystem of the outer Gulf comprising Paga island, Bhaidar Tapu, Noru Tapu, Chank Tapu, etc., has been depicted in Figure 13. The mangroves of this ecosystem contribute to about 19% of the total mangroves of the Gulf. Being located in the outer Gulf, the commercial activities in the Gulf have very little impact on this island ecosystem.

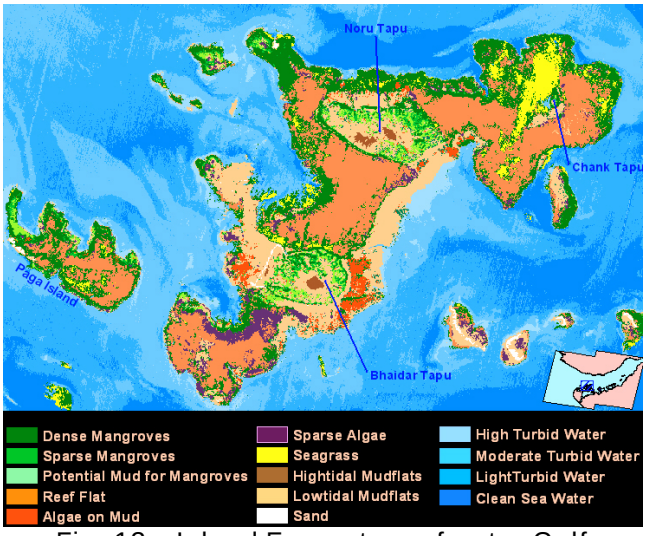


Fig. 13 - Island Ecosystem of outer Gulf

Dense Mangroves	-	34.56 km^2
Sparse Mangroves	-	6.11 km^2
Potential Mud for Mangroves	-	4.24 km^2
Reef flat	-	37.21 km^2
Algae on mud	-	3.43 km^2
Sparse Algae	-	8.18 km^2
Seagrass	-	6.26 km^2
Lowtidal Mudflats	-	25.62 km^2
Hightidal Mudflats	-	0.74 km^2

4.2.1.1.3 Central Gulf

Along the southern coast, the mangroves are occupied mostly in the central part extending from Salaya/Karumbhar island to little above Bedi (Figs. 14 and 15). And along the northern coast, other than Jakhau and Kori creek areas, the mangroves are present only at Mundra region (Fig.16). The details of area under mangroves in these pockets are given in Table 6.

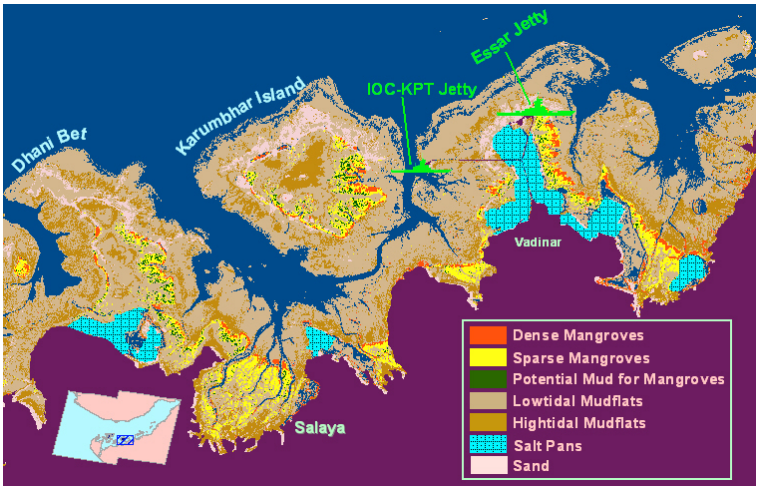


Fig. 14 - Mangroves in and around Karumbhar Island

The mangroves of this pocket contribute to around 4% of the total mangroves of the Gulf. Avicennia marina is dominant with an average height of 1.0 m.

This pocket of mangroves contributes as high as 27% to the total mangroves of the Gulf. Avicennia marina is dominant; Avicennia officinalis and Ceriops tagal occur frequently; Rhizophora

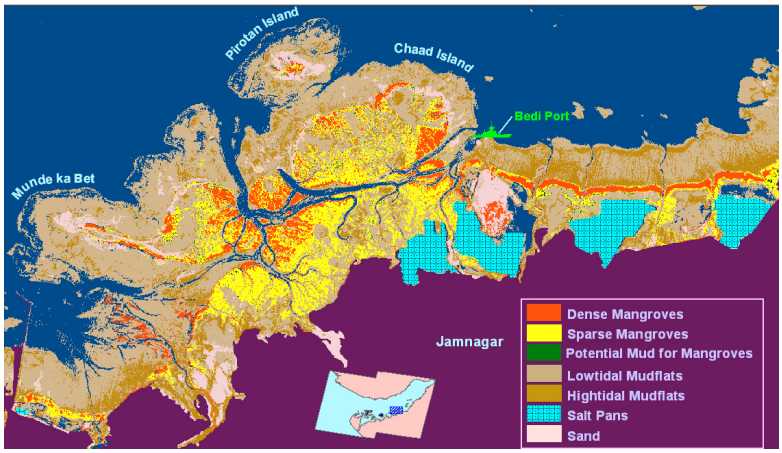


Fig. 15 - Mangroves of southcentral Gulf

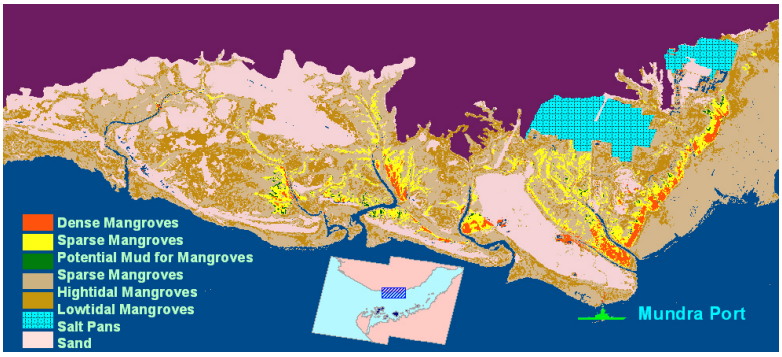


Fig. 16 - Mangroves of Mundra region

This patch of mangroves contributes to only 5% of total mangroves. A.marina is dominant with stunted bushy distribution having an average height of 1.0 m.

Table 6 - Mangrove and Mudflat cover in the north/south central Gulf

(Area in km^2)

S.No	Classification	In and around		
		Karumbhar Island	Islands of south central Gulf	Mundra region
1	Dense Mangroves	8.11	20.10	2.55
2	Sparse Mangroves	20.57	36.24	7.33
3	Potential Mud for Mangroves	3.13	1.23	0.40
4	Lowtidal Mudflats	189.51	14.93	69.92
5	Hightidal Mudflats	51.98	40.40	25.92
6	Salt Pans	20.79	21.29	9.22
7	Sand	22.39	21.77	33.57

4.2.1.1.3 Inner Gulf

A serious set back was to the mangroves of inner Gulf, where, as per 1972 SOI toposheet they were the thickest extending to an area of 506 km^2, but have almost vanished now leaving out small pockets, which amounts to 49.26 km^2 (Fig.17). This is due to rise in mudflat level along with transformation to hypersaline soil conditions which have created conducive environment to support the mangrove growth. A massive 9 fold increase in salt pan area between 1975 and 1982 for the entire Gulf (Table 2) and a 3 fold increase especially in the inner Gulf between 1972 and 2001 (Table 7) together with a significant increase in Little Gulf after 1972 was evident. High amount of bittern discharged from this expanding salt industry over the years has led to the conversion of substratum to hypersaline in nature.

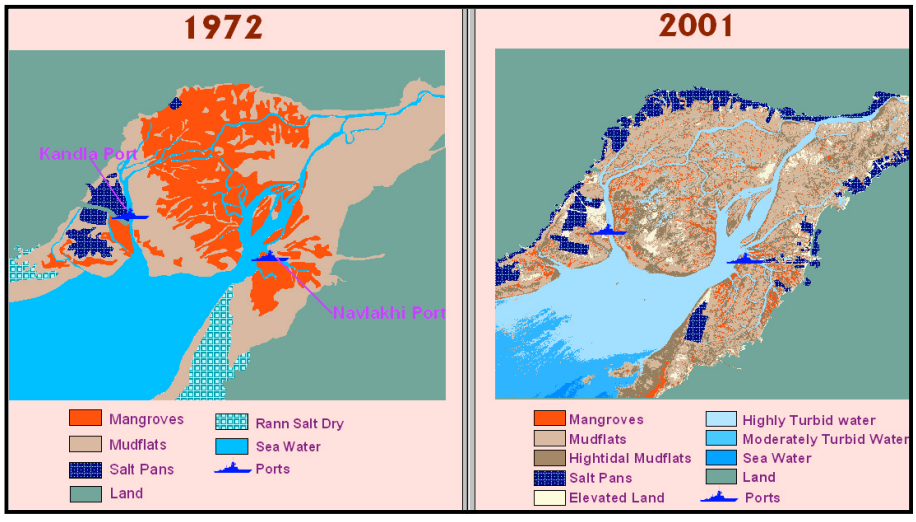


Fig. 17 - Change in Mangrove cover of the inner Gulf

Table 7 - Area change for the ecosystem of inner Gulf.

