

# Chlorophyll and Sediment Distribution Study of the Gulf of Kutch using Remote Sensing

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## ABSTRACT

This study is largely based on the resulting series of SeaWiFS images and OCM images of Gulf of Kutch, which shows chlorophyll distribution on about 160 (cloud-free) dates between October 1998 and August 2001 period and sediment distribution pattern during January 2000 respectively. Full resolution (1km) SeaWiFS data covering the Gulf of Kutch are processed using the NASA Seadas software to produce geometrically corrected images. Standard algorithms from Seadas were used to extract chlorophyll concentration. It is obvious that Gulf water, being typical Case-2 water, contains chlorophyll and sediment in distribution plume patterns. To study sediment distribution pattern, instead of SeaWiFS data, principal component images, generated from Ocean Color Monitor (OCM) data collected on-board Indian Remote Sensing Satellite were utilized. High distribution variability in time and space has been observed in high tide dominated Gulf waters. Monthly composites of SeaWiFS data indicated maximum concentration of chlorophyll during winter months and along periphery of the Gulf. By studying turbidity distribution patterns and sediment transport indicators from OCM images, sediment distribution and dispersion have been studied. The study deciphers that the sediments are transported to the Gulf from north as well as from south and are mainly season dependent.

**Keywords :** chlorophyll distribution, sediment transportation, Gulf of Kutch, remote sensing

## INTRODUCTION

The importance of satellite images of offshore watercolor pattern for showing the spatial and temporal variability of primary productivity is now widely recognized. Standard procedures and algorithms are widely made available to measure Chlorophyll and primary productivity and their frequency and distribution accurately. However, same procedures and algorithms produce doubtful results while applied to coastal waters in general and Gulf waters in particular. The Gulf waters being case 2 waters, contains chlorophyll as well as suspended sediment plume patterns together. High tidal currents prevailing in gulf complicates separation of chlorophyll and sediments further.

The orbital remote sensing with its capability to produce synoptic comprehensive images repetitively, has been used to detect dynamic changes and related phenomena that often cannot be observed from low altitude or in-situ studies. This article documents an attempt, made to understand frequency and distribution of Chlorophyll using SeaWiFS data and to address sedimentation process by detecting and monitoring movements of dispersed suspended

sediments pattern within Gulf of Kutch using OCM data.

## The Gulf of Kutch

The 170 km long Gulf of Kutch (GoK) lies approximately between latitudes 22° to 23° N and between longitudes 68° to 70° 30' E. It is a 7300 km<sup>2</sup> east west oriented indentation north of the Saurashtra peninsula. The GoK presents a complex set up of a macro-tidal region, marked by existence of shoals, channels, inlets, creeks and islands (Figure 1). The floor of GoK is highly irregular. Depth ranges from a maximum of about 60 m at the mouth to less than 20 m at the head of the Gulf. The climate is semi-arid and the maximum rainfall is of the order of 50 cm/yr. It has therefore little run-off from land and no major river flows into it. Located about 100 km northwest of the Gulf is the mouth of the river Indus (Figure 2), which discharges an annual suspended load of 435 million tons and has a delta about 8500 km<sup>2</sup> in area which is prograding the shelf (Nair et al. 1982).

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). The gulf has an average tidal range of 4 m. It varies from 3.06m at Okha at the mouth to 5.89 m at Kandla at its head, and has a spring tide range of 6.2 m at its head. 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). Because of the high tidal range, low runoff from land and the irregular topography, the waters of the Gulf are homogenous in term of salinity and temperature (Varkey et al. 1977).

At the mouth of the gulf, Lushington shoal, and to the southeast side of it is a channel with the depth varying between 30 and 50 m (Figure 1). There are three more shoals in the area namely Gurur, Bobby, Ranwara. The presence of Chanka reef and Ranwara shoal narrows down the mouth of Gulf (Navigation Chart No. 203).

