

Study of Sediment Transportation in the Gulf of Kachchh  
using 3D Hydro-dynamic Model Simulation  
and Satellite Data

August 2003

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三次元水理モデルの数値実験と人工衛星データを用いた  
コチ湾の堆積物輸送の研究

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## Abstract

A 3D hydrodynamic model 'COSMOS' is applied to the Gulf of Kachchh to predict tidal variation, ocean currents, residual tidal current, sea surface temperature distribution etc. The model is based on the hydrostatic and Boussinesq approximations and uses a vertical double sigma co-ordinate with a step-like grid. In addition to the momentum and continuity equations, the model solves two-transport equations for salinity and temperature and an equation of state to include the baroclinic effects. The other objectives are to quantitatively assess suspended sediments by digitally analyzing SeaWiFS data using SeaDAS software and to monitor suspended sediment movement by image processing of ocean color monitor data and finally establish relations between residual tidal currents and sediment transport.

The Gulf of the Kachcha (GoK) lies approximately between latitudes  $22^{\circ}$  to  $23^{\circ}$  N and between longitudes  $69^{\circ}00'E$  to  $70^{\circ}45'E$ . The GoK presents a complex macro-tidal region. The model is set up for the GoK, and is validated using remotely sensed data. Sea surface temperature, Salinity, river input, meteorological parameters and five components of tide are utilized in COSMOS model. Five boundary conditions, such as land-ocean boundary, air-sea boundary, sea bottom friction boundary, discharge from river boundary and Gulf-open ocean (open) boundary are defined and used. Programs constituting the COSMOS model were executed along with initial input cards to simulate the model using an Alpher mini-computer system at the CEReS, for November and December months of 1999. While modeling, the water column is divided into five layers and at each layer the distribution of current velocity and direction, pressure water temperature, salinity and turbulent energy were computed. Comparing the simulated results with the measured data available for those locations has validated the model.

The model results showed that the dominant current system is controlled by tidal variation. The tidal and residual tidal currents simulated by the model are similar to the results obtained by previous researchers. Surface current distribution slightly changes if wind stress is applied to the model. The subsurface layers and bottom layer display almost similar current distribution patterns. However, current speed reduces from the surface towards the bottom. Residual current velocity distribution displays an anti-cyclonic eddy. Several divergence and convergence areas were located in the center of the GoK. The current velocity decreased from 50 to 20 cm/s and the eddy pattern vanishes under uniform depth, which concludes that bottom topography plays an important role in determining the distribution of residual current velocity. The model results of sea surface temperature showed good agreement with temperature structure and pattern obtained from NOAA/AVHRR Data.

From sediment plume pattern studies using Sea WiFS and OCM images, it was concluded that the sediments are transported to the Gulf from the north as well as the south and are seasonally dependent. The residual current velocity distribution map for Dec-99 matches well with the map showing gross geomorphic subdivisions of the Gulf of Kachchh. Whereas, sediment distribution boundaries roughly match with those boundaries defined by current velocity distribution. A properly validated hydrodynamic model and sediment transport study of the Gulf would be of interest for coastal defense, management and economic purpose.

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## 要旨

インド大陸西岸域におけるコチ湾は、海洋力学的にも地質学的にも大変興味ある内湾である。その理由は、テイグリス・ユフラテス河から流出する莫大な堆積物を含んだ河川水がインド大陸西岸を流れる海流によって選ばれ、湾内に流入されるからである。ここで、コチ湾の堆積物が海流によって流入する結果、湾内でどのように分散されるかを3次元力学モデルによる数値実験と人工衛星観測結果を照合する事によって、その過程を検証した。

3次元流動モデルとして COSMOS を採用し、コチ湾における潮汐変動、海流、残差流、海面温度分布等を推定するモデルにより、水温と塩分の2つの輸送方程式を計算した。もう一つの目的は、堆積物の湾内の輸送過程を解析するために、人工衛星・SeaWiFS 海色データを使用した。最終的に、湾内の潮汐残差流と堆積物の因果関係を明確にすることが出来た。

コチ湾は、緯度 22~23 度、経度 69~70.45 度に位置し、複雑な潮汐が混在する内湾域である。COSMOS の流動モデルを数値計算するにあたり、海面温度、塩分、河川からの流量、気候値的大気物理量と5つの分潮が用いられた。又、陸—海、大気—海洋、海底地形、河川からの流入、及び、外洋の5つの境界層条件が設定された。COSMOS による数値計算は、1999 年、10 月と 12 月のケースを、深度方向に5層に分け各層における流速、流速方向、水温、塩分、乱流エネルギーを計算した。そして、現場の実測値との比較照合し、そのモデルの有用性が示された。

モデル計算の結果を見ると、支配的な流れは潮汐残差流の変動によるものであることが分かり、本研究による潮汐残差流の計算は、以前に行われた研究結果よりも空間分解能と縦直プロファイルにおいて更に精度良い結果が得られた。湾内の潮汐残差流の表層流成分は、海面応力による大きな変動を示したが、中層と底層も、類似したパターンを示した。この結果は、NOAA/AVHRR の表層水温分布とほぼ一致した。また、流速は、当然のことながら、表層から下層に行くに伴い、減少する傾向を示し、最終的にそれらの渦は、ある一定の深さで消滅した。このことは、残差流の流速の分布は、海底地形に対し堆積物の輸送に対し重要な役割をしている事を示している。