1972 SOI Toposheet		2001 Satellite Image	
Classification	Area (km^2)	Classification	(Area km^2)
Mangroves	506.02	Mangroves	49.26
Mudflats	865.73	Potential Mud for Mangroves	48.00
Salt Pans	60.47	Lowtidal Mudflats	746.02
Rann-Salt dry	108.52	Hightidal Mudflats	395.57
		Salt Pans	192.12
		Elevated land	110.13

4.2.1.2 Corals

The underwater studies based on videography and still photography during February, 1999 has revealed details of corals and their associated ecosystem at Beyt Shankhodar, Boria Reef, Karumbhar and Pirotan Islands (Gujarat Ecological Society, 1999). The locations of these sites are shown in Figure 18.

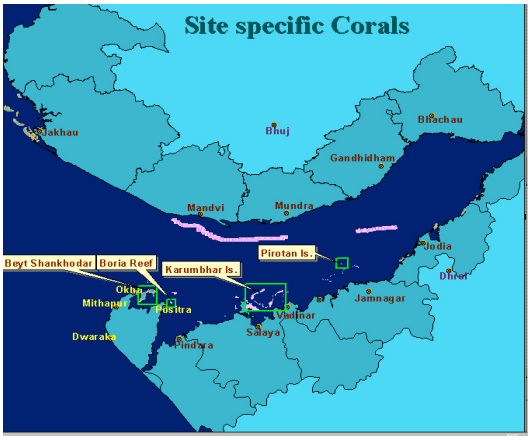


Fig. 18 - Locations of site specific corals studied

4.2.1.2.1 Beyt Shankhodar

The southern tip of Beyt Shankhodar (22°25.197'N, 69°05.069'E) is 5.5 km away from Okha Port and 4.5 km from Mithapur Bay. The coral reef of this point is of fringing type. The seabed is rocky with coral sand. Soft corals are more in density than hard ones. There is a good growth of sponges, which are pharmacologically important and some as large as 100 x 50 cm. Sea lilies were very common and the flora was dominated by red algae.

4.2.1.2.2 Boria Reef

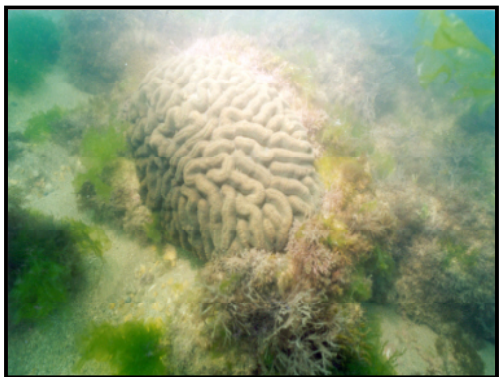
The coordinates of this point are 22°24.423'N and 69°13.124'E. The Boria Island is very close to the Positra point where the proposals for a container port and chemical industrial estate are under consideration. This is also a fringing reef which gets exposed only during low tides. Growing soft corals like Sinularia were abundant at various stages of growth along with gorgonians and sea lilies.

4.2.1.2.3 Karumbhar Island

The reef at Karumbhar is a platform reef. The southern end of the reef of this island, when exposed during low tides, is just about a kilometre north of the jetties of Indian Oil Corporation (IOC) and Essar Oil at Vadinar. Two Single Point Moorings (SPM) lie in between. Around 5 km to the east of the reef lies the SPM of IOC at Narara Bet, and the SPM of Reliance Petrochemicals at Sikka. The Salaya-Mathura oil pipeline passes along the shore nearby. Bharat Petroleum has proposed one SPM in the vicinity and an oil pipeline from Vadinar to Bina. A sub-sea pipeline across the Gulf from Vadinar to Kandla will also pass through this area. All these are self-explanatory, indicating the vulnerability of the Karumbhar coral reef. One small to medium-size oil spill will be adequate to make this luxuriant reef pass away into oblivion. However, present day very large crude carriers are expected to be equipped for tackling small oil spills. The shore establishments of the oil companies must have their contingency plans for tackling oil spills immediately on its occurrence.

Studies were carried out at two sites: one of the site was at 22°28.728′N and 69°37.992′E at a water depth of 5-6 m. The bottom was rocky with coral sand and covered with good growth of seaweed Sargassum. Abundance of hard corals was less, but the growing soft corals and juvenile gorgonians were plenty (Fig.19). The soft corals – gorgonians in particular, also contain the anti-fertility chemical prostaglandin. Continuing siltation made the visibility very poor.

Three Scleractinian corals – Goniopora, Favia and Turbinaria



Brain coral – Platigyra synensis associated by red coralline and green algae

Fig. 19 - Corals at 10 m depth of Karumbhar Island

The second site was at 22°21.841′N and 69°37.074′E at a depth of 10 m. The bottom consisted of rocks and coral sand. Growing soft corals and gorgonians associated with diverse fauna were recorded. The algal growth was less. Siltation was even more than that noted at the first site.

At both the locations tidal currents at the bottom were fairly strong, represented by some dead and partially bleached corals.

4.2.1.2.4 Pirotan Island

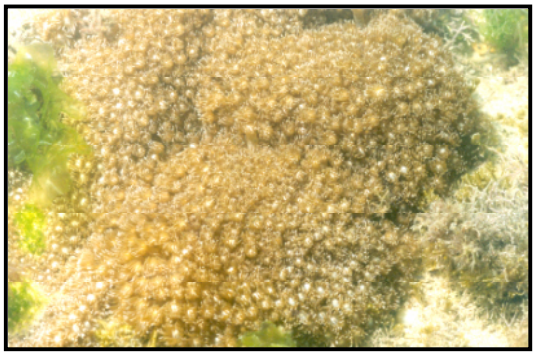
The coral reef at Pirotan is a fringing reef and is the northernmost reef in the Gulf. Recently, a few patches of corals have been identified along the northern coast near Mundra. Two sites - northern and northeastern sides of the island, were studied at the subtidal region beyond the exposed coral reef.

The first site at 22°37.273'N and 69°58.274'E at a water depth of 5-6 m, composed of rocks and coral sand is full of luxuriant vegetation, live and colourful corals with their associated fauna consisting of juvenile gorgonians (sea fan), spiny lobster, several varieties of coral fishes, Crown of Thorns, star fishes, etc. There were more vegetation than animals at the bottom. The bottom looked like an underwater garden teeming with life. Some dead and /or dying corals were also sighted.

The second site at 22°37.066' N and 69°57.491' E at a water depth of 7 m, with rocks and coral sand at the seabed, is full of life with coral population dominating over algae.

Except the coral Tubastrea aurea all other forms have been reported earlier from the Pirotan reef. The visibility at both the places is not good due to continuing siltation. About 20% of the total corals in the area were found to be dead. Some broken branches of the coral Acropora are also present, but they were not fossilised.

Figure 20 depicts the pictures of corals in the sub-tidal region of Pirotan Island. The coral ecosystem of the Gulf is depicted in Table 8.



Live coral Goniopora nigra with long polyps

Bleaching of corals

Fig. 20 - Subtidal Corals of Pirotan Island

Table 8 - Coral ecosystem of the Gulf

Location	Nature	Species Diversity
Beyt Shankhodar (22°25.197′N, 69°05.069′E)	Stony corals	Turbinaria peltata, Favia favus, Favites melicerum, etc.
	Soft Corals	Nepthea sp., Sinularia sp., Lobophyton pancigolsum, Scleronephthya sp., Dendronephthya sp., D.brevirama, Gorgonians, etc.
	Flora	Halymenia sp., Sargassum sp.
	Fauna	Good growth of sponges along with molluscs, Sea lilies, Sea anemones
Boria Island (22°24.423′N, 69°13.124′E)	Stony corals	Montipora sp., Porites sp., etc.
	Soft Corals	Dendronephthya dendrophyta, D.brevirama and Nepthea sp., Gorgonians, etc.
	Flora	Ulva lactuca, Codium adhaerens, Sargassum sp., Padina tetrastomatica, Gracilaria corticata, Hypnea valentiae, Solieria robusta, Caulerpa sp., Hayimenia sp., Giffordia sp., Spyridia sp., Coralline algae
	Fauna	Sea lily, gastropods, cowries, Discoma sp. (Sea anemone)
Karumbhar Island		
22°28.728′N, 69°37.992′E	Stony Corals	Favia speciosa, Goniopora planulata, Montipora sp., Porites compressa, Platygyra sinensis, Favites melicerum, Goniastrea pectinata, etc.
	Soft Corals	Dendronephthya bravirama, Nepthea sp., Gorgonians, etc.
	Flora	Sargassum, Amphiroa, Solieria, Hypnea, Ulva, Halymenia
	Fauna	Perch fishes, Pomacanthus annularis, sponges, gastropods, cowries, sea lilies
	Algal biomass	Ulva lactuca 0.2 kg/m^2, Halimenia sp. 0.8 kg/m^2 and Sargassum sp. 3.2 kg/m^2 on wet weight basis
22°21.841′N, 69°37.074′E	Stony Corals	Favia favus, Montipora sp., Porites sp., Symphyllia radians (brain corals), Tubastrea aurea, dead Acropora branches, etc.
	Soft Corals	Dendronephthya dendrophyta, Nephthea sp., Astromuriacea stelligera (red gorgonians), Lophogorgya lutkeni (gorgonians), etc.
	Flora	Ulva lactuca, U.reticulata, Enteromorpha flexosa, Sargassum sp,, Hypnea valentie, Soliera robusta, Caulerpa sp. and Coralline algae
	Fauna	Polychaetes, tubeworm – Triphyllozoan sp., Bryozoans and Hydrozoans were common, juvenile edible fishes, Brittle star, Periclimenes sp. (shrimp), sea anemones