#### MATERIALS AND METHOD

The SeaWiFS data for about 661 dates between October 1998 and August 2001 period, pertaining to the West Coast of India were browsed using available browsing facility at GSFC data center. Only 160 cloud-free or partially clouded images were selected for downloading. Full resolution (1km) SeaWiFS data for 160 cloud-free images were processed using Sun Solaris System and SEADAS algorithm. Coefficient for OC4 (Maximum band ration, 4<sup>th</sup> order polynomial) is defined as follows:

$$\text{Chl } a \text{ (ug/l)} = 10.0.(a(0)+a(1)*R + a(2)*R^2 + a(3)*R^3 + a(4)*R^4)$$

Where

$$R = \text{MAX}(\text{MAX}(\text{Rrs443}, \text{Rrs490}), \text{Rrs510}) / \text{Rrs555}$$

$$a = \{0.366, -3.067, 1.930, 0.649, -1.532\}$$

Using above standard algorithm of OC4, Seadas software produces derived products like chlorophyll concentration. As chlorophyll concentration was sparse on individual dates, monthly composites were made. Seadas software provides 24 flags. These flag provide much of diagnostic information useful in interpreting the images. As on-date Seadas is not providing any standard procedure or algorithm for separating suspended sediments in case 2 waters, Ocean Color Monitor image processing techniques were utilized for sediment distribution study.

The Ocean Color Monitor (OCM) is a solid-state camera, onboard Indian Remote Sensing Satellite (IRS P4). It provides resolution of 360 m in 8 VNIR bands covering a swath of about 1500 km, every alternate day. OCM data (Path 9, Row 13, dated 2<sup>nd</sup> Jan 2000, and time 07:23:43, during mean tide) were digitally processed using an image processing system. Principal component analysis was performed, as described in Kunte (1988) and false color composites was generated from principal components (PCs) 2, 3

& 4 (RGB) (plate 1) and was used for interpretation. Attention was paid towards mapping of sediment plumes to understand the distribution and dispersion of suspended and settled sediments (plate 1). Topographic maps (41 F & J) and navigation charts (NHC-203) were used as maps reference. Geomorph units, distribution and directions of suspended sediments, and current directions are marked on the OCM PC image (Plate 1).

#### RESULTS AND DISCUSSION

Plate 2. shows monthly composite images for chlorophyll distribution. The Scale at the bottom shows chlorophyll values corresponding to each color. Land is masked (to dark blue) from database included in Seadas and cloud is masked to black using a SeaWiFS radiance threshold. From set of composite images of chlorophyll, it is observed that

1. Maximum amount of chlorophyll distribution is observed in Composite made from 14 Scenes of December month.
2. Comparatively less in months – January, November, February, March, April, May and least in October.
3. Inter-annual variability is more or less maintained.
4. In all monthly composites, constant range is maintained between 0-60 for comparison.
5. In all monthly composites northeastern part does not show chlorophyll probably because mudflats cover that part.
6. In all other monthly composites except December, Northwestern part does not show chlorophyll probably due to presence of sand shawls and suspended sediments.
7. Due to presence of heavy clouds, scenes from Monsoon months June, July, August and September do not show Chlorophyll.
8. Off Kutch Gulf, maximum chlorophyll distribution is located in November and January scenes.
9. In all scenes, more chlorophyll concentration is observed near coast than in middle.
10. Except in November and January scenes, variation in chlorophyll is distribution is limited and algal booms are almost absent.

Although the absolute radiance values are in error, SeaWiFS provided useful data on relative patterns and is especially valuable for detecting and showing the spectral properties.

On the satellite images, the sharp contrast between various sediment-laden waters is clear and mapable. Tonal/color variation is considered as a measure of sediment concentration. Texture and pattern help in monitoring distribution and dispersion of sediment masses. On the satellite images, the sediment-laden plumes indicate the current directions as they become elongated and pointed towards flow. Using these

basic principles, all enhanced satellite images were visually analyzed and the geomorphic features within gulf and shore were finally marked on PC-FCC image (Plate 1.) by assigning letters and direction arrows.