衛星データ (SeaWiFS と OCW) より観測した海色センサ資料の解析は、堆積物の輸送分布において、北部から湾内及び南部に流入している事を示し、その変動は季節に依存していることが分かった。1999 年 12 月の残差流速分布は、大まかな湾内の地質分布区分を示した地形図と良く一致している事が分かった。即ち、海底堆積物の分布は、湾内の流速分布より得た結果とほぼ一致していることを示した。

この結果、コチ湾の海洋流動モデルによる数値モデル実験と人工衛星・海色センサの解析による比較照合実験は、より精度の高い堆積物輸送過程を示し、その湾内の堆積物の輸送過程を正確に示す事が分かった。この研究結果は、将来の沿岸保護、沿岸管理等に大いに役立つものと思われる。

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# CONTENTS

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**Title (in English)**

**Title (in Japanese)**

**Abstract (in English)**

**Abstract (in Japanese)**

**Acknowledgements**

**Contents**

**List of Figures**

**List of Tables**

Chapter – 1	Introduction	1
	1.1 Environmental setup	2
	1.2 Previous studies	6
	1.3 Aim and objectives	14
Chapter – 2	Sediment Transport Mechanism	
	2.1 Introduction	17
	2.2 Forces triggering the sediment transport	18
	2.3 Coastal response to natural forces	23
	2.4 Processes of sediment transport	25
	2.5 Sediment transport measurements	32
	2.6 Modeling approach	35
Chapter – 3	Digital Remote Sensing Data Processing	
	3.1 Introduction	39
	3.2 Ocean remote sensing	43
	3.3 Ocean color remote sensing	46
	3.4 Quantitative assessment using SeaWiFS data	51
	3.5 Monitoring sediment patterns from OCM images	57
	3.6 Sea surface temperature extraction from AVHRR/ NOAA	63
	3.7 Extraction of wind data from QuikSCAT	68

Chapter – 4	3D Numerical Hydro-dynamic Model	
4.1	Introduction	71
4.2	"COSMOS" the 3D numerical model	72
4.3	Model description	72
4.4	Basic governing equations	73
4.5	Boundary conditions and specifications of the model	74
4.6	Model calculation conditions	78
4.7	Assumptions and conditions	82
Chapter – 5	Model Results and Validation	
5.1	Introduction	87
5.2	Modeling tidal velocity currents during ebb and flood tide	88
5.3	Modeling surface current velocity distribution	90
5.4	Modeling residual current distribution and validations	92
5.5	Modeling of residual current velocity for constant depth	97
5.6	Tide features and tide mixing effects	98
5.7	Sea surface temperature and salinity distribution	102
5.8	Summary	108
Chapter 6	Sediment Transport and Model Results	
6.1	Introduction	110
6.2	Sediment transport towards Gulf of Kachchh	111
6.3	Quantitative assessment of suspended sediments	114
6.4	Sediment dynamics within Gulf of Kachchh	.115
Chapter 7	Summary & Conclusions	118
	References	

## List of Figures

Figure 1.1	Location map of Gulf of Kachchh showing geomorphic features and bathymetric contours	3
Figure 1.2	Generalized surface sediment distribution (modified after Hashimi et al. 1978).	7
Figure 1.3.	Gross geomorphic subdivisions of the Gulf of Kachchh	9
Figure 1.4	Concept diagram for an operational hydrodynamic model System	16
Figure 2.1	Illustrates the relationship between average particle sizes of sediments and the currents speeds. (Modified after Wright et al. 2003)	26
Figure 2.2	Describing longshore sediment transport (from the web)	28
Figure 3.1	The electromagnetic spectrum	41
Figure 3.2	Suspended sediment plumes in Gulf of Kachchh derived from Sea WiFS data	55
Figure 3.2	Suspended sediment plumes in Gulf of Kachchh derived from Sea WiFS data	56
Figure 3.3	False color composite of 5(B), 6(G), 7(R) bands of Ocean Color Monitor of Gulf of Kachchh (FCC1).	57
Figure 3.4	Principal Component Images generated from Principal Component analysis of OCM data.	58
Figure 3.5	a (FCC2) and b (FCC3).	59
Figure 3.7	Principal Components 1-2-3 bands of OCM are displayed with Red-Green-Blue colors respectively Bathymetry contours are superimposed	62
Figure. 3.8	Sea surface temperature measured by NOAA/AVHRR for 5 days of December-99.	66
Figure 3.9	Sea surface temperature measured by NOAA/AVHRR for 4 days of November-99.	67
Figure 4.1	Profiles of temperature and salinity measured at the estuary of Gulf of Kachchh	76
Figure 4.2	Detailed depth contour map of the Gulf of Kachchh	79
Figure 4.3	Wind speed variations over the Gulf of Kachchh estimated from Quikscat data from Nov. 1999 to Feb. 2000	80
Figure 4.4	Relative humidity and air temperature variation around Gulf of Kachchh	81
Figure 4.5	Cloud fraction over the Gulf of Kachchh in one year (from Da Silva et al. 1994).	82
Figure 5.1	Model result showing high tide condition on 13 <sup>th</sup> Dec, 1999 at 0400 hrs	88
Figure 5.2	Model results showing low tide condition on 12 <sup>th</sup> Dec 99 at 2100 hrs.	89
Figure 5.3	Surface current velocity distribution from 3-D numerical model (after high tide at Okha around open boundary).	90