Location	Nature	Species Diversity
Pirotan Island		
22°37.273′N, 69°58.274′E	Corals	Favia favus, Goniopora nigra, G.planulata, Favites melicerum, Montipora sp., Porites compressa, Tubastrea aurea, Gorgonians, etc.
	Flora	Ulva lactuca, U.reticulata, U.fasciata, Enteromorpha flexosa, Codium elongatum, Sargassum sp., Padina tetrastromatica, Gracilaria corticata, G.verrucosa, Hypnea valentiae, Amphiora fragilissima, Solieria robusta, Caulerpa sp., Coralline algae, etc.
	Fauna	Panularis polyphagus (spiny lobster), Puffer fish, Perch fishes, Acanthaster planci, Bornella sp., Lytocarpus colony, Sabella sp.
	Algal biomass	Ulva lactuca and Amphiora fragilissima were 1.48 and 0.6 kg/m^2 respectively on wet weight basis
22°37.066′ N 69°57.491′ E	Corals	Tubastrea aurea, Favia favus, Favites melicerum, Goniopora nigra, Platigyra sinensis, juvenile gorgonians, etc.
	Flora	Ulva lactuca, Gracilaria, Hypnea, Sargassum sp., etc..
	Fauna	Crabs, fishes, gastropods

The primary investigation by dredging during February 2000 revealed for the first time the presence of a plethora of live corals off Mundra (~8 km^2) and off Mandvi (~3.5 km^2) consisting of Tubastrea sp., soft coral Dendronephthya sp., gorgonians, bryozoans etc., and associated fauna such as brittle star, sea urchins, holothurians and polychaetes and flora such as Ulva sp. and dead Acropora branches indicating that a considerable area in the northwestern Gulf of Kachchh has growing corals. Luxurious benthic vegetation (23 species of marine algae) and fauna (28 species dominated by sponges, echinoderms, puffer fish, spiny lobsters) were also observed at the edges of the intertidal coral reefs in the sub-tidal zone to a depth of 10-12 m.

4.2.1.3 Mud Flats

he Gulf carries huge amount of mud flats due to high tidal range. Along the southern coast, the intertidal zone extends to around 1 km in the outer Gulf, 2 to 3.5 km in the central Gulf and 3.5 to 5 km in the inner Gulf (Fig. 21). Along northern coast, the intertidal zone varied from 2 to 5 km between Mundra and Kandla creek, while the coast between Jakhau and Mundra exhibited very thin to no mudflats. Overall, the Gulf occupies low tidal mudflats of 1590 km^2 and high tidal mudflats of 586 km^2 (Tables 5 & 6).

Mud Flats of Sikka (Reliance Tank Farm in the background)

Mud Flats of Salaya

Fig. 21 - Intertidal Mud Flats of Sikka and Salaya

4.2.2 Biodiversity

The primary data on phytoplankton, zooplankton and marine benthos were collected for the periods March 1999 and February 2000 at five locations viz. Okha, Karumbhar Island, Pirotan Island and Mangra-Kandla along southern coast and Mundra region along northern coast. Mandvi region was monitored additionally during February 2000. However, intertidal benthic and seaweed data were collected for the above locations during March 99 and October 99. Two stations have been monitored for each location, but the data on phytoplankton, zooplankton, benthos and algae were pooled and compiled locationwise and yearwise.

4.2.2.1 Phytoplankton

As a whole, 38 species of phytoplankton were recorded during March 1999. Bacillariophyceae were dominant with 32 species, contributing to more than 80% of the population and the remaining was constituted by 1 species of Chlorophyceae, 5 species of Dinophyceae and 1 species of Chrysophyceae recorded during March 1999. However, during February 2000, 51 species of phytoplankton were recorded including 43 species of Bacillariophyceae, 2 species of Chlorophyceae, 5 species of Dinophyceae and 1 species of Chrysophyceae. The spatial distribution of phytoplankton is illustrated in Table 9.

Table 9 - Spatial distribution of Phytoplankton

Location	Bacillariophyceae	Dinophyceae	Chlorophyceae	Others	Total
	MARCH 1999				
Okha	20	4	1	--	25
Karumbhar	20	2	1	--	22
Pirotan	21	3	--	--	24
Mangra-Kandla	25	4	--	--	29
Mundra	25	4	--	--	29
	FEBRUARY 2000				
Okha	37	3	--	2	42
Karumbhar	34	4	1	2	41
Pirotan	33	3	2	2	40
Mangra-Kandla	21	--	--	1	22
Mundra	37	4	1	3	45
Mandvi	31	4	1	2	38

The most widely recorded genera were Thalassiothrix, Thalassionema, Thalassiosira, Navicula and Nitzschia in both the periods. Species of Rhizosolenia were abundant at Pirotan, Mundra and Mandvi during February 2000. The abundance of phytoplankton in the water column was minimum with 1,22,500 nos.l^{-1} at Okha and maximum with 2,49,500 nos.l^{-1} at Mangra-Kandla during March 1999. The range was between 66,900 nos.l^{-1} at Mangra-Kandla and 4,54,800 nos.l^{-1} at Mundra during February 2000. The species diversity and abundance was more in the mid-depth samples at many stations, which can be related to the optimum conditions prevailed for the phytoplankton growth. Interestingly, it is noticed that in both the observations healthy phytoplankton population and their density were exhibited at Mundra and Mandvi along northern coast compared to southern coast in spite of the latter's occupation with rich ecosystem, may be due to the impact of commercial activities along southern coast on the ecosystem.

4.2.2.2 Zooplankton

The secondary productivity of the Gulf during the study periods was very poor. Only 7 species were recorded during March 1999, Crustaceans dominating with 6 species. While the diversity during February 2000 was better with 11 species, Crustaceans remained dominant with 9 species and Sagittoideans and Scyphozoans represented by one species each. The rich crustacean fauna provides a congenial feeding ground for prawns and fishes.

Surface temperature and intense solar radiation in addition to geographical variations are known to be responsible for poor zooplankton population in the surface waters. Qualitative analysis revealed that the Copepods were the common group with Paracalanus sp., dominating at almost all stations in both the observations. The other copepods recorded were Acartia, Acrocalanus, Centropages, Macrosetella, Oithona, Metacalanus, Sagitta and Evadne. The spatial distribution of zooplankton (Table 10) showed least diversity at Pirotan in both the periods while Mangra-Kandla and Mandvi observed highest diversity out of all stations and observations.

Table 10 - Spatial distribution of Zooplankton

Location	Crustaceans		Sagittoideans		Others/ Groups		Total	
	Di*	De#	Di*	De#	Di*	De#	Di*	De#
	MARCH 1999							
Karumbhar	5	693	--	--	7	974	12	1667
Pirotan	2	282	1	47	2	913	5	1195
Mangra-Kandla	5	516	--	--	6	1250	11	1766
	FEBRUARY 2000							
Okha	4	2986	1	411	6	1972	11	4958
Karumbhar	6	1577	--	--	8	1294	14	2871
Pirotan	4	1235	--	--	8	1564	12	2799
Mangra-Kandla	7	4948	1	568	10	4043	18	8991
Mundra	6	5244	1	556	7	3821	14	9065
Mandvi	7	2374	1	110	10	1655	18	4029

* Di: Species Diversity; # De: Density (nos.m^{-3})

Zooplankton abundance ranged from 1195 nos.m^{-3} at Pirotan to 1766 nos.m^{-3} at Mangra-Kandla during March 1999 and from 2799 nos.m^{-3} at Pirotan to 9065 nos.m^{-3} at Mundra during February 2000. Importantly larval groups contributed to around 50% of zooplankton density, the prominent groups are fish eggs & larvae, gastropod veliger, zoea, lamellibranch, nauplii, mysis larvae, etc. However, fish larvae were more abundant than fish eggs. The abundance of these larval groups addresses the importance of mangrove and coral environments of the Gulf as nursery grounds.

4.2.2.3 Marine Benthos

As a whole, 68 species of benthic organisms were recorded during March 1999 and 50 species during February 2000. The major groups observed were molluscs, polychaetes and crustaceans. Bivalves ranked first followed by Gastropods while crustaceans, scaphopods and polychaetes witnessed the least in both the periods. Stationwise, Mangra-Kandla recorded lowest diversity and it was maximum at Okha and Karumbhar (Table 11) due to the proximity of these places nearer to ecological areas. Among the bivalves genus Arca, Tellina and Solen were common. Nassarius sp., Arca sp., polychaete tubes, coral polyps, hydrozoans and bryozoans dominated at most of the stations.

TABLE 11. Spatial distribution of Marine Benthos

Location	Bivalves	Gastropods	Crustaceans	Scaphopods	Others	Total
	MARCH 1999					
Okha	9	17	1	1	3	31
Karumbhar	14	7	1	1	3	26
Pirotan	13	13	--	1	2	29
Kandla	5	--	--	--	4	9
Mundra	14	7	1	--	3	25
	FEBRUARY 2000					
Okha	5	11	2	--	7	25
Karumbhar	9	16	--	1	8	34
Pirotan	7	10	--	1	6	24
Kandla	--	--	1	--	3	4
Mundra	6	7	--	1	6	20
Mandvi	1	3	2	--	4	10

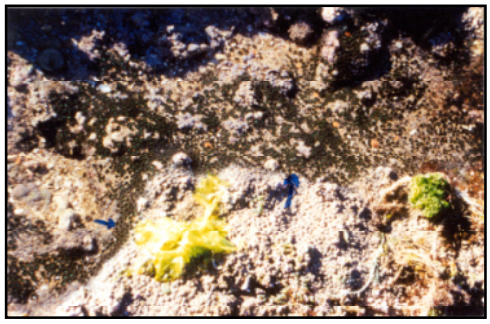
The number of offshore benthic fauna was about 4 to 10 times higher during February 2000 compared to March 1999 at all the locations except Mangra-Kandla where it is almost similar and observed least density (555-584 nos.m^{-2}). Okha has recorded rich benthic population with 10762 nos. m^{-2} followed by Karumbhar (7948 nos.m^{-2}), Mundra (6140 nos. m^{-2}), Pirotan (4705 nos.m^{-2}) and Mangra-Kandla (555 nos.m^{-2}) during February 2000. This indicates a gradual declining trend of benthic faunal density from outer to central Gulf and there after drops suddenly to the inner Gulf. This is possibly due to low siltation and better mixing at outer Gulf which sustains a good faunal growth.

