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Analysis of IRS-P4 OCM Data for Estimating the Suspended Sediment Concentrations along the Mangalore Coast, India

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Abstract

Information on Suspended Sediment Concentration (SSC) in coastal waters is necessary for the understanding and management of the coastal environment. In the present study, estimation of SSC has been carried out along the Mangalore Coast, West coast of India, using both in-situ and Indian Remote sensing Satellite (IRS) – P4 Ocean Color Monitor (OCM) data. The OCM Data Analysis Software (OCMDAS) developed by Space Applications Centre (SAC), Ahmedabad, India, which is based Tassan's algorithm was used to estimate the SSC and validated through sea-truth data collected along the Mangalore Coast. Eighty six surface water samples were collected during the post-monsoon (21.11.1999) and pre-monsoon (07.05.2000) period, near synchronized with IRS-P4-satellite overpass, and SSC was measured using 0.47µm Whatman filter papers with the help of Millipore filter assembly. Out of ninety water samples, eighty two were used to generate the SSC map of the study area and eight samples at few important locations (rivermouth with/without breakwater, man-made coastal structures, and open beaches) were selected to validate the algorithm. Measured SSC varied between 26mg/L and 48mg/L in pre-monsoon and between 16mg/L and 40mg/L during post-monsoon period. The estimated SSC varied between 11mg/L and 47mg/L in pre-monsoon and between 14mg/L and 33mg/L during post-monsoon period. The co-efficient of determination for the relationship developed between measured and estimated SSC is about 0.90 and root mean square error is <14 mg/L.

Key Words: *Suspended Sediment Concentration, Ocean Color Monitor, Water-leaving radiance, Solar radiation, Long wavelength atmospheric correction method, Differential Global Positioning System.*

Mathematical subject classification number: 00A99

Journal of Economic Literature (JEL) Classification number: O30

1. Introduction

Large quantities of sediment are often found in estuaries, shallow water and near ocean sewerage out falls of large cities. The study of its distribution and movement is essential for solving many problems in coastal and marine engineering such as beach erosion/accretion, proper location of coastal structures, modification of harbour basins and siltation in the harbour, maintenance of navigable channel and land use planning in the adjacent hinterland area. Confined by operation conditions, conventional investigation involves hard field work to locate many sites for the accurate mapping of the distribution of suspended sediment in a large water bodies. Although this approach yields accurate measurement, it is costly, time consuming and involves lots of manpower. Furthermore, point based result may involve considerable errors, if extrapolated spatially over a large area (Nanu and Robertson, 1990). Point based method alone cannot be used to estimate the volume of suspended sediments. However, if combined with remotely sensed data, this hybrid approach is good for studying the spatial distribution and concentration levels of suspended sediments.

The principle of remote sensing of Suspended Sediment Concentration (SSC) is based on the interaction of incident solar radiation with suspended materials in water, resulting in an increase in the remotely sensed spectral radiance [$L_{(\lambda)}$] returned to the sensor. The fundamental relationship between SSC and $L_{(\lambda)}$ was described in detail by Curran and Novo,1988. The optimum wavelength for remote sensing of SSC is 0.55-0.65 µm (Novo et al., 1989).

The spatial distribution of Suspended Sediment Concentration (SSC) has been studied from various remotely sensed data such as landsat MSS (Reddy, 1993), IRS- P4 OCM (Chauhan, 2000; Forget et.al., 2001; Nayak,1985,1998,2001; Singh et.al., 2001, 2002; Mikkelsen 2002; Santhosh, 2002; Selvavinayagam et.al., 2003; Menon 2004; Miller and McKee 2004). Using remote sensing techniques SSC can be estimated in coastal waters (Khorram, 1985; Nayak and Sahai, 1985; Curran *et al*., 1987; Daniel et al., 1987; Rimmer *et a*l., 1987; Tassan, 1987, 1988; Jensen *et al.,* 1989; Doerffer *et al.,* 1989; Chauhan, 1996, 1998; Desai, 2000). As the radiation transfer processes in water are very complicated, many models have been proposed to obtain the relation between remote sensing data and SSC in coastal waters (Khorram, 1985; Khorram and Cheshire, 1985; Curran *et al*., 1987; Topliss et al.,1990; Lathrop, 1992; Xia, 1993; Tassan 1993; Froidefond et al., 1993; Nanu and Robertson, 1993; Froster *et al*. 1994; Ferrier, 1995, Gao and O'Leary, 1997). Earlier models started with linear relationship, improved later by logarithmic relationship (Xia, 1993). After the establishment of popular logarithmic models for the estimation of SSC, the Gordon model, the Negative Index model and Improved Negative Index model were developed. All these models give only the aerial extent of the SSC and its distribution. A number of studies had been undertaken to determine the accuracy of the estimated SSC (Khorram, 1985; Ritchie and Cooper, 1988; Doerffer *et al.,* 1989; Ritchie et al., 1990; Tassan, 1993, 1997) and to quantify SSC (Froidefond *et al.,* 1993, Xia, 1993 and Pattiaratchi *et al.,* 1994) in the selected area.