Figure 5.4	Surface current velocity distribution from 3-D numerical model (before high tide at Okha)	91
Figure 5.5	Tide stream current one and half hour before high at Okha	91
Figure 5.6	Residual current velocity distribution at the surface of the Gulf of Kachchh	92
Figure 5.7	Residual current velocity distribution of the Gulf of Kachchh the middle layer	93
Figure 5.8	Residual current velocity distribution of the Gulf of Kachchh in the bottom layer	94
Figure 5.9	Tide residual current distribution in the Gulf of Kachchh at the surface (Sinha et al. 2000).	94
Figure 5.10	Residual current velocity distribution of the Gulf of Kachchh for December at the surface layer	95
Figure 5.11	Residual current distribution of the Gulf of Kachchh for Dec-99	95
Figure 5.12	Residual currents at different layers from surface to bottom	96
Figure 5.13	Residual current velocity distribution of the Gulf of Kachchh for Dec-99 assuming uniform depth of 30 m	97
Figure 5.14	Tide amplitude of $M_2$ in the Gulf of Kachchh	98
Figure 5.15	Phase distribution of $M_2$ Tide (in degrees)	99
Figure 5.16	Tide amplitude distribution of $K_1$ in cms	99
Figure 5.17	Distribution of phase of Tide $K_1$ in degree	100
Figure 5.18	Distribution of Tide amplitude of $M_2$ in cms	100
Figure 5.19	Distribution of Tide phase of $M_2$ in Gulf of Kachchh	101
Figure 5.20	Distribution of Tidal amplitude of $K_1$ in cm	101
Figure 5.21	Distribution of Tide phase of $K_1$ in degrees	103
Figure 5.22	Sea surface temperature measured by NOAA/AVHRR for Dec-99	103
Figure 5.23	Sea surface temperature in the first layer of the Gulf of Kachchh derived using COSMOS model	104
Figure 5.24	Sea surface temperature derived using COSMOS model for 5 different layers respectively for Dec-99	105
Figure 5.25	Sea surface temperature in the first layer of the Gulf of Kachchh derived using COSMOS model for Nov-99	106
Figure 5.26	Sea surface temperature distribution measured by NOAA/AVHRR for Nov-99	107
Figure 6.1	Inferred sediment transport direction (after Nair et al., 1982)	111

### **List of Tables**

Table 2.1	Natural and man-induced causes of erosion	27
Table 2.2	Indicators of shore drift direction	35
Table 3.1	Remotely detectable oceanographic parameters and sensors	44
Table 3.2	The specifications of sensor on-board historic, current and scheduled satellites used in ocean color remote sensing	47
Table 3.3	Various Ocean color sensors and their specific properties	50
Table 3.4	A listing of AVHRR wavelength channels	64
Table 4.1	Important tidal constituents at Port Okha	77
Table 4.2	Tide components data used in this research	78
Table 4.3	River input to the Gulf of Kachchh in m <sup>3</sup> /s	79
Table 4.4	Mean wind velocities over the Gulf of Kachchh from Quikscat	80
Table 4.5	Simulation conditions used in Gulf of Kachchh	83
Table 4.6	Output parameters retrieved after running the model	83
Table 4.7	Simulation control parameters	84
Table 4.8	Constants used in model	84
Table 6.1	Drift direction indicators and thumb rules.	112



## Chapter 1 – Introduction

# Chapter 1

## Introduction

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Human population and activities in the world are generally concentrated near the coast. Over sixty percent of the human population lies in the coastal zone and about two third of worlds large cities are located along the coast. The pattern of runoff and the delivery of nutrients and sediments to coastal waters are modified through human activities in catchments. Coastal development leads to modification of foreshore, loss of key habitats such as mangroves and sea grasses, changes to flushing rate, resuspension of sediments, and direct inputs of nutrients and toxicants through outfall. Coastal waters are also a major resource for human life as they contribute ninety percent of world fish catch. Human recreational activities and tourism are concentrated in coastal waters. As a result of this collision of impacts and uses, managing coastal zone is a high priority for all coastal nations.

The interaction of multidimensional and strongly interdependent processes or entities in the coastal environment makes it necessary to consider the coast as a system, to be examined as a whole by quantitatively analyzing and describing actions and relationships between its parts. Coast has to be viewed as a complex, dynamic large-scale system with an integrated arrangement of separate component systems, which vary in morphological form, pattern and configuration and cannot be fully comprehended with conventional time-limited studies. Since this complex systems involve interrelationships between and among many variables and parameters that the best way to gain insight into their structure, organization and functioning is through the use of numerical models.