4.2.2.4 Intertidal Benthos

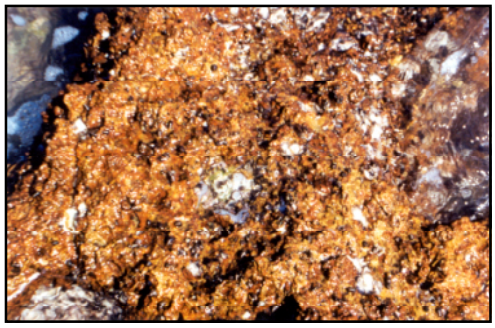
The data on intertidal benthos were collected for two seasons viz. March 99 (pre-monsoon) and October 99 (post-monsoon). Post-monsoon is rich in diversity with 176 species, while pre-monsoon registered 81 species for the overall Gulf. By far, gastropods constituted the largest group with 50% of total diversity of each season followed by bivalves, crustaceans and anthozoans. Polychaetes were represented by 16 species during post-monsoon, whereas only one species was recorded during pre-monsoon. All the stations studied were rich in intertidal benthic fauna (Fig.22).

Giant Sea anemone at Pirotan Island

Antedon sp – a feather star at Okha



Zoanthus colonies growing on rocky substratum in the upper mid littoral zone at Okha



Oyster spat in the upper littoral zone at Okha

Fig. 22 - Intertidal Benthic species

During post-monsoon, intertidal habitats of Beyt Shankhodar had the highest number of fauna with 87 species (Table 12) followed by Karumbhar (65), Pirotan (51) and Jodia (35). Temporal variation in species diversity and abundance was most prominent at Beyt Shankhodar with gastropods as dominant group followed by Pirotan island.

Table 12 - Spatial distribution of Intertidal Benthos

Location	Bivalves	Gastropods	Crustaceans	Others	Total
	MARCH 1999				
Beyt Shankhodar	8	17	--	10	35
Karumbhar	8	1	3	10	22
Pirotan	5	13	6	8	32
Jodia	6	17	4	1	28
	OCTOBER 1999				
Beyt Shakhodar	22	51	2	12	87
Karumbhar	22	16	7	20	65
Pirotan	9	26	7	9	51
Jodia	15	6	7	7	35
Mundra	4	8	5	--	17

A zonewise typical distribution pattern of the species was evident along the intertidal gradient depending on its physical tolerance and food availability. While the zonation was pronounced in the rocky intertidal expance (Okha), it was less clear in exposed/semi-exposed intertidal shores of other sites (Beyt Shankhodar, Pirotan and Jodia). The zonation appears to be seasonal as it was observed to be influenced by the physical characteristics of the shore caused by the seasonal wave exposure and instantaneous faunal distribution.

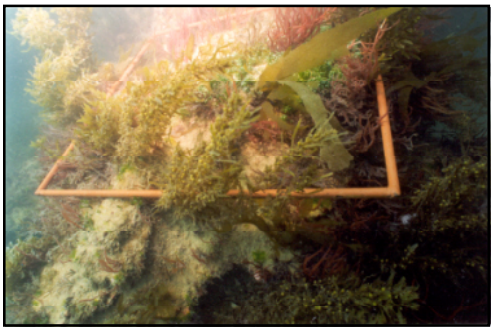
Gastropods and bivalves dominated throughout the intertidal region. The supra-littoral zone was characterised by the presence of species of Cerithium, Drupa and Oliva (Beyt Shankhodar), the muddy substratum (Jodia) was dominated by crab holes mainly species of Uca. While the mid-littoral and sub-littoral zones exhibited more biodiversity dominated by Trochus, Turbo, Cerithidea etc., barnacles and brachyuran crabs dominated the lower intertidal zone (Jodia).

4.2.2.5 Marine Algae

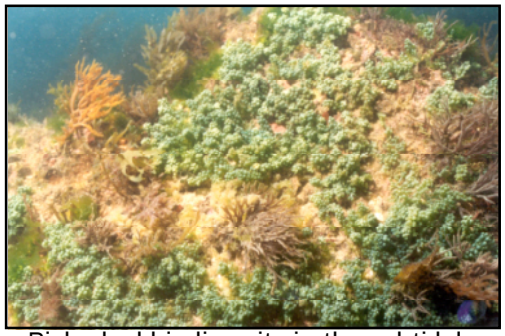
Overall, the pre-monsoon diversity of marine algae was rich with 78 species belonging to Rhodophyceae (26), Chlorophyceae (25) and Phaeophyceae (21). The overall diversity during post-monsoon was less with 44 species again comprising almost equally with Rhodophyceae (13), Chlorophyceae (13) and Phaeophyceae (14). Cyanophyceae and Bacillariophyceae contributed least.

Distribution of marine algae in the southern and northern coasts of the Gulf exhibited a clear cut contrast between each other. While the algal growth was luxuriant on the southern coast (Fig.23), the northern coast had very poor algal biodiversity. Availability of large inter-tidal expanse (1-5 km) with gradual slope and the coralline substratum on the southern coast favoured luxuriant growth of diverse species of algae in the Marine Sanctuary area and most other stations. Beyt Shankhodar recorded 72 species followed by Pirotan (40) and Karumbhar (36) and least and poor diversity at Jodia (10). This spatial distribution of decreasing trend from outer to central Gulf and fall out suddenly to inner Gulf (Table 13) follows closely with that of intertidal benthos. The substratum of northern coast being sandy/muddy did not support much algal growth. Only 2 species of Chlorophyceae and one species of Phaeophyceae were found in the mangrove area of Mundra region.

Caulerpa racemosa in the intertidal zone of Beyt Shankhodar



Sargassum sp. at subtidal zone of Karumbar Island



Rich algal biodiversity in the subtidal zone of Pirotan Island

Caulerpa peltata and Amphiprora fragilissima at Pirotan Island

Fig. 23 - Marine Algae of the Gulf of Kachchh

Table 13 - Spatial distribution of Marine Algae

Location	Rhodophyceae	Chlorophyceae	Phaeophyceae	Others	Total
	MARCH 1999				
Beyt Shankhodar	26	21	19	6	72
Karumbhar	13	12	9	2	36
Pirotan	11	12	15	2	40
Jodia	3	1	6	--	10
Mundra	--	2	1	--	3
	OCTOBER 1999				
Beyt Shankhodar	13	11	14	2	40
Karumbhar	6	2	2	2	12
Pirotan	8	8	8	2	26

The zonation and distribution pattern of the seaweeds is almost the same at all the stations of the Southern Gulf (Fig.24). The supra-littoral zone was dominated by the green algal species (Ulva sp.). Other common algae in this region were green algae e.g., Ernodesmis, Struvea and Microdictyon and nonarticulated coralline alga – Melobasia (red algae). Brown algae belonging to the order Dictyotales were common in the mid-littoral zone; dominated by Padina, Dictyota along with Colpomenia and Iyengaria (Scytosiphonales). Sargassum sp. and red algal species like Kjellimania,

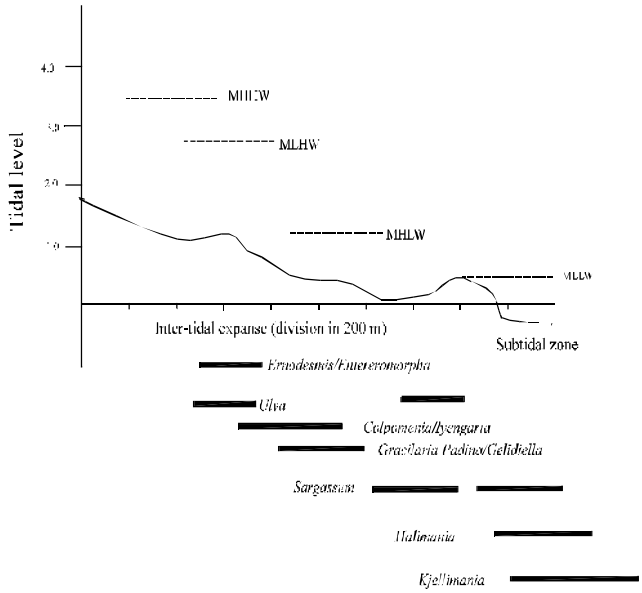


Fig. 24 - Zonation of marine algae along the Gulf

Halimenia, Griffithsia, etc., dominated the lower mid-littoral and subtidal zones. Sargassum species contribute the maximum to the total biomass of the Gulf of Kachchh region (>1 $kg.m^{-2}$ wet weight). The sub-tidal region (below 5 m depth) is dominated by species like Sargassum, Turbinaria and Kjellimania.

4.2.2.6 Fish and Fisheries

The gulf is an important fishing ground for shrimps, lobsters, pomfrets, catfish, bombay duck, mullets, sharks and clupeids. The Park and Sanctuary area supports approximately 200 species of fishes and 27 species of shrimp. Eagle ray, stiny ray, electric ray, shark, butterfly fish, sole fish, porcupine fish, puffer fish, etc., are abundant. It also supports good landings of gastropods and bivalves especially edible oysters, windopane oysters and pearl oysters. Based on the average oyster density of 7.6 nos.m^{-2}, the biomass of windopane oysters in the Pindara Bay was estimated to be 6300 tons. Windowpane oyster fishery of Gulf of Kachchh is unique and nowherelse along the Indian Coast except that in Kakinada Bay, Andhra Pradesh it forms an important fishery. Gulf of Kachchh provides suitable ecological and environmental conditions and sustains a variety of exploitable species of finfishes and shellfishes with an average catch of 1.4 x 10^5 tons/y. Details on fish catch in the Gulf of Kachchh area for the year 1997 are given in Figure 25 and Table 14.