2. Objective

The objective of the present study is to use the existing SSC model [Ocean Colour Monitor Data Analysis Software (OCMDAS)] developed by Space Application Centre (SAC), Ahmedabad, and to validate the same through the in-situ data collected along the coastal waters off Mangalore Coast, Karnataka, West Coast of India and also to give new appraisement and to suggest improvement for existing model, based on the results of validation.

3. Study Area

Mangalore Coast, starting from Talapady in the South and Mulky in the North, in Karnataka State, along the West Coast of India, is the study area. It lies between 12° 45’ – 13°45’ N latitudes and 74°45’ - 74° 55’ E longitudes (Figure 1). The length of the coastline is 40 km and it is oriented along the NNW-SSE direction. The climate is tropical and the mean daily temperature recorded so far is 36°C. The study area receives a very heavy downpour during the Southwest monsoon (June to September). The average annual rainfall is 3954 mm of which 87% is received during the monsoon (Murthy et. al., 1988). River Netravati and Gurupur join the Arabian Sea at Mangalore, while Mulky - Pavanje River joins Arabian Sea at Mulky. These rivers originate in the Western Ghats and flow westward, takes 90° turn near the coast and then flow parallel to the coast before joining the sea.

New Mangalore Port Trust (NMPT) is all weather port, situated at about 10km North of Mangalore. NMPT is having two breakwaters of length 770m and an approach channel with length 7.5 km and depth –15.4 m chart datum. About 13km of total length of Mangalore coast have been protected by constructing the seawalls at the places of severe erosion.

Severe waves are experienced only during the Southwest monsoon and the predominant wave directions are Southwest and West, and occasionally Northwest. In the non-monsoon months the maximum wave heights are less than 1m in height. The tides are semi-diurnal in nature and the tidal range is approximately 1.6m. From the U.S. Naval hydrographic charts, it is observed that, the current pattern in the West Coast of India is from North to South with velocities ranging from 0.11 to 0.40 ms^{-1} during February to September and South to North with velocities of 0.11 to 0.30 ms^{-1} for the remaining period (KREC Study Team, 1994).

4. Data Products

4.1 *In-Situ* Data

In the present study *in-situ* measurements were made during pre-monsoon (07.05.2000) and post-monsoon (21.11.1999) periods, near synchronized with IRS-P4 satellite overpass.90 water samples were collected within 10 cm from water surface using a fabricated water sampler similar to Nanson reversible water sampler. The samples were collected at pre-determined sites such as, along the coast, river mouth with/without breakwaters, manmade constructions, industrial effluent outfall, rocky outcrops and open beaches (Figure 1). Along the coast, water samples were collected at about 500m offshore distance from the shore, which is beyond the breaker zone of Mangalore Coast which is around 300m. This 500m offshore distance was fixed to avoid bottom reflectance, shoreline effects on the reflectance values and also by considering the draft required for the motor boat used during the sea-truth data collection. The approximate depth of water at 500m from the shoreline is 6m. To study the variations in the concentrations, at eight locations samples were collected during both pre-monsoon and post-monsoon period. These eight locations were selected nearer to important features in th study area such as river mouth, breakwaters, seawalls, approach channels and open beaches. At each locations Secchi Disk Depth (0.2 m diameter painted black and white quadrant disk), temperature, total depth and time of sampling were also noted. Each sampling site was geographically located within ± 100m accuracy using handheld Global Positioning System (GPS). All these measurements were made on the day of satellite overpass, between 8 am. and 4 pm., since equatorial crossing time of IRS-P4 satellite is 12 noon ±20 minutes.