Numerical models are considered as imitations or approximations of proto types. Models are not reality, and no model, however complex can be more than a representation of reality. While the models are only abstractions or simplifications of a system, they are valuable for simplification, reduction, experimentation, explanation, prediction and communication and they are also useful for providing insights for the generation of hypotheses. Numerical model allows complex equations to be solve with computational ease and since problems can be both linear and nonlinear, numerical modeling can be successfully used to study various aspects of the coastal system. A Gulf is one such important component of the coastal system and the Gulf of Kachchh is ideal site for such study.

### **1.1 Environmental setup**

The 170 km long and 75 km wide (at the mouth) Gulf of Kachchh (GoK) lies approximately between latitudes  $22^{\circ}$  to  $23^{\circ}$  N and between longitudes  $69^{\circ}00'E$  to  $70^{\circ}45' E$ . It is a  $7300 \text{ km}^2$  east west oriented indentation in the coastline of India at the western extremity (the inner gulf is, however, oriented NE-SW). The GoK is situated to the north of the Saurashtra peninsula, in Gujarat state. Bordering the Gulf at its head is the Rann of Kachchh, a desiccated region. The GoK presents a complex set up of a macro-tidal region, marked by existence of shoals, channels, inlets, creeks and islands (Figure 1.1).

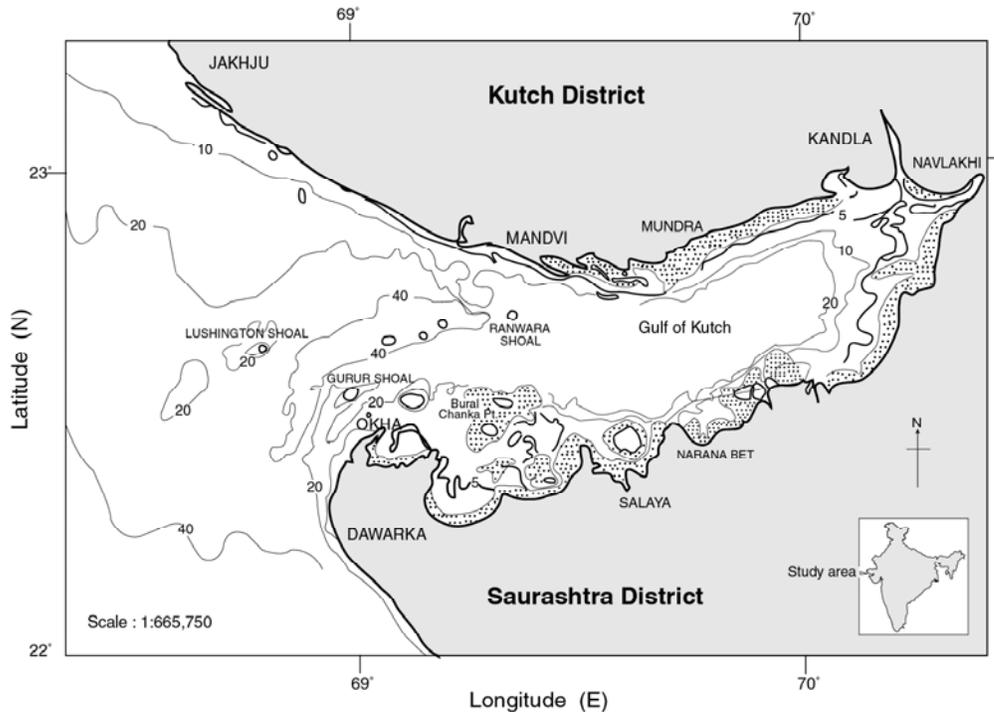


Figure 1.1 Location map of Gulf of Kachchh showing geomorphic features and bathymetric contours.

Continuous data of sea surface temperature (SST) and air temperature observed at a few stations shows that during morning hours the sea surface is warmer than the air, and as the day progresses the air becomes warmer than the sea surface. On a few occasions, the difference between the air and sea surface temperature is found to be as high as 10<sup>0</sup>C. Though available information indicates that the water temperature in GoK may generally vary between 20 and 30<sup>0</sup> C, local increase up to 35<sup>0</sup> C can occur in inshore water pools formed in the intertidal zone during ebb tide. In general, temperature profiles reveal a nearly homogeneous water column in the GoK.

The large variation of air and water temperature and scanty rainfall, makes the GoK a high saline water body. In general, the maximum salinity ranges from 36.6 psu (at mouth) to 45.5 psu (at the head of GoK). There is no much salinity variation between the surface and bottom layers, confirming

that the waters are well mixed. Also salinity does not show any marked variation with the progress of winter to summer season. The reason for high saline waters in the GoK is low river runoff in the gulf and high evaporation rate of the order of 1m/y due to large variation in SST and air temperature. This feature along with tidal stages influences the diurnal variation of salinity. Salinity as high as 50 psu occurs in numerous creeks of the little Gulf of Kachchh during dry season and salinities of the order of 8 to 20 psu are encountered in some creeks due to fresh water flow from the brief spell of monsoon.