Suspended sediments (in buff color denoted by Ss) are seen in dispersed pattern or as sediment plumes. Along the southeastern side of the southern shore, sediment plumes are seen approaching northwards. Further northwards, majority of the plumes are entering the Gulf near Okla. From the northwestern side, dispersed sediment plumes, pointing southeastward are entering the Gulf. The direction of sediment movement is inferred as plumes elongate and point in the direction of movement. Due to presence of shoals the suspended sediments are dispersed in the central part of Gulf. Deep water is indicated by deep blue color located to the southwestern side and in the central and eastern part of gulf. The area marked by a red square shows progressive gradation from light pink-buff-yellowish blue-blue indicating variation in sediment contained. Depending on the direction of elongation of submerged shoals and sediment plumes, the direction of tidal currents is inferred. At the locations denoted by 'Cs' clockwise, anticlockwise or curly movements of sediment indicate the eddy currents. An anti-clockwise eddy structure is located at 'E'.

Based on the above observations, it is inferred that large volumes of suspended sediment (highly turbid waters) are entering the Gulf from the northwestern side. From the south, low turbid water masses travel northwards along the southeastern coast and finally move towards the northeast and east before entering the Gulf. The sediments remain in suspension due to the presence of several islands, pinnacles and turbulent tidal currents. The diffused textural and tonal patterns of turbid water indicate that these sediments consist mostly of clay particles, which remain in suspension for a long before finally settle as mud flats towards the head of the Gulf. The eastward movement of the sediment has also been confirmed by eastward growing spits (an indicator of sediment transport) situated along northern coast. Equally strong ebb tides, which may be drawing suspended sediments out of the Gulf, are not visible on the image due to time of data collection.

The above observations support the earlier study (Nair et al. 1982) in which the inferred sediment transport directions in the region were marked as shown schematically in figure 2. As in this study, the bulk of Indus river-borne sediment is probably funneled by the canyon head to the depths of the Arabian Sea, giving rise to the Indus cone. Lesser amounts of sediment are deposited as delta and some of it is carried along in a southeasterly direction into the GoK. Within the Gulf, the sediments are in transit under the action of the high-velocity tidal currents. The ebb-tide jet transports sediments out of the Gulf and to the slope depth (>200 m). However, as

revealed from the present study, the sediment contribution from the southern side that is clearly shown by northward moving sediment plumes and shoals remained unnoticed. Also present the study could not detect the presence of any ebb-tide jet. The above difference can probably be explained on the basis of seasonally changing wind patterns. The coastal currents have been reported to be northward during the northeastern monsoon months (December to March), whereas reversal in direction is observed during the southwest monsoon season (June to September). And hence, for the present study, OCM data that have been collected during January 2000 is showing sediment contributions from south as well as from north. Whereas, the earlier study (Nair et al. 1982) carried out during the SW monsoon season, has demonstrated a sediment contribution from the north alone.

## CONCLUSIONS

From the above study, it is concluded that,

1. High distribution variability in time and space has been observed in high tide dominated Gulf waters.
2. Monthly composites of SeaWiFS data indicated maximum concentration of chlorophyll during winter months and along periphery of the Gulf.
3. By studying turbidity distribution patterns and sediment transport indicators from OCM images, sediment distribution and dispersion can be studied.
4. The study deciphers that the sediments are transported to the Gulf from north as well as from south and are mainly season dependent.

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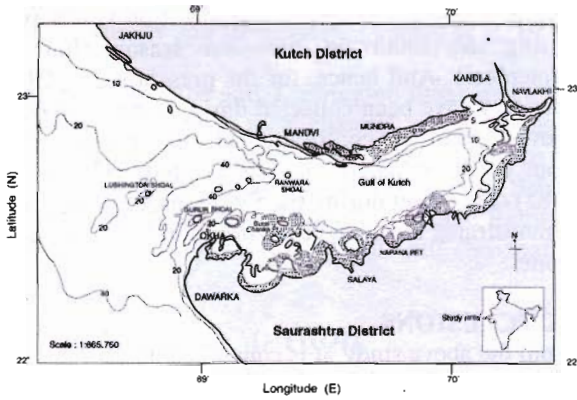


Figure 1. Location map of Gulf of Kutch showing geomorphic features and bathymetric contours.