4.2 OCM Data

The study area is covered by 9 / 14; path and row of IRS – P4 satellite. To match with the *in-situ* data collection, OCM data during 17.11.1999 and 27.11.1999 for post-monsoon and 7.5.2000 and 9.5.2000 for pre-monsoon were used in the analysis. The digital data in all the 8 bands of OCM were obtained from the National Remote Sensing Centre (NRSC), Hyderabad, India.

5. Methods

5.1 *In-Situ* Data Analysis

The water samples were filtered through pre-weighed 0.47µm Whatman filter paper, using Millipore filter assembly. Then the filter papers were oven dried at 80°C for about 50min. The final weight of the filter paper was noted using electronic weighing machine and the SSC was calculated as the difference between weight of the filter papers before and after filtration.

5.2 OCM Data Analysis

5.2.1 Algorithm Developed For SSC Estimation Using OCM Data

The digital data in all the 8 bands of IRS-P4, OCM were purchased for different seasons (17/11/99, 27/11/99, 07/05/2000 and 09/05/2000) from the NRSC, Hyderabad. The satellite based retrieval of ocean colour parameters e.g. phytoplankton pigment concentration and concentration of suspended matter in nearshore waters, involves two major steps, first is known as atmospheric correction of visible channels to obtain normalised water-leaving radiances and the second is application of bio-optical algorithm for water parameters retrieval (Gordon et. al., 1980). The process of retrieving water-leaving radiance (L_w), from the total radiance measured at the sensor (L_t) is usually known as atmospheric correction. The concentration of suspended matter is obtained from a suitable bio-optical algorithm making use of the retrieved spectral water-leaving radiance.

The remote sensing of ocean colour deals with measurement of radiance that carries information about the radiance back scattered out of the water and transmitted to the top of the atmosphere (TOA) (the water-leaving radiance), which is at most 10% in the blue and typically much smaller in the green wavelengths. The rest of the signal is comprised of radiance reflected from the atmosphere due to molecular and aerosol scattering and the sea surface. Thus, the water-leaving radiance must be extracted from the measured radiance, a process known as atmospheric correction OCM scenes were corrected for Rayleigh and Mie scattering effects using long wavelength atmospheric correction method, initially developed for IRS-P3 MOS data (Mohan et.al., 1998) and later modified for IRS-P4 OCM data (Chauhan et.al., 2001).

The radiance received by a sensor at TOA in a spectral band located at a wavelength λ, $L_t(\lambda_i)$ can be divided into the following components.

$$L_t(\lambda_i) = L_a(\lambda_i) + L_r(\lambda_i) + T(\lambda) L_g(\lambda_i) + t(\lambda_i) L_w(\lambda_i) \quad \text{\_ \_ \_ \_ \_ \_ \_} \quad (1)$$

where

L_a and L_r -the radiance generated along the optical path by scattering in the atmosphere due to aerosol and Rayleigh scattering,

L_g -specular reflection or sun glitter component

L_w -desired water-leaving radiance.

T and t -direct and diffuse transmittance terms.

Gordon and Clarke (1981) had shown that, for NIR channels the water-leaving radiance coming out of ocean can be assumed near zero, and if the effect of sun glitter is also neglected then equation (1) can be written as

$$L_t(\lambda_i) = L_a(\lambda_i) + L_r(\lambda_i) \text{ for } \lambda_i > 765 \text{ nm i.e., } L_w \approx 0 \quad \text{\_ \_ \_ \_ \_ \_ \_} \quad (2)$$

From equation (2) it is clear that, over the clear oceanic water regions, the TOA radiances in 765 nm and 865 nm channels, mainly corresponds to the contribution coming only from the atmosphere, as water-leaving radiance L_w (765 and 865 nm) can be safely assumed to be equal to zero. The Rayleigh scattering term $L_r(\lambda)$ is computed using this well established theory. Using equation (2), once L_r is known, L_a can be determined as

$$L_a(\lambda_i) = L_t(\lambda_i) - L_r(\lambda_i) \text{ for } \lambda_i \geq 765 \text{ nm} \quad \text{\_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_ \_} \quad (3)$$

IRS-P4 OCM payload has 765 nm and 865 nm channels in NIR region. Using these two bands, a relationship was obtained for the spectral dependence of the aerosol optical depth on pixel by pixel basis. Gordon and Wang (1994) had proposed an exponential relationship for spectral behaviour of aerosol optical depth, which was reported to give better results compared to a power law based spectral relationship of aerosol optical depth for marine aerosols. Similar approach was used to estimate an epsilon function for 765 nm and 865 nm bands for each pixel.