The GoK is under pronounced tidal influence. Tides in the GoK are mixed type and predominantly semi-diurnal with a large diurnal inequality. The time taken for a tidal wave to travel from the mouth to the head is approximately 3 to 3.5 hr (phase lag). Bathymetry, funnel shape of GoK, coastal configuration and orientation of the coast are probable reasons for the geometric effect contributing amplification of tide. Therefore, the tidal front enters to the Gulf from the west and due to shallow inner regions and narrowing cross-section, the tidal amplitude increases considerably upstream of Vadinar. Thus for instance, the mean high water spring tide of 3.47 m at Okha increases to 5.38 m at Sikka and further to 7.21 m at Navlakhi, at the head the of Gulf. The gulf has an average tidal range of 4 m. The Tidal result shows that ebb to flood takes slightly longer duration (6.25 hr) compared to flood to ebb, which is 6.0 hrs. It is seen that as celerity increases with depth, mid-gulf tides progress faster than the tides near the shore.

The wind pattern in the area is mainly seasonal with rare cyclonic disturbances. Predominant wind directions in the area are west southwesterly and north northeasterly during June to September and December to March respectively. Higher wind speeds are likely to occur during June to September with winds up to 74 km/hr from west and southwest (Srivastava and John 1977). It is noted that surface currents are driven mainly by tides,

except during a short spell (July-August), when surface currents are influenced by the monsoon winds. Study also show that surface and bottom currents are nearly the same, except at few places. Surface currents vary from 1.5 to 2.5 knots at the mouth to 3 to 5 knots in the central portions of the gulf (NHO chart 203). Presence of the numerous shoals gives rise to closed as well as open circulation cells. The currents are purely induced by tides with complete reversal over a tidal cycle. It is also noted that the reversal of flood to ebb is sharp and fast while ebb to flood is smooth and slower.

The 352 kms of Kachchh coastline chiefly have raised mudflats and raised beaches deposited during the high Holocene strandline and the present-day coastal deposits. On the basis of different morphological features, nature of sediments and depositional history, the coastal Holocene shoreline can be classified in to three well-defined segments:

1. The outer segment from Koteshwar in the north to Suthri in the south – Chiefly made up of extensive tidal mud flats and a series of offshore sandbars.
2. The middle portion of the coast between Suthri and Bhujpur overlooking partly the Arabian sea and partly the GoK – dominantly made up of sandy beaches with the coastal dune ridges and a rocky platform
3. The innermost segment extending from Bhujpur to Cherai in the east falls within the Gulf, and is marked by a featureless vast terrain, most of which comprises either tidal mud deposit or saline wasteland merging further east into the little Rann.

The E-W trending coast that lies inside the GoK is sandy and silty with narrow beaches; it merges into the little Rann to the east. The northern coast of Saurashtra trending E-W overlooks the Gulf and shows a crenulated rocky

shoreline with the sub tidal zone consisting of channels, shoals, submerged islands, sandbars, coral reefs and mangroves.

## **1.2 Previous studies**

The floor of GoK is highly irregular. The depth of GoK varies from a maximum of about 60 m at the mouth to less than chart datum at the head of the Gulf. Though water depths of 25 m exist in the broad central portion up to latitude of 70° E, the actual freeway is obstructed by the presence of several shoals. At the mouth of the gulf, Lushington shoal with depths nearly 5 m below chart datum is present. On the southeast side of Lushington, a channel with the depth of water varying between 30 and 50 m is present (Figure 1.1). Besides Lushington, there are other shoals in the area namely Gurur, Bobby, Ranwara etc. The presence of Chanka reef and Ranwara shoal narrows down the Gulf. The little Gulf of Kachchh is a vast marsh criss-crossed by innumerable big and small tidal creeks. The coastal configuration of the Gulf is very irregular with a number of islands, creeks, bays, marshes, reefs etc. (Navigation Chart No. 203).

The topography is very irregular at the mouth and the central part of the gulf and consists of pinnacles and scarps ranging in height from 6 to 32 m (Nair et al. 1982). Towards the head, the relief is subdued due to the covering of fine-grained sediments. A large area of the floor of the mouth of the gulf, at the depths greater than 20 m is covered with algal limestone, aragonite cemented sandstones and dead corals (Figure 1.2). On the low-energy margin of the gulf, especially on the southern side, wide tidal flats with patches of coral in the intertidal zone are present. The remainder of the gulf is floored by silt and clay with patches of fine sand (Hashimi et al. 1978).