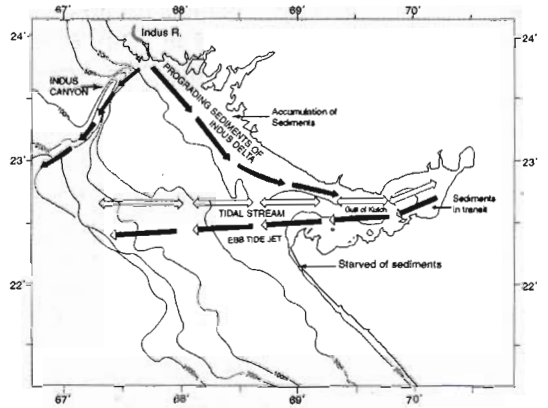
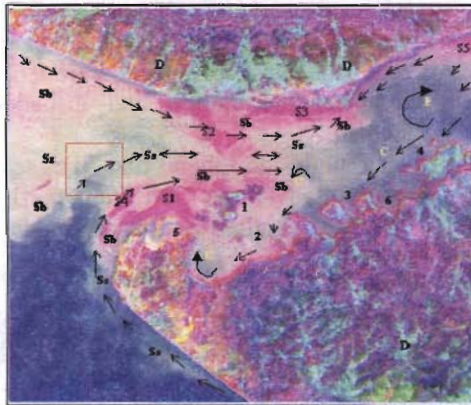
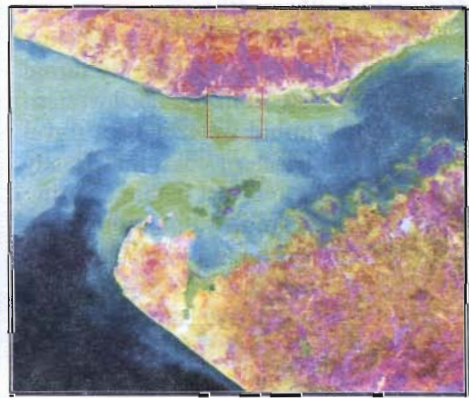


Figure 2. Inferred sediment transport direction (modified after Nair et al. 1982)

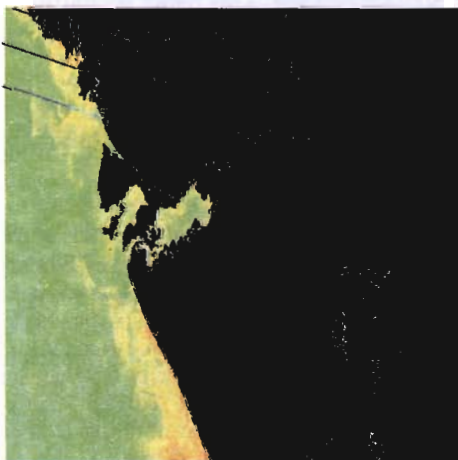


Principal Components 2-3-4 bands of OCM are displayed with Red-Green-Blue colors respectively.

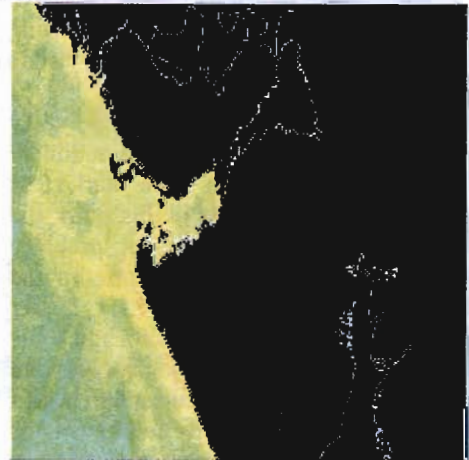


Principal Components 1-2-3 bands of OCM are displayed with Red-Green-Blue colors respectively.