The epsilon function is defined as

$$epsilon(c) = \frac{L_a(765)}{L_a(865)} \qquad (4)$$

$$L_w(\lambda_i < 750) = \frac{L_{ac}(\lambda_i) - L_a(865) * \exp \frac{Log(epsilon)}{(865-765)} * (865 - \lambda_i)}{t(\lambda_i)} \qquad (5)$$

where, $L_{ac}(\lambda_i)$ - the Rayleigh and ozone corrected radiances for λ_i < 750 nm
$t(\lambda_i)$ - diffuse transmittance term.

Prior to the atmospheric correction procedure, a cloud screening algorithm was applied on the OCM data, using band 8 (i.e. 865 nm) data and computing albedo in this channel. If the band 8 albedo is more than 1.1% then the pixel is masked as cloud. It was found that the use of this threshold value also taken care of masking land and sun glint affected pixel. Therefore, only the valid water pixels were used in the processing for atmospheric correction and subsequent retrieval of SSC.

5.2.2 SSC Algorithm For Manglore Coast

The algorithm developed by Space Applications Centre (SAC), Ahmedabad, for estimation of SSC, which is based on Tassan's algorithm, for Mangalore Coast is as follows;

$Log_{10}SSC = 7.06 * X_s + 0.41$ for $1.0 < SSC < 100$ mg/L ________(6)

where

$$X_s = [(Rrs555 + Rrs670)] * \left[\frac{(Rrs555)}{(Rrs490)} \right]$$

R_{rs} - reflectance of OCM data.

The OCM digital data was processed using OCM Data Analysis Software (OCMDAS) developed by SAC. For the analysis, band 3 (490 nm), band 5 (555 nm) and band 6 (670 nm) were considered, since the water-leaving radiance of these bands matches well with the typical ocean water-leaving radiance values (Chauhan, 2000a. 2000b; Selvavinayagam, 2003). These water-leaving radiance derived from OCM data after atmospheric correction, were used in the algorithm (Equation 6) to estimate the SSC along the Mangalore Coast.

By adopting image to map registration techniques, since it is more accurate compared to image to image registration each image was geometrically registered and then each sample location was identified in the image using the coordinates obtained from GPS. For the validation of the model, *in-situ* measurement values at the river mouths, along the coastal stretch and at manmade constructions were chosen. Minimum, maximum, mean and nearest pixel values were extracted by moving a minimum size of the window, namely 3 x 3 pixels (representing an area of 1080 x 1080 m) centered at each sampling location to reduce both scatter of the data and errors in locating the sites. Then SSC values were computed using the Equation 6 and compared with *in-situ* SSC measurements. The closer value was selected as the estimated SSC. Accuracy of the estimated values was checked by scatter plots of measured and estimated SSC.

6. Results and Discussion

The result of the representative samples of 90 *in-situ* water samples and IRS-P4 OCM data analysis for the estimation of SSC are given in the following sections.

6.1 Pre-Monsoon Season

The field measurement of SSC along the Mangalore Coast, in the pre-monsoon season varies between 26 and 62 mg/L with a mean concentration of 37.88 mg/L, which is higher than the mean concentration of post-monsoon season. This is probably due to the onshore movement of sediment because of the swell wave condition prevailing during this period. The SSC estimated using OCM-data varies between 11 and 47 mg/L at almost all the selected locations (Table 1).

It is also observed from the digital analysis of OCM data (Figure 2A) that the concentrations in the sediment plumes decreasing towards South in the entire stretch of the study area, indicating the movement of sediments from North to South. This can be attributed to the current direction in this region, which is from North to South during February to September. The concentrations at the Netravati – Gurpur and Mulky – Pavanje river mouths are minimum, indicating the low sediment discharge from these rivers during the pre-monsoon period. The uniformly varying concentration towards offshore region, especially at the open beaches, clearly shows the onshore movement of sediments. During the monsoon period due to high wave activity sediments move towards offshore region, resulting in the erosion of the beach. Once the wave activity slows down, onshore movement of sediment predominates and continues till the end of pre-monsoon period and once again the beach builds up. Hence, the dynamic nature of beaches maintained by the waves along the Mangalore Coast (Dwarakish and Usha Natesan, 2001; KREC Study Team, 1994; Santhosh, 2002) is also observed from the analysis of satellite data.