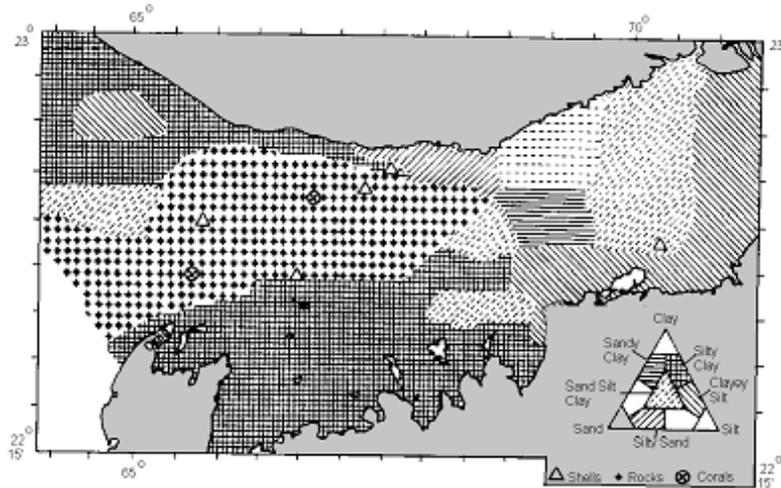


Figure 1.2 Generalized surface sediment distribution (modified after Hashimi et al. 1978).

The floor comprises of numerous topographic irregularities, like pinnacles, as much as 10 m high, separated by flat-topped features. The topography of the mouth and at the middle of the gulf is relatively more rugged as compared to the head of the gulf. The southern shore is marked by low-level coastal plain with indentations, deep inlets, a number of offshore islands and several river mouths having inlets covered with brushwood and surrounded by the coral reef. The northern shore consisting mainly of sand and mud is inforted by numerous shoals.

The most conspicuous sedimentary formations are predominantly marine, tidal, littoral, or sub-littoral fluvial and aeolian deposits of quaternary age, border the study area. Geological formations from middle Jurassic to Holocene over a crystalline basement are reported from the study area (Biswas, 1971). The Gulf is bounded on the south by Deccan traps, which are found in the Saurashtra Peninsula. On the northern side in the interior of Kachchh area a complete series starting from Jurassic to Pleistocene is found. The Jurassic rocks occupy a large area and are bordered successively by Deccan Traps and Tertiary rocks which extend to the coast and have dips towards the south and southwest.

The region surrounding the Gulf was subjected to earthquakes. The great earthquake of Sind in 1819 is reported to have raised the central area of the northern border of the Rann of Kachchh by several feet. An east-west fault along the northern border of the Rann of Kachchh is reported and it is thought to be of lower or middle Pleistocene age (Hashimi et al. 1978).

The sediments distribution map (Figure 1.2) is based on samples collected from the area and shallow seismic data show presence of coarse sand with shells around the mid-shoal surficial sediments in the major portion of the kandla creek comprise of gravelly, shelly sand and pieces of rock. The sediments are poor to extremely poor sorted, the skewness is highly variable and there is no relation to either the texture or mean size of the sediment.

The mouth of GoK, however is marked by extensive occurrences of calcareous sandstone rocks, algal limestone, aragonite cemented sandstone and dead corals. Apparently the high tidal ranges in the gulf generate powerful currents that are not conducive to sediment deposition. On the low energy margin of the gulf, especially on the southern side, wide tidal flats with patches of coral in the inter-tidal zones are present. The remainder of gulf consists of silt and clay with patches of fine sand. The beaches consist of dominantly terrigenous sands and contain an appreciable amount abraded and unabraded mollusk shell fragments, foraminifers, ostracods, algae, corals etc.

The floor of the gulf can be divided into 3 distinct morphologic units: even, uneven, and rough (Figure 1.3). The area covering the eastern margin of the Gulf extending from the north of Sikka Creek to the head of the Gulf and the northern margins are marked by even topography.