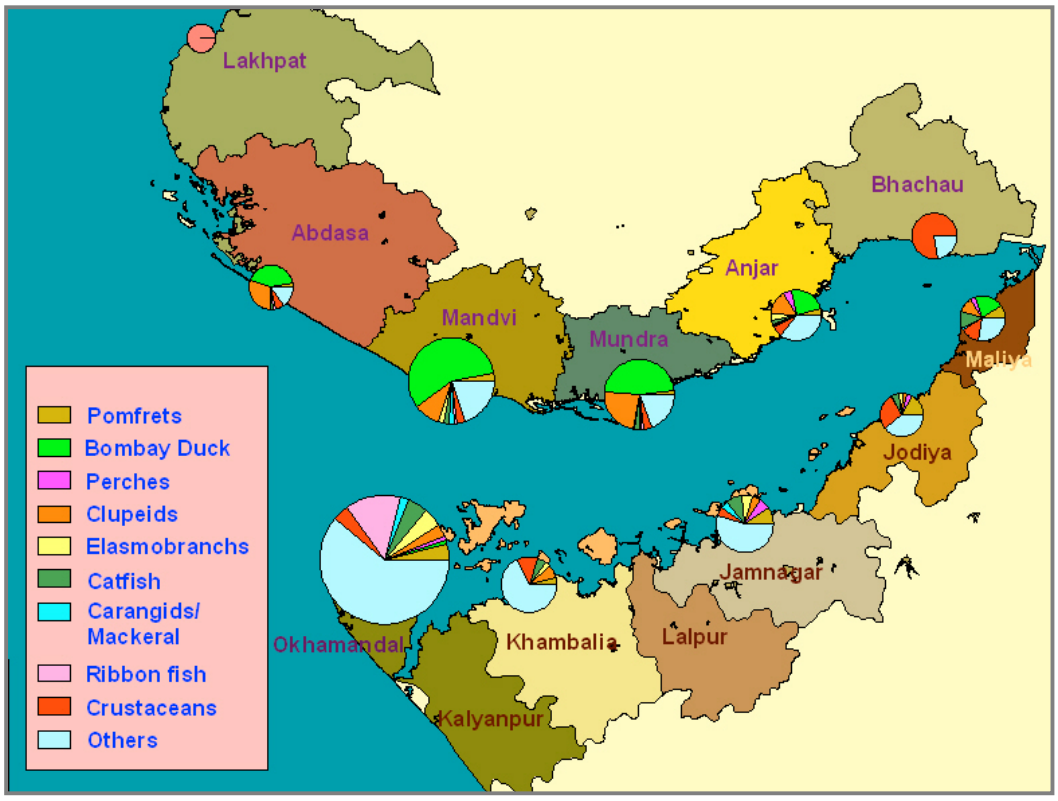


Fig. 25 – Species-wise distribution of fish catch in the Gulf

Table 14 - Details of fish catch in the Gulf during 1997-98

S. No.	Taluk	Active Fishermen	No. of Boats	Fish landing (Ton)
	Jamnagar Dist.			
1	Okhamandal	1157	158	35963
2	Jamnagar	2007	674	3015
3	Jodiya	611	42	411
4	Khambhalia	1739	402	1040
	Rajkot Dist.			
5	Maliya	320	162	823
	Kachchh Dist.			
6	Bhachau	674	128	888
7	Anjar	1439	173	1692
8	Mundra	1425	189	6644
9	Mandvi	1054	186	13418
	Total	10426	2114	63894

4.3 Water Quality

4.3.1 Ground Water

Ground water salinity ingress is one of the biggest problems of the coastal areas of Gulf. It has been observed that the area up to 6 km from sea coast is severely affected by seawater intrusion in most part of the coast. Moderate to strong soil salinity has also been recorded in the coastal tracts. Seawater intrusion and extent of soil salinity are on the increase every year. The State Govt. has made certain efforts and has been able to counter the salinity ingress in selected regions by constructing salinity ingress prevention structures in the form of tidal regulators and spreading channels. However, attempts are discrete and hence the benefits are localised. It is felt that efforts of voluntary organisations should also be channelised in order to reach larger masses for solving this problem of salinity ingress. Talukwise details of the area affected by seawater intrusion and area under saline soils in the Gulf of Kachchh are shown in Table 15.

Table 15 – Taluk-wise details of salt affected areas

Taluks	Area of saline soils (ha)	Change of area (ha) affected by seawater intrusion (TDS>2000 ppm)		
		Years		
		1979-80	1990-91	1991-92
Kachchh District				
Abdasa	32215	--	--	--
Mandvi	43062	--	--	--
Mundra	13973	--	--	--
Anjar	73300	--	--	--
Bhachau	15300	--	--	--
Jamnagar District				
Okhamandal	35402	67510	62954	62984
Kalyanpur	73374	57880	67648	63132
Khambalia	--	7420	16693	19506
Lalpur	--	1690	1820	2101
Jamnagar	3333	1170	18169	28813
Jodiya	7068	47254	46172	49428
Rajkot District				
Maliya	2040	--	--	77000

4.3.2 Sea Water

Any coastal based commercial activity will certainly lead to deterioration of the aesthetics and quality of surrounding water body. The effect would be much higher in immediate vicinity (nearshore areas) than away from coast. In order to differentiate the level of pollution in these areas, the study areas have been divided into two categories viz.

(i) Zone-I (stations having sonic depth below 10 m) and

(ii) Zone-II (stations having sonic depth above 10 m).

The COMAPS data on water quality of the Gulf for the periods March, 1998 (pre-monsoon) and November-December, 1998 (post-monsoon) has been considered to synchronise the study periods of biodiversity. The entire data for the stations falling under each zone for the above periods have been pooled separately for the transects at Okha, Positra, Vadinar, Bedi and Kandla.

Diurnal variations in temperature are small and follow the profile of atmospheric temperature. In general the water temperature lies below 30°C. The water column is well mixed thermally and so the temperature gradients are minor.

The salinity variations showed an increase of salinity from 36.1 PSU at outer Gulf to as high as 40.2 PSU off Kandla and even higher (50.0 PSU) in the Little Gulf. Owing to the negative water balance of the Gulf having high evaporation over precipitation, release of bittern from salt pans and drainage of sea water from vast intertidal mudflats exposed during low tide are considered to contribute to the high salinity. Fresh water flow during an occasional spell of precipitation during brief monsoon results in much wider fluctuations in salinity of the creeks but the influence is only marginal on the Gulf proper with salinities of 35-37 PSU occurring off Sikka and Salaya during normal monsoon periods (Zingde, 1999). The swift tidal movements, strong currents and eddies due to high turbulence renders the Gulf and the creeks well mixed vertically as well as laterally through small temporal salinity changes.

The distribution of suspended solids in the Gulf is variable and patchy (Fig 26). The deeper regions sustain low suspended load while it is markedly high in the areas close to mudflats and creeks. Much of this suspended load results from the dispersion of fine grained sediment by tidal currents sweeping the Gulf due to which bottom water invariably contains higher suspended load. The inner Gulf areas which are subject to high tidal inundation are highly turbid touching the values as high as 700 $mg.l^{-1}$ which is the case in the Little Gulf as well as most of the creeks.

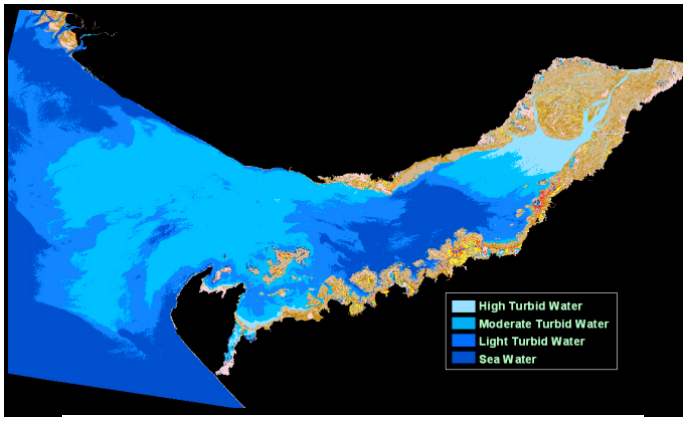


Fig. 26 - Turbidity Map of the Gulf

The average DO throughout the Gulf exceeds 5.5 $mg.l^{-1}$ which is close to saturation and prevailing good oxidising conditions. In general, the temporal variation of DO showed a decrease from outer to inner Gulf (with an exception at Bedi having high values) which is in reverse to salinity distribution but corroborates its solubility level. However, DO is reported to be higher in zone-II than zone-I during post-monsoon while they are almost similar during pre-monsoon. BOD values are generally below 3.0 $mg.l^{-1}$ indicating the effective oxidisation of

organic matter in the column maintaining a healthy balance between consumption and replenishment of DO.

The levels of nitrate indicate an increasing trend from the inner to outer Gulf, while that of nitrite are low with a marked increase in the inner Gulf (off Kandla). However, the levels of phosphate are the highest at Bedi where the intermediate port is proposed to expand for a major port designated for agricultural usage. High phosphate and nitrate concentrations characterised the creeks. These creeks are perhaps opened to domestic sewage that contain a wealth of dissolved inorganic nutrients and readily oxidisable, biologically active particulate organic matter capable of promoting additional autochthonous products to the Gulf.