6.2 Post-Monsoon Season

The *in-situ* SSC in post-monsoon season ranges between 16 and 62 mg/L with a mean concentration of 27.62 mg/L. The estimated values of SSC using OCM data vary between 14 and 33 mg/L. A comparison of estimated SSC with that of measured SSC (Table -2) shows that, estimated SSC are on the lower side. During the Southwest monsoon due to heavy rainfall in the catchment area, Netravathi - Gurpur rivers bring lot of suspended sediments into the sea. Silt and clay fraction of sediments are taken deep into the sea and sand is deposited near the river mouths. Since, the waves are approaching the coast from Southwest direction and currents are from South to North, the SSC pattern is showing a Northward moving trend. This phenomenon is clearly observed at the Netravati-Gurupur river mouth from OCM data analysis (Figure 2B). The maximum concentrations at the river mouth started decreasing towards the North, indicating Northward movement of sediments. The sediment plumes of different concentrations are identified from the digital analysis, which was observed during the field data collection also. The sediment trend matrix drawn based on the statistical parameters (mean, standard deviation, skewness) of sediments collected along the beach also shows that the sediments are moving away from the river mouth with maximum percentage being moved towards Northern side (KREC Study Team 1994). The semicircular fringe of distribution of sediment is observed at the Mulky - Pavanje river mouth (without breakwaters). The concentration at this river mouth is less than that of Netravati - Gurpur river mouth, due to less carrying capacity (Dwarakish and Natesan 2001).

6.3 Comparison Between Measured And Estimated SSC.

On the day of satellite overpass, 90 surface water samples were collected and tested in the laboratory for SSC. The satellite remote sensing data belongs to four different dates, within ±7 days of in-situ data collection, were analysed in the present study due to limitations in computer processing time and other constraints, maximum of 8 in-situ sample locations were selected during validation of the developed model. As the exact identification of individual sample location on the image might be difficult, the average reflectance value of the 3x3 window was considered. Figure 3 shows the scattered plot of estimated versus measured SSC and the points are scattered around central line. During the pre-monsoon period the co-efficient of determination (R^2) is 0.9077 for synchronized field and satellite data set (7/5/2000), and it is 0.4569 when the satellite data is two days later (9/5/2000) than the in-situ measurement. To increase the number of points, these two date data sets were combined together. For the post-monsoon period, remote sensing data was not available for 21.11.1999, due to more cloud cover. The value of R^2 is 0.79 for combined satellite data and in-situ data.

When pre and post – monsoon data sets were combined together, the relation between measured and estimated SSC was not so encouraging and the value of R^2 is 0.5438 and the co-efficient of correlation (R) is 0.74. It is clear from the present study, that the R^2 value is greater than 0.90 for both pre-monsoon and post-monsoon data. Root mean square error is <14mg/L, the standard error of estimate is 5.37 mg/L and the correlation is significant at 0.01 level. Also, the range of percentage error between measured and estimated SSC, for synchronized data (07/05/2000) is 2.08 to 18.52%. This indicates that the modified algorithm developed for estimation of SSC along Mangalore Coast is satisfactory. To improve the accuracy of the model further refinement is necessary. The performance of the model may be improved by using Differential Global Positioning System, by reducing the time lag between date of in-situ sampling and available satellite data, and proper geometric rectification of remote sensing date. The amount of bottom reflectance varies with SSC in the water. If the water has high SSC, then a large portion of the solar radiation will be scattered and /or absorbed by the suspended sediments before it can reach the bottom. In the present study, all the samples were collected around 500m offshore, beyond breaker zone. Although such an assumption does not portray the interaction of solar radiation with the water realistically, it certainly has some merits as the regressed relation suggests that bottom reflection has been effectively eliminated by the use of 500m threshold in this study. However, the 500m threshold may have to be modified accordingly if another area is studied.