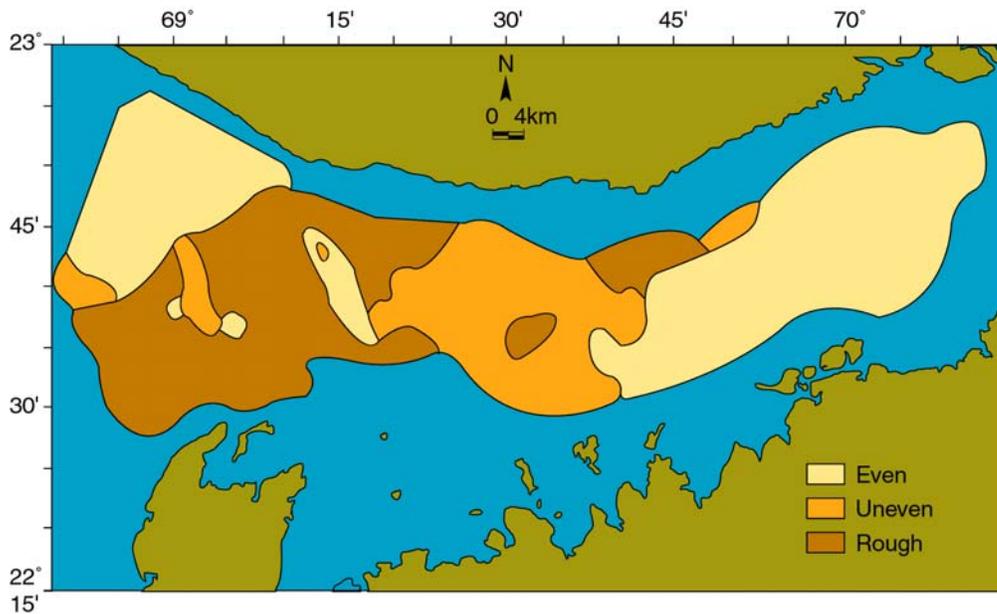


Figure 1.3 Gross geomorphic subdivisions of the Gulf of Kachchh

The region of even topography is flat, gentle and smooth. The flatness of the surface is principally attributed to the land derived sediments masking the underlying topography. In case of the region of uneven topography, variations range approximately from 2 to 5 m. and in the region of rough topography variations ranges up to 25 to 30 m. The seabed in the area of rough topography consists of sharp pinnacles, ridges, valleys etc. The region of rough topography extends from the southern side of the entrance to the Gulf to a distance of about 50 km. In the central part of the Gulf the topography is uneven with a small patch of rough surface. The distribution of uneven and rough topography mainly coincides with the area where rock is exposed on the seabed that extends to a distance of about 75 km in the central part of the Gulf.

The Gulf abound in marine wealth with its diversified flora and fauna which include living corals, thriving as patches, rather than reefs, either on the intertidal sand stones or on the surface of the wave-cut eroded shallow banks and variety of mangroves, is considered to be one of the biologically richest marine habitats along the west coast of India. The high biodiversity is

due to the availability of different habitats like sandy, muddy, rocky, calcareous and coral beds in relatively sheltered waters. Because of this natural bio richness several stretches between Okha and Jodia including coral reefs and mangrove habitats covering an area of 16289 ha as Marine National Park and 45798 ha has been declared as Marine sanctuary. The core area of Marine National Park is centred around the Pirotan Island. The marine flora of GoK is highly varied and includes sand dune vegetation, mangroves, sea grasses, macrophytes and phytoplankton.

Until early nineties, the development along GoK was limited to salt works and isolated industrial pockets apart from major port related activities at Okha, Navlakhi and Kandla. However, decision to set-up two large grass-root refineries at Sikka and Vadinar as well as proposal to establish ports and new industries, is expected to accelerate all round development along the shore of GoK. Along the southern shore, the major industries like soda-ash industries at Mithapur, oil terminal at Vadinar and a thermal power plant and cement factory at Sikka, are established. The availability of relatively deep waters near southern shore and relative protection of monsoon waves has made the GoK attractive for the import of crude oil through Very Large Crude Carriers (VLCCs) and unloading the cargo via Single Point Mooring (SPM) systems to shore based tank farms. Two such SPM are already there and three more are proposed. Kandla port handles traffic of about  $3.8 \times 10^7$  t/year of Petroleum Oil and Lubricants (POL) and industrial chemicals. Another major port is partially operational is at Mundra and two more are proposed at Bedi and Poshitra. A few more captive jetties are also proposed or some completed. At present, the traffic of tanker ships carrying POL and other bulk chemicals, which is estimated around 1000 ships per year and is expected to be more than double when proposed ports and jetties are completed. This multifold increase in traffic of crude oil and POL enhances the risk of oil spills due to tanker accidents, hose ruptures, sub-sea pipeline leakages, and operational discharges etc.

If these ports and other industries development are not planned, executed and managed in an environmentally conscious manner, the rich ecology of the Gulf which needs to be protected, may come under anthropogenic stresses. Hence, a comprehensive marine environment protection strategy encompassing the GoK is required to be evolved with a holistic approach. Periodic marine environmental monitoring is a key component of any marine environmental management strategy. Successful implementation of such a monitoring programme requires that the baseline status be established and model development which will enable taking remedial measures.

Srivastava and John (1977) studied current regime in the GoK. From measured current data they concluded that the major steady currents exist in the area of tidal origin. However, during southwest monsoon period, strong westerly winds would generate wind driven currents; with surface speeds reaching about 0.5 m/sec. They also reported that density currents in the GoK are negligible. Though, vertical distribution of temperature and salinity in the GoK shows nearly homogeneous condition in the water column, Varkey et al. (1977) based on the analysis of their data collected, showed that some micro-fluctuations do occur within vertical distribution of temperature and salinity. Hashimi et al. (1978) collected and analyzed several samples from GoK and reported sediment characteristics, coarse fraction composition, texture, grain size variation and presented generalized surface sedimentation distribution. They inferred sources within the Gulf and from the River Indus. Based on the analyses of echo-sounding results Wagle (1979) demarcated prominent geomorphic features and classified rugged underwater GoK surface in three units – even, uneven and rough. Nair et al. (1982) recorded that difference in the bathymetry, bottom topography and the abundance of mica and clay minerals on the continental shelf north and south of GoK, a micro tidal bay, indicated presence of two sedimentary environments. After

considering the tide variation in the Gulf, the Central Electricity Authority of India (1985) investigated the possibility for tidal power development in the GoK.