Plate 1.



<Dec 1998>



<Jan 1999>

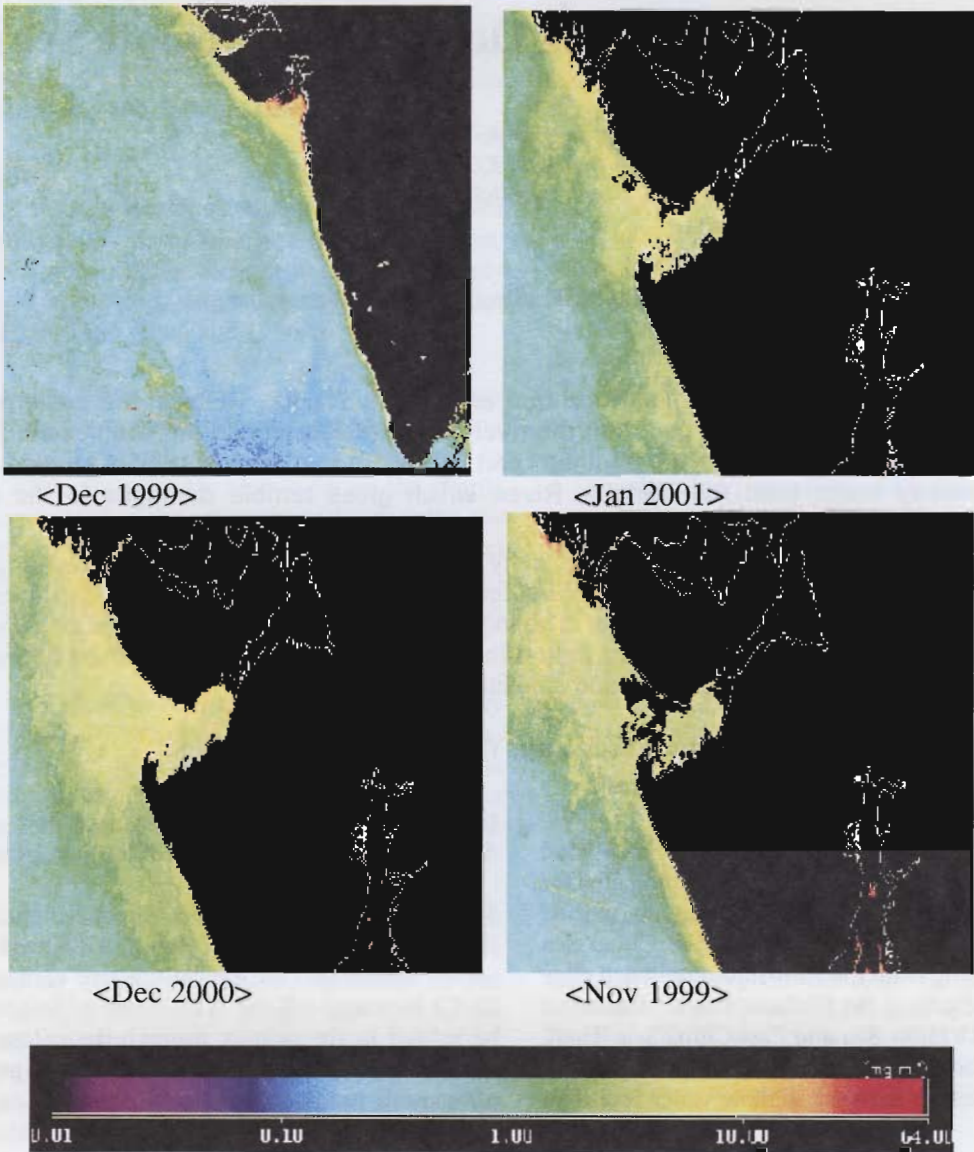


Plate 2.