7. Conclusions

In the present study, SSC along the coastal waters off Mangalore coast has been estimated using IRS-P4 OCM data and in-situ data collected near-synchronised with the IRS-P4 satellite overpass. OCM data was processed using OCMDAS algorithm developed by SAC, Ahmedabad. In general, there is a close, linear relation ($r^2 > 0.90$) between estimated SSC from the algorithm in the range of 1 mg/L and 100 mg/L and measured SSC along the coastal waters off Mangalore coast. Higher concentrations of SSC was observed nearer to the Netravathi-Gurpur compared to Mulky-Pavanje rivermouth, during pre-monsoon period. Also, based on the results of validation, it is concluded that, further refinement of the algorithm is necessary to achieve still better results, through more in-situ data sets. The performance of the model may be improved by using Differential Global Positioning System, by reducing the time lag between date of in-situ sampling and available satellite data.

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Table 1 – Validation Of The Algorithm Using Selected Pre-Monsoon Data

Date of in-situ measurements	7/5/2000	-				7/5/2000	-			
Satellite overpass	-	7/5/2000				-	9/5/2000			
Stn. ID	Measured SSC(mg/L)	Estimated SSC(mg/L)	Error			Measured SSC(mg/L)	Estimated SSC(mg/L)	Error		
			Absolute	Relative	%			Absolute	Relative	%
2	26	23	03	0.1154	11.54	-	-	-	-	-
4	33	35	-02	-0.0571	5.71	-	-	-	-	-
7	-	-	-	-	-	28	23	05	0.1786	17.86
9	-	-	-	-	-	40	29	11	0.275	27.5
12	44	38	06	0.1364	13.64	-	-	-	-	-
16*	48	47	01	0.0208	2.08	48	29	19	0.3958	39.58
17	-	-	-	-	-	34	29	05	0.1471	14.71
25	-	-	-	-	-	34	15	19	0.5588	55.88
27*	27	22	05	0.1852	18.52	27	15	12	0.4444	44.44
35	-	-	-	-	-	29	11	18	0.6207	62.07

Table 2 – Validation Of The Algorithm Using Selected Post-Monsoon Data

Date of in-situ measurements	21/11/1999	-				21/11/1999	-			
Satellite overpass	-	17/11/1999				-	27/11/1999			
Stn. ID	Measured SSC(mg/L)	Estimated SSC(mg/L)	Error			Measured SSC(mg/L)	Estimated SSC(mg/L)	Error		
			Absolute	Relative	%			Absolute	Relative	%
2	-	-	-	-	-	20	15	05	0.25	25.0
4	28	28	0.0	0.0	0.0	-	-	-	-	-
5*	28	28	0.0	0.0	0.0	28	24	04	0.1428	14.28
6	-	-				31	24	07	0.2258	22.58
7	-	-				27	24	03	0.1111	11.11
10	-	-				16	14	02	0.125	12.5
11	-	-				18	15	03	0.1667	16.67
16	38	29	09	0.2368	23.68	-	-	-	-	-
31	25	26	-01	-0.04	3.85	-	-	-	-	-
39*	33	33	0.0	0.0	0.0	33	28	05	0.1515	15.15
40*	33	28	05	0.1515	15.15	33	28	05	0.1515	15.15