The levels of Petroleum Hydrocarbons (PHC) in water are important in the context of prevailing traffic of crude oil and Petroleum Oil and Lubricants (POL) and projected multifold increase in this traffic in near future. The highest PHC levels recorded at Vadinar (where SPMs are under operation) were 16.2 $\mu g.l^{-1}$ (March, 1998) and 31.2 $\mu g.l^{-1}$ (Nov, 1997). These values largely indicate the dissolved and dispersed PHC to which the pelagic organisms are exposed. Relatively high ambient temperatures, moderate wind speeds and tidal circulation conducive to efficient dispersion, are expected to remove the lighter petroleum compounds fairly quickly from minor oil spills when they occur and the remaining residue would be widely dispersed and/or transported to the shore under the prevailing circulation. In fact patches of petroleum residues are occasionally encountered in low energy mangrove swamps and mudflats bordering the Gulf (Fig.27). It is well known that through evaporation most of the spilled oil gets removed from the marine environment. But one has to understand clearly that this is only a phase transformation of oil and its associated hazards from the marine environment to the atmosphere above it. This may lead to chronic health disorders in terrestrial animals and human beings and contribute to global warming.

Fig. 27 - Oil residues on the intertidal zone

4.4 Commercial Activities

With the prevalence of vast coastline, the State Govt. of Gujarat is intended to promote the industrial and port activities on both the sides of Gulf. In recent years Gulf of Kachchh is drawing attention of many entrepreneurs for setting up of major and minor developmental projects due to the liberalisation of industrial policy by the Government, proximity of the area to import the crude oil, suitability of the environment to setting up the Single Point Moorings for unloading crude oil from the large vessels, availability of mineral resources on the hinterland, etc.

4.4.1 Industries

About 10,000 SSI units mostly of natural salt, agro and food processing, wood based industries and engineering sector are existing in coastal Taluks. Gujarat Industrial Development Corporation (GIDC) Estates are established in both the districts of the Gulf, the estates of Jamnagar District are mainly engaged in manufacturing of brass parts and engineering utensils.

There are around 40 medium and large industrial projects around Gulf of Kachchh and the major ones are situated in Jamnagar district. The major six chemical industries are Tata Chemicals Ltd., Reliance Petrochemicals Ltd., Gujarat State Fertilisers Ltd., Gujarat Thermal Power Station and Digvijay Cements at Sikka in the Jamnagar district and Indian Farmers Fertilisers Corporation Ltd., in the Kachchh district. The other major industries are Birla VXL Ltd., Jamnagar, Export Processing units in Kandla Free Trade Zone, Mining project of GMDC, Lignite based GEB power plant and Akrimota Thermal Power Station by GMDC in the Kachchh district. Apart from the above, two more major industries viz. Essar Oil in the Jamnagar district and Sanghi Cements near Kharo Creek, Kachchh district are under commissioning stage. Except Tata Chemicals Ltd., all the remaining industries including Essar Oil and Sanghi Cements have made provision for their own jetties at the nearest location of the industries for their export and import activities.

Indian Oil Corporation (IOC) is having a Depot for storing crude oil near Narara Bet. IOC is having two Single Point Moorings (SPMs) in the Gulf near Narara Bet (Fig.28) through which the crude oil from the ships is being pumped and stored in the depot. Crude from this depot in turn is being pumped to various refineries situated in the northern India. Also, Reliance Petroleum Ltd., is having two SPMs towards east of IOC's SPMs for their import and export activities of crude oil and refined products. Apart from these, there are proposals for

more SPMs by several agencies in the Gulf. With these, the traffic of crude oil is projected to increase from the present 1.18×10^7 t/y to over 7×10^7 t/y and the traffic of very large crude carriers (VLCCs) is expected to increase from the present level of about 80 to over 480 in the coming years.

Fig. 28 - Single Point Mooring of Indian Oil Corporation near Vadinar

4.4.2 Ports

The major port of the Gulf is the Kandla, situated in the inner Gulf. The intermediate ports are Mundra, Mandvi, Sikka, Bedi and Okha and minor ports are Jakhau and Salaya. Among these, Mundra Port has almost become dead. Eventhough Okha Port is handling the cargo like coal, rice, etc., it is not being utilised to its full capacity. Two more ports are proposed : one at Bedi and the other at Positra. In addition, the refinery of RPL has constructed state-of-the-art product jetties at Sikka for evacuation of products by tanker ships. A few more captive jetties in the Gulf are under consideration. Hence, the traffic of tanker ships carrying Petroleum Oil Lubricants and other bulk chemicals, estimated to be around 1000 ships per year today (excluding crude carrying tankers of RPL and solid cargo vessels) is expected to increase considerably in the coming years. At a projected growth rate of 20% of vessel traffic (of all kinds) per year, the projected vessel traffic in Gulf will be about 16000 vessels per year by 2005 AD compared to the figure of 6000 vessels as of now.

4.4.3 Salt Pans

There are only a few locations in India that are suitable for salt production based on climate, soil, terrain, extent of area and other supporting infrastructure facilities. Gujarat is the largest salt producing State, accounting for about 70% of the total salt production in the country. The hinterland of Gulf of Kachchh spanning over the coast of Jamnagar, Rajkot, Surendranagar, Patan and Kachchh Districts has excellent conditions for production of salt through salt farming as it has (i) vast barren mudflats with gentle slopes and impermeable soil to allow stagnation of water for evaporation, (ii) several creeks and creeklets to supply salt water with close proximity, (iii) high temperature and high wind velocities leading to enhanced evaporation rates. Several small farmers as well as large scale producers of salt are involved in salt farming. At present, totally 21 salt work industries are functioning in unclassified forest area along the coast of Jamnagar and total 103.3 km^2 (10211 ha Forests and 144 ha Revenue) area is leased out for this purpose. Salt works are operating all along the coast from Jodiya to Okha. About same number of salt farms have developed in Rajkot

(near Suranjbari) and Kachchh. The Anjar and Bhachau taluks in northern coast and Okhamandal taluk in southern coast have accounted for highest area of salt farming. While the easternmost part of the Gulf, the Little Gulf connected with the Rann of Kachchh, accounts for largest salt farming area of around 131 km^2. About 82 million tons of salt is being produced annually in the Gulf. The talukwise area details of salt pans as obtained from satellite image are illustrated in Table 16.

Table 16 - Area details of Salt Pans

S.No.	Taluk / Zone	Area (km^2)
1	Abdasa	22.35
2	Mundra	0.82
3	Mandvi	10.21
4	Anjar	74.88
5	Bhachau	70.46
6	Maliya	63.32
7	Jodia	21.12
8	Jamnagar	18.95
9	Lalpur	12.61
10	Khambalia	6.33
11	Kalyanpur	17.89
12	Okhamandal	85.10
13	Little Gulf	131.36
	Total	535.41

Apart from the above mentioned commercial activities, many other proposals were submitted to the Govt. of Gujarat, which are under processing / implementation stage (ICMAM, 2000).

4.4.4 Impacts of Commercial Projects on the Gulf environment

The activities of all these commercial establishments showed adverse impacts on the Gulf environment as discussed earlier (ICMAM, 2000). The alkaline effluents of Tata Chemicals Ltd., have totally eliminated macrobenthos of around 200 m area in the Mithapur Bay. Also, the intertidal segment associated with about 3 km of the shoreline sustains very poor to moderate macrobenthic standing stock. The petroleum products and oil leakage can damage the roots and leaves of mangroves, their growth retardation, mechanical clogging of lenticals, air holes in prop roots, affect pneumatophores, defoliation and lead to ultimate

death of growing seedling and plants. The leakage of fertiliser / chemicals for example, phosphoric acid, could trigger rich growth of algae which may lead to enhanced stress on corals which are already threatened by sedimentation. The corals of Sikka area are under constant stress due to the sedimentation of fly ash from the Thermal Power Plant.

An annual output of 2.95 million kiloliters of bittern is expected to be discharged from salt pans which along with negative water balance of the Gulf resulted in increase of sea water and soil salinity. Bittern is toxic to certain species of mangroves. Corals are highly susceptible to change in sea water quality, specially salinity. Considering enormous quantity of freshwater requirement and scanty rainfall on both northern and southern sides of the Gulf, desalination of seawater appears the only sustainable option in the region. It is to be ensured that reject from the desalination facility is discharged into the sea at suitable temperature and in such a manner that the dilution factor is very large. The existing salt manufacturers discharge bittern on the coast, which is carried into the sea by the tidal action. The discharge of bittern from the salt work through suitable diffusers into the sea would ensure that pockets of high concentration, which may be injurious to biota are avoided.

5. **Oil Spill Model – Integration with** GIS

The strategic location of the Gulf of Kachchh nearer to the oil producing Gulf countries has attracted establishment of facilities for refining and piping of petroleum products and related activities in the recent years to meet the growing demand for the consumers of northern India. Four Single Point Moorings (SPMs) are already catering in the Gulf waters to handle the crude and eight more are proposed by various agencies to serve that extra demand. Projections are there to handle a traffic of 480 very large crude carriers (VLCCs) with the crude oil handling capacity of 7×10^7 tons/y in the coming years which is 6-7 times the present capacity. The incidence of oil spills resulting from tanker traffic, loading, unloading and associated activities will increase in the years to come as the demand for petroleum and its products continue to rise. The threat due to the oil spills on the ecology of the Gulf and consequent economic losses need to be addressed through scientific techniques. Prediction of the oil slick thickness and dynamics, distribution of oil in the water column and atmosphere are of interest and the extent of areas of ecologically sensitive mangroves, corals, mudflats, beaches, etc., affected by oil can be mapped from the Geographical Information System in order to make a contingency planning and assessing environmental impact.