Space observations provide synoptic and repetitive coverage of the ocean in contrast to the sparse and isolated in-situ ship observations. Certain measurements specific to the orbital platforms such as sea surface height have been possible only through satellite oceanography. Despite the fact that measurements provided by sensors pertain to the sea surface only, they do manifest the oceanic processes beneath. To monitor key relevant ocean parameters, a wide range of satellite systems and sensors are and will become available during coming decade. Microwave sensors acquire data independent of sunlight and clouds, and are used to monitor wind, waves, ocean currents, oil spills, and sea-ice. Visible and infrared (IR) sensors (e.g., NOAA/AVHRR (Advanced Very High-Resolution Radiometer), ERS-ATSR (Along Track Scanning Radiometer), IRS-P3-MOS, SeaWiFS) monitor sea-surface temperature (SST), fronts, currents, eddies, and ocean colour. Small-scale features such as oil slicks, near-shore circulation, and wave fields, can, under favourable meteorological conditions (normally wind speed must be in the range of  $3-11 \text{ m s}^{-1}$ ), be monitored with high-resolution polar orbiting radar sensors.

Singh et al. (2001), based on digital analysis of IRS P4 OCM data, collected information prior to and after the Gujarat earthquake of magnitude 7.8 which occurred on 26 January 2001, have reported significant increase in suspended sediment concentration and chlorophyll distribution. Using image-processing techniques, Kunte et al. (2002b) processed Ocean Color Monitor (OCM) data gathered onboard Indian Remote Sensing Satellite, and mapped coastal and underwater features along with suspended sediment plumes. Their study indicated that the sediments are transported to the GoK from north as well as from south and are mainly season dependant. They also

demonstrated that OCM data could also be derived from up to 20 m water depth (Kunte et al., 2003).

Numerical modeling studies in the Gulf of Kachchh have been carried out only in recent years. Shetye (1999) studied the amplification of tide in the GoK based on analytical and numerical model of linear, viscous and cross-section averaged equations for tidal motion and found that the semi-diurnal constituents  $M_2$  and  $S_2$  get amplified approximately threefold due to a combination of quarter wavelength resonance, geometric effect and sea bottom friction. Unnikrishnan et al. (1999) used 2D barotropic model to study tidal regime in the GoK and found that computed  $M_2$  residual currents show the presence of topographically generated eddies. Their analysis of momentum balance shows a balance between the pressure gradient and friction near the coast. While in the central region, the local acceleration attempts balancing the pressure gradient. He also observed rapid increase in constituent  $M_2$  and suggested a resonance at semidiurnal period. Sinha et al. (2000) proposed a vertically integrated model to study tide circulation and currents with tide forcing along the open boundary of the model domain for the construction of the proposed tidal barrage, and found the importance of the bathymetry of the Gulf in simulating the current field.

In the GoK, past numerical modeling investigations have been mostly carried out using measured and observed hydrographic data using two-dimensional models. Only main tidal components and bathymetry were mainly used as inputs. Remote sensing data was neither used as model input nor for validation of results. However, Zao, Kunte and et al. (2003) used a 3D numerical model to study tide variation, ocean currents, residual currents and sea surface temperature distribution and to understand ecosystem and sediment/pollutant transportation in high tide dominated GoK. The model performed well in simulating dynamical parameters and provided various results that are comparable with other earlier studies. Additionally they could

extract features from subsurface layers as well. They used wind speed and direction derived from satellite observation as input to the model along with air-sea heat flux and five components of tide. They validated model results with sea surface temperature derived from satellite observations.

### **1.3 Aim and objectives**

The objectives of the present study are:

1. To detect and monitor the movements of dispersed suspended sediment pattern within GoK by image processing of ocean color monitor data.
2. To quantitatively assess suspended sediments of study area by digitally analyzing SeaWiFS data using SeaDAS software.
3. To use 3-dimensional numerical hydrodynamic model, to study tidal variation, ocean currents, residual tidal currents, sea surface temperature distribution etc. within Gulf of Kachchh region.
  - To retrieve sea surface temperature data from AVHRR/ NOAA for validation,
  - To extract wind components from satellite observation for using as input to the model.
4. To establish relation between residual tidal current with erosion, movement and deposition of sediments in the GoK.

Figure 1.4 shows a concept diagram of COSMOS hydrodynamic model system, summarizing various inputs and outputs and the links between the various parts. The core is a hydrodynamic model linked to various input parameters like wind stress, SST, salinity, sea level and river input, and

output systems. The model is validated by in-situ data as well as data obtained from AVHRR/NOAA data. All possible links and feedbacks between these component models are shown here. The results from the model are applied to sediment transport studies within the Gulf of Kachchh.

The present study is organized in seven chapters. The first chapter includes, general introduction, description of the study area, review of earlier studies, and objective of the study. The second chapter covers various agents that trigger sediment transportation, ways and means and quantification of sediment transport. The third chapter is devoted to digital remote sensing data processing that includes ocean color remote sensing, qualitative and quantitative measurements of suspended sediments and extraction of SST and wind data. Fourth chapter describes COSMOS model, governing dynamical equations, boundary condition, data requirement, assumptions and calculation conditions. Fifth chapter describes model results and validation. Sixth chapter details sediment transport studies conducted, and its comparison with model results. Seventh chapter summarizes and concludes the entire study. It is followed by references and acknowledgements.

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Figure 1.4. Concept diagram for an operational hydrodynamic model system.