* Stn. ID selected for checking the consistency of the data

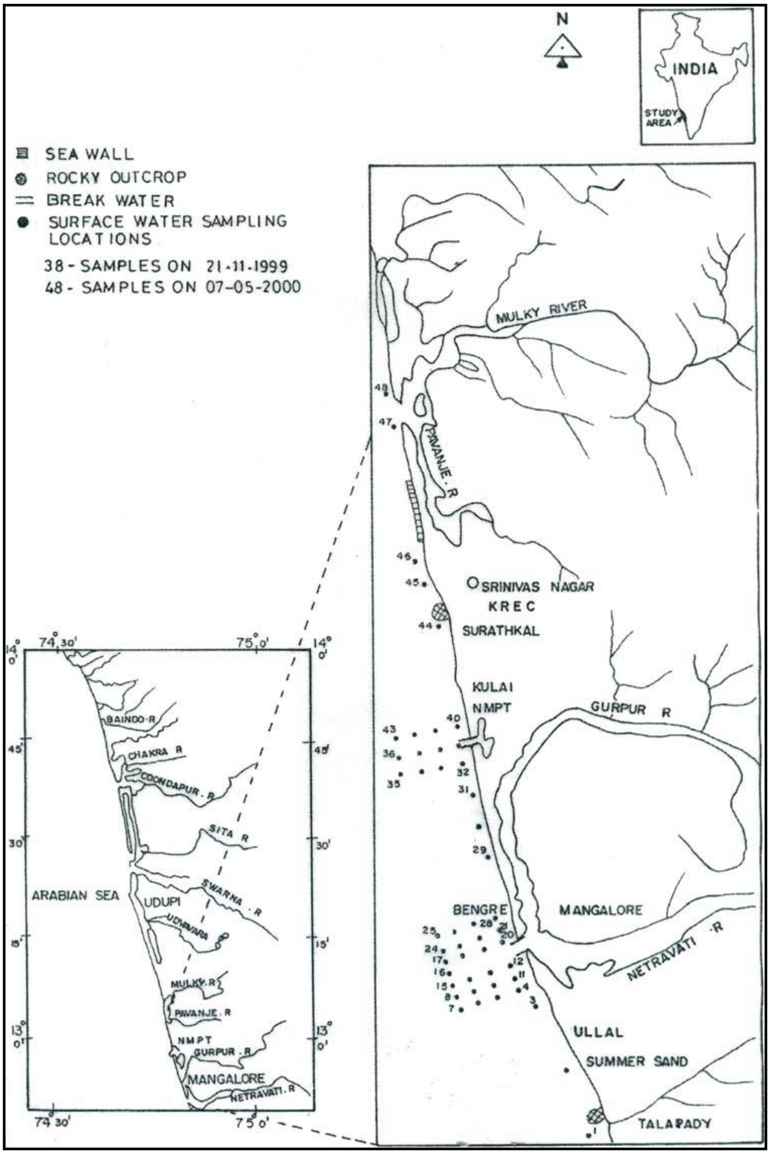

Figure 1 – Study Area And In-Situ Sample Collection Locations

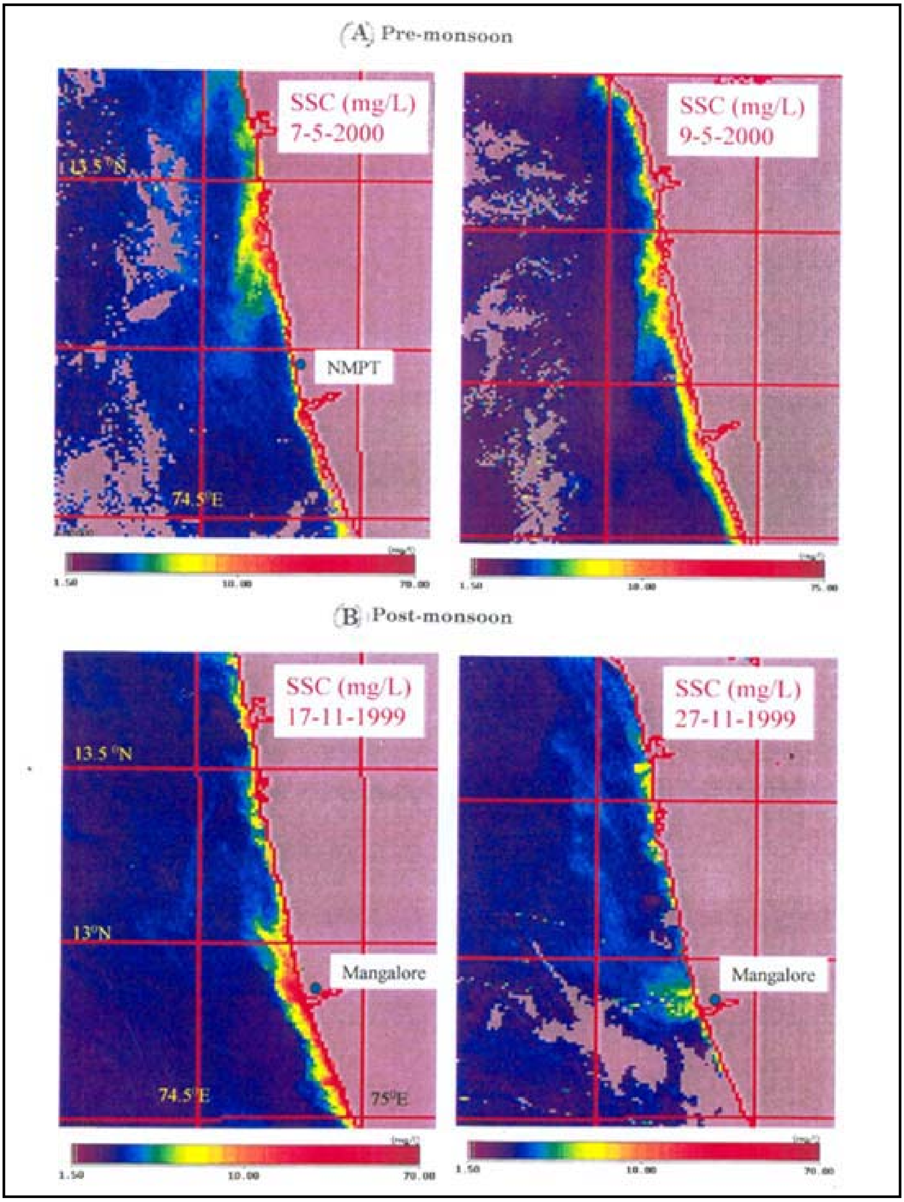