5.1 Oil Spill Modeling

Transport and fate of spilled oil in water bodies are governed by physical (advection, turbulent diffusion, evaporation, dissolution, emulsification), chemical (photo-oxidation, hydrolysis) and biological (biodegradation) processes that depend on the oil properties, hydrodynamics, meteorological and environmental conditions. When oil spill occurs on the sea surface, it spreads to form a thin film – an oil slick. The slick spreads over the water surface due to a balance between gravitational, inertial, viscous and interfacial tension forces, while changing its mass and physico-chemical properties.

Composition of the oil and oil phases are changing from the time of spill to its dispersal later. Light (low molecular weight) fractions evaporate first while water soluble components dissolved in the water and immiscible components become emulsified and disperse in the water column as small droplets (Fig.29). The formation of oil- water emulsion depends upon turbulence, but usually occurs within days to weeks after the initial spill. After a long time, this mass may disintegrate into lumps of tar. In certain cases, the oil droplets may become attached to sediment particles in the water column and carried to the seabed where the oil may be buried and bacterial degradation will be much slower. Tar balls and mousse present a small surface area compared to their volume and degrade extremely slowly for this reason. Given enough time, the combined action of weathering and biodegradation can eliminate most of the spilled oil.

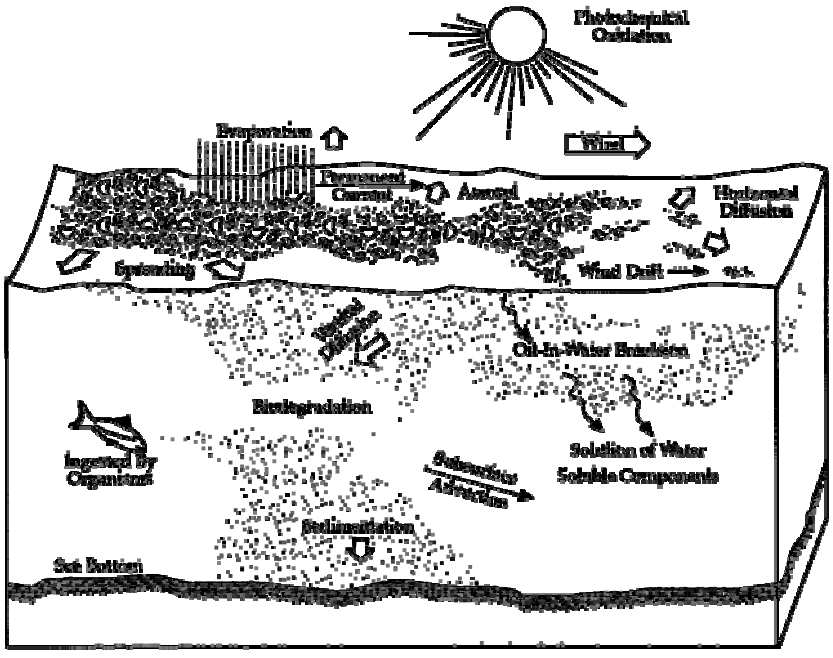


Fig. 29 - Effects of various factors on the movement of polluting oil at sea

5.1.1 Construction and simulation of Model

The numerical modeling approach emerges as an useful tool to simulate the scenarios and addresses the issue as to how the oil will disperse in the case of a spill. A two dimensional hydrodynamic model MIKE 21 developed by DHI was constructed for the entire Gulf. The basic parameters like baseline and bathymetry were taken from NHO chart and weather conditions, currents and tide data of the Gulf were considered from the literature. The model was set up with tide as open boundary between Okha in the southern coast and Chachi point in the northern coast. The model was calibrated with the water level at Kandla and was in good agreement with the tidal amplitude and its phase difference from mouth to head of the Gulf.

The output of hydrodynamic model was used to simulate the transport of oil spill. Since Arabian light crude oil is being handled mostly in the Gulf, its physical properties along with spill characteristics were used in oil spill modeling. The oil is represented by a large ensemble of small parcels and sets of spatial coordinates are assigned to each parcel. It is assumed that these parcels advect with the surrounding water body and diffuse as a result of random processes. The movement and mass of each particle are recorded as function of time with reference to a fixed hydrodynamic grid system. Then the density distribution of the ensemble can be interpreted as the concentration of oil. The model includes the process of advection, diffusion, evaporation, emulsification, dissolution, etc.

The calibrated hydrodynamic model was simulated for an oil spill located at Reliance SPMs, the selection of these SPMs was in accordance with their highest handling capacity over other existing SPMs of IOC. A minor accidental oil spill of 100 m^3 was specified and modeled for a maximum duration of 48 hrs from the time of spill. Historical wind data available for the Gulf indicate that winds are predominantly N-NW and S-SW in direction. Taking this into account, three wind scenarios are assumed for simulating the oil spill model:

Scenario I	-	No Wind
Scenario II	-	5 $m.s^{-1}$ from 240°N
Scenario III	-	5 $m.s^{-1}$ from 330°N

The results showed that the light fractions get evaporated during the initial hours after the spill and the evaporation rate is negligible after 6 hrs which matches with the relative oil fractions. The rate of oil dispersion in the water column increases as time progresses and oil becomes dense due to evaporation and emulsification. The output clippings were stored for alternate grid points for plotting purposes.

5.2 Evaluation of Model results on Geographical Information System

The output for every 3 hours time step from the oil spill model was captured and in sequence they were accurately overlayed on the ecological map of the Gulf, which was prepared earlier. The overlayed maps (Fig. 30) showed the transport of oil towards the downwind direction and spread onto mudflats during high tide. In no wind condition, the spilled oil has moved between Karumbhar Island and Narare Bet. While the movement of oil is towards northern coast when wind blows from southwest, in the northwestern wind condition, the first oil residue hits the coast at Narare Bet in 12 hours and moved further towards Sikka affecting the ecological habitats. Out of the three scenarios, the second scenario ie., southwestern wind condition will have least impact as the spilled oil moved towards north, which either takes long time to hit the coast or may dissipate in due course of time. However, under first and third scenarios the spilled oil will damage the critical habitats of southern coast and island especially between Dhani Bet and Sikka.

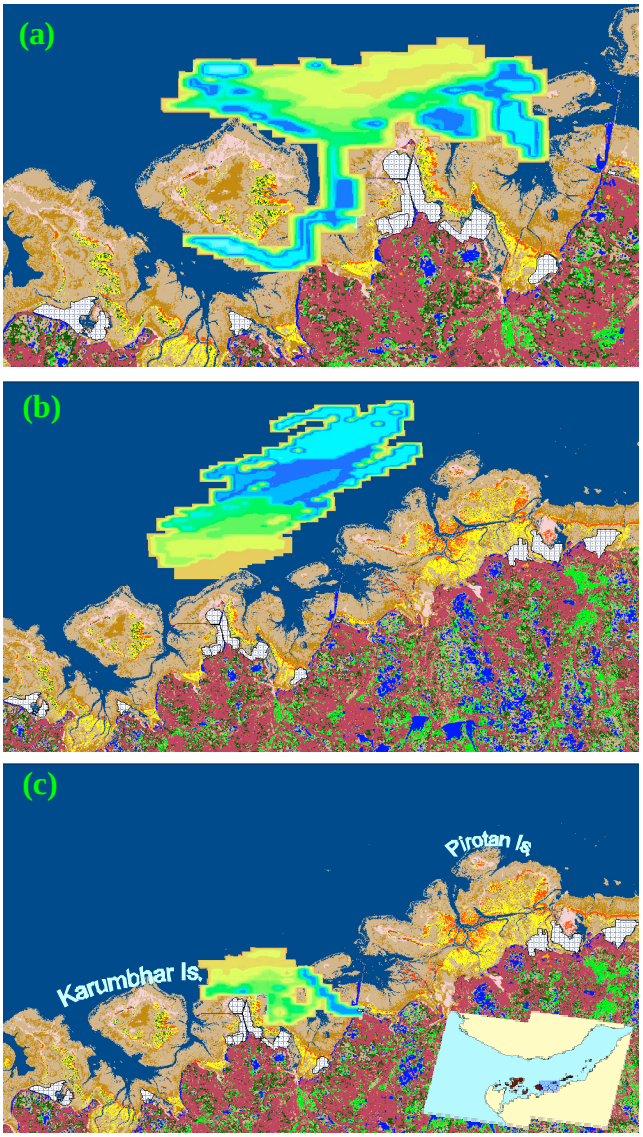


Fig. 30 - Areas affected by oil cover after 48 hrs of spill in 3 wind scenarios (a) No wind, (b) 5 m/s from 240°N and (c) 5 m/s from 330°N

6. Vacant sites for Developmental Activities

The southern coast of Gulf of Kachchh is almost occupied with ecologically sensitive features like mangroves, corals and mudflats – some of which are potential for regeneration of mangroves. The ecology along southern coast is already under severe stress exerted through the major commercial projects already situated, hence the southern coast can not withstand any further stress from the future developments which are under proposal / sanctioning stage. Along northern coast, two lengthy stretches are available without any ecologically sensitive zones that could be utilised as future development zones to a limited extent, the details of which are illustrated in Table 17.

Table 17 - Pockets of vacant areas along the Kachchh coast

S. No	Location		Co-ordinates		Approx. length of the coast (km)
	From	To	From	To	
1	Jakhau	Mandvi	23.10°N; 68.74°E	22.80°N; 69.42°E	78
2	Mundra	Kandla creek	22.82°N; 69.76°E	22.97°N; 70.08°E	38*

* - This zone is occupied with intertidal and high tidal mudflats.

6.1 Jakhau-Mandvi

Along the northern coast, a lengthy coastline of around 78 km between Jakhau and Mandvi is totally devoid of mangroves, corals and even mud flats (Fig. 31). The western tip of this belt is covered with a huge mangrove area of 36.7 km^2 and mudflats of around 36.7 km^2, a major portion of these mudflats are potential for mangrove afforestation. Its eastern tip is close to Mundra with a total mangrove cover of around 40 km^2 and mudflats of 18 km^2. Newly discovered live corals between Mandvi and Mundra are close to this pocket. In the hinterland side more than 75% of the land is barren type between Jakhau and Mandvi, while the zone between Mandvi and Mundra represents relatively rich fallow land and vegetative cover. However, Mundra is having maximum vegetation.

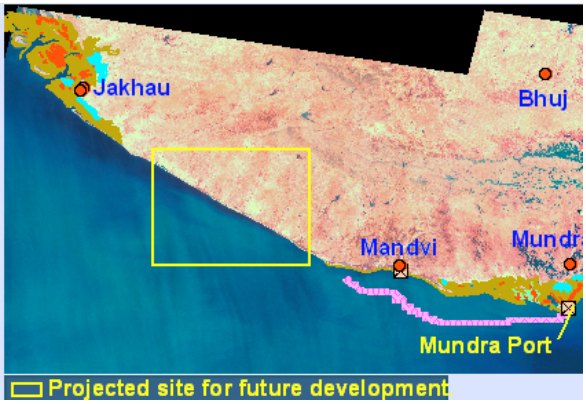


Fig. 31 - Vacant site between Jakhau and Mandovi

The 2D model results of Unnikrishnan et al. (1999) in the Gulf of Kachchh have shown that on average, the residual currents have magnitudes of less than about 5 $cm.s^{-1}$. Two eddies are found in the residual current field in the lower Gulf, between Okha and Mandvi (Fig. 32), where very sharp lateral gradients in depth are found. (i) A clockwise residual eddy is found centered around 22°40′ N and 69°30′ E (central portion of the outer Gulf). In this region, there are abrupt changes in topography, which generate residual eddies. (ii) Similarly, downstream of Mandvi, centered around 22°40′ N, another clockwise eddy is found, which is around a region of a shoal. As residual eddies in the tidal field are generated in the regions of abrupt variations in topography, an eddy center has been formed around Navinar Point (off Mundra) covering nearly the entire width of the Gulf. Due to sharp gradients in the curvature of coastline at Mundra, asymmetries found during ebb and flood cause the formation of this residual eddy. These clock-wise eddies will lead to the sinking of nearby surface waters to deeper layers, the centrifugal action of these eddies is directed towards the southern coast (Fig. 32). So, the pollutants of developmental activities along the northern coast line close to these eddies will certainly be directed towards southern coast and may affect the island ecosystems of this coast. However, more details are needed to understand the effect of these eddies on the coastal circulation of this region.

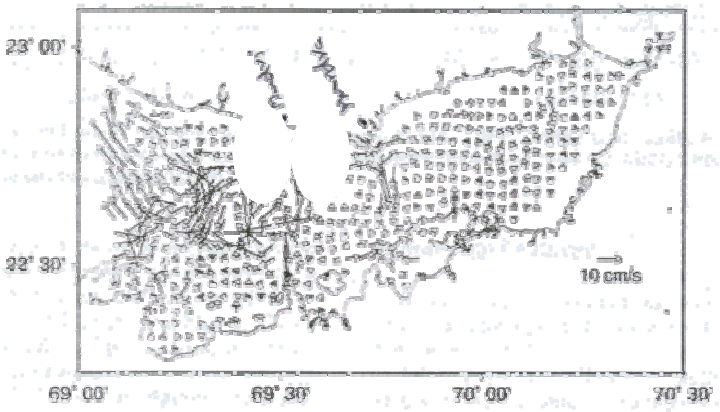


Fig. 32 - Residual currents showing the eddies in the Gulf of Kachchh

On the safer side, it is advisable to use the zone between 10 km after Jakhau with co-ordinates 23.04°N; 68.84°E and 22.84°N; 69.20°E before the sharp curvatures of Mandvi, the coastal length stretching to around 42 km, should only be used for development. This is to protect the mangroves and mudflats in the western end and to avoid the conflicts arising out of eddies off Mandvi and Mundra and also to protect the new live corals. The data on water quality of this zone are not available. However, the data off Mundra during monsoon period shows that these waters are heavily silted (Zingde, 1999) and oxygen values are lower than 5.5 $mg.l^{-1}$. Except suspended solids, all other chemical constituents show well mixed conditions along the water column. The 10 m contour line is close to coast (around 1.5 km) towards western side, which moves away from the coast towards its eastern tip with a maximum distance of 5 km, at Mandvi. Owing to this zone being located right in the

outermost Gulf, the current velocity of >0.5 $m.s^{-1}$ in this belt is expected to be sufficient for better dispersion of pollutants and hence some of the developmental activities like Ports/Jetties, disposal of treated industrial effluents and salt pans can be permitted, to a limited extent.

6.2 Mundra-Kandla creek

Another 38 km long stretch between Mundra and west of Kandla creek is occupied by rich intertidal mudflats (Fig. 33) of area around 115 km^2. The eastern tip is characterised by a scattered mangrove area extending to 4.3 km^2. Recently, Scientists discovered live corals near Mundra, the exact location and details of them are yet to be studied. The 15 km hinterland area is characterised mostly with barren land and to a lesser extent with fallow land. Vegetative cover is very sparse. As mentioned in section 6.1, the waters off Mundra are vertically mixed. Off Kandla also the waters are heavily loaded with suspended solids probably because of carrying of sediment particles from vast mudflat systems of inner Gulf during ebb tide and also due to the spillages of heavy cargo handled by Kandla Port Trust. Very strong tidal currents are the dominating driving force in this zone. Developmental activities like Ports and Salt Pans will convert these productive mud flats to commercial zones. However, the activity like controlled waste disposal may be permitted in this zone. In order to protect the newly found coral beds of Mundra and also to minimise the effect of eddy off Mundra (as discussed in section 6.1), it is suggested that controlled waste disposal activities be located atleast 10 km away from the coral beds. It is also suggested that the entrepreneurs who are permitted for this activity in this zone may be given the responsibility of afforestation of mudflats of this zone and innermost Gulf. This will help in reduction of sedimentation and safeguarding the newly discovered corals.

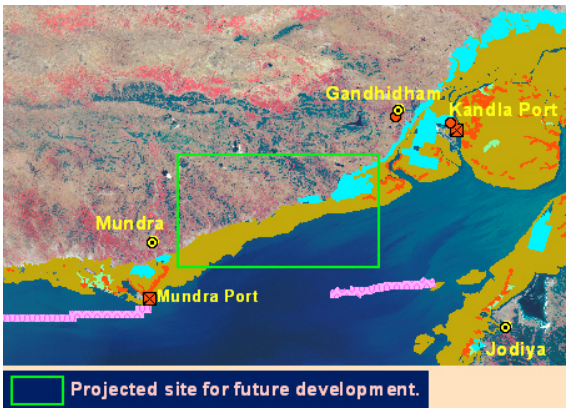


Fig. 33 - Vacant site between Mundra and Kandla creek

7. Management Solutions

- The major problem faced by Gulf ecosystem is the upcoming of several commercial activities in the core zone of the Marine National Park and Sanctuary (MNPS), which threatens their sustenance and conservation. In certain cases uncontrolled and lack of coordinated development of port and fisheries activities

have also led to the loss of biodiversity and degradation of ecosystems. This is a result of lack of clear cut earmarking of the boundaries of MNP and notification of overlapping areas under Port Act for maritime activities. It is suggested that an inter-departmental coordination among the stakeholders headed by Gujarat Government be set up to demarcate the boundaries of MNP and others so as to avoid conflicts in implementation of measures to protect the Gulf environment.

- The newly found coral bed area along northern coast should be brought under MNPS for their protection and conservation.

- The regulation of commercial ventures along the southern coast of the Gulf is required in order to protect/conserve the sensitive ecosystem. However, future proposals can be considered judiciously in the two long pockets of vacant sites (as detailed in Section 6.0) that are available along the northern coast.

- Cattle grazing is one of the main causes for mangrove degradation in the Gulf. Fodder cultivation similar to that being practiced at Bunny area of the Kachchh district may be extended to other suitable hinterlands of the Gulf to augment the fodder requirements thereby mangroves can be protected.

- Formulation of zoning atlas for the Gulf of Kachchh based on hydrodynamic conditions and ecologically sensitive areas.

- A suitable organisation or body consisting of experts from various disciplines be setup to look after various developmental activities that have already taken place and also the proposed activities in the Gulf of Kachchh. The body may be sufficiently empowered for checking the statutory requirements including Environmental Management Plans (EMP) of all these activities and if required, to amend the rules and regulations as and when required, by which the marine environment and its ecosystem could be protected.

8. Conclusion

The GIS based Information System is useful in assessing the status of mangrove, coral, mud flat and other coastal ecosystems. Remote Sensing is a useful suitable tool to identify these spatial features with geographic accuracy. GIS and Remote Sensing could be effectively used for monitoring these ecosystems over the years. This Information System could serve as a baseline database for the decision makers to monitor these areas and to draw up suitable management plans.

The results of modeling studies based on the hydrodynamics, physico-chemical and biological parameters would be useful in understanding the governing factors of the Gulf environment. Using overlay facility of GIS, these models could be presented to decision makers to project the likely threats to enable them to draw proper management solutions and their implementation for the conservation of Gulf ecosystem.

The Information System should be upgraded with suitable information for preparation of zoning atlas, in view of increased developmental activities in the Gulf of Kachchh.

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