Figure 2 - Sediment Distribution Pattern Along Mangalore Coast From OCM Data

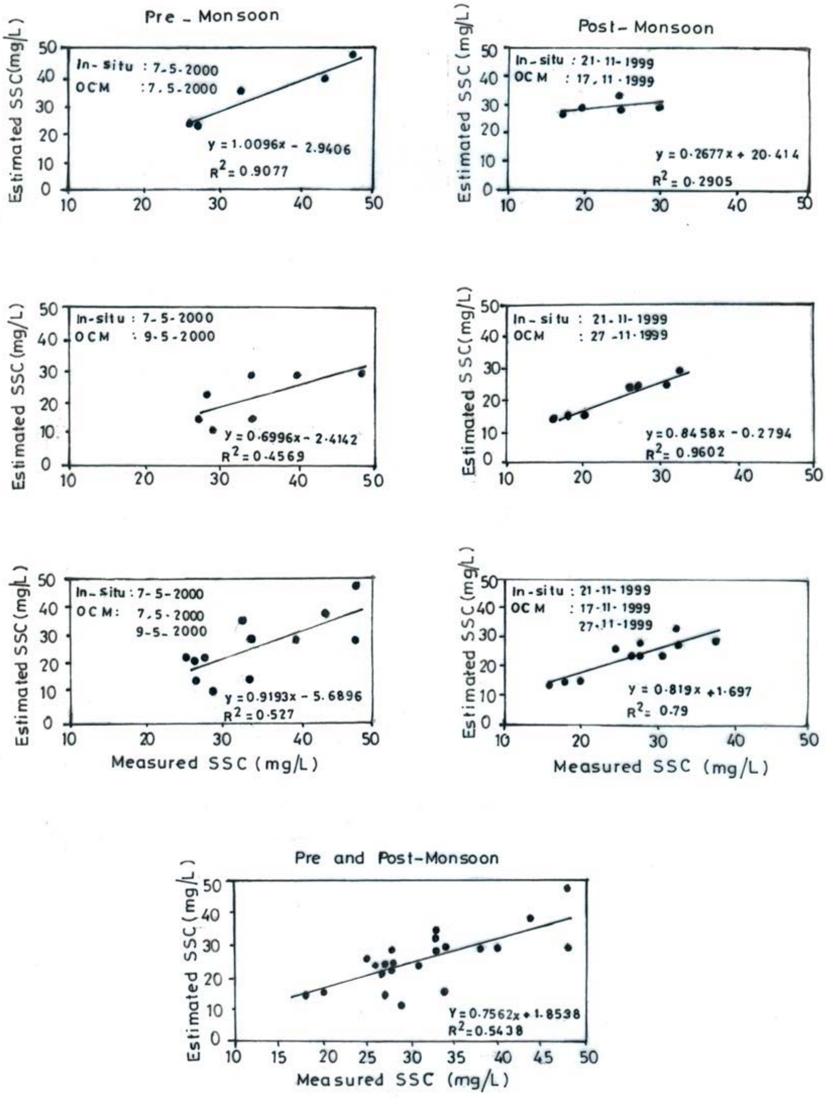

Figure 3 – Scatter Plot - Measured Versus Estimated SSC (mg/L)

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