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Evaluation of Land Cover changes of Mangroves along Mandovi, West Coast of India using RS and GIS

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***Abstract*—*Mangroves habitats are highly adoptable halophytes found in intertidal regions of tropical estuaries, are threatened by variety of anthropogenic activities including mining. Many mining sites and loading points are located along the course of Mandovi estuary, West Coast Of India, Goa which sustains mangrove habitats. Mangroves are of a great significance in arresting mining rejects and recycling its constituents and have proved to be a good indicator for detecting and quantifying short-term changes in the coastal zones. Time lapse satellite data suggested changes in land use patterns. The present study showed that mangrove cover along the stretch of Mandovi increased by 116.68% during 1997-2011, a decline of 12.52% from 2001-2006. The increased in mangrove cover could be attributed to government's rehabilitation initiatives and invasion by mangroves on agricultural farms; besides a new mangrove formations in the areas on deposited mudflats between the existing mangrove and open mudflats. Isle within the mid-stream of river was noticed with more proliferation with mangroves due to sediment deposition due to mining rejects and also from spilling of ores during transported. Mangroves have inherent characteristics to withstand pollutions to certain extent due to its robust nature. All these lead to tremendous improvement of mangroves. Mining may not affect mangrove distribution (area, content and canopy cover) to greater extent but its associated biological, hydrological and sediment logical features could get adversely affected. Current findings will serve in understanding the land cover changes of mangrove habitants and in devising effective strategies for their conservation and rehabilitation.*

Keywords*— *Mangroves; RS; mining; land use pattern; sediments; conservation; rehabilitation.

I. INTRODUCTION

Many global coastal zones are currently subjected to stress owing to spur of anthropogenic activities associated with economic consideration, land use, and resource development. India, in particular, is facing increasing stress as a result of cumulative environmental changes driven by urbanization, industrialization, unsustainable growth, and ever increasing population leading to degradation of coastal zones and ecosystems (Jagtap *et al.*, 2003).

Though, land cover change is a complex environmental indicator from regional to global level, but is an important aspect of resource management and environmental mitigation. Therefore, any unplanned interference can prove detrimental to its inherent value. Trends in vegetation cover dynamics, is an important aspect as it provides information about landscape processes and ecological status (Nagi, 2008). Remote Sensing data having good spectral and spatial resolution are found to be very effective in evaluating and monitoring land use and land cover changes (Lillesand *et al.*, 2004).

Mangroves form an ecological sensitive habitat in the tidal influenced intertidal regions of tropical estuaries and are of a great significance in arresting mining rejects and recycling its constituents, particularly metals (Kathiresan, 2000). Marine vegetation, particularly mangrove, plays a significant role in stabilizing the shores by preventing soil erosion. Besides, mangrove ecosystems inhabit various kinds of fauna of ecological and socio-economical significance (Ajana, 1980; Jagtap, 1985). These habitats have proved to be a good indicator for detecting and quantifying the short-term changes in the coastal zones (Filho *et al.*, 2006).

Many estuaries of Goa namely, Terekhol, Chapora, Mandovi, Zuari, Sal, Talpona, Galgibag and along its coastline (~120 km) sustain mangroves. The Chorao island of Mandovi estuary sustains the best mangrove formation in the State. The major mangrove plantations (~ 80%) in Goa are located along the Mandovi-Zuari-Cumbarjua estuarine complex (Jagtap, 1986). This particular complex is extensively used to transport mining ores from loading points located along the bank of the Mandovi to Mormugoa harbour for shipment to other countries. Mining, a centrepiece of Goa's economy, forms the major source of sediment and oil to the close-by estuary areas. During recent years, Goa has been undergoing tremendous changes in its land use patterns (Murali *et al.*, 2006). Mangrove ecosystems are important for fish production and serve as nursery, feeding and breeding grounds for many fish and shellfish. The healthy ecosystem of mangroves is vital in context of Goa since many mining sites are located around the catchment areas of many estuaries and also significant number of its population from the coastal areas are in the fisheries occupation.

The objective of this work is to assess the changes in mangrove vegetation along Mandovi estuary during last fourteen years (1997-2011) and to assess its prevailing situation using remote sensing (RS) and Geographical Information Systems (GIS) techniques. This will greatly help in monitoring and management of major mangrove habitats of Goa and also help to evaluate the extent of possible impact of mining on mangrove ecosystem along the course of Mandovi estuary.

II. STUDY AREA

Mandovi River originates in the Barwa Ghat of the Sahyadri hills in Karnataka, flows downstream as Mandovi estuary (Fig. 1) and after traversing a stretch of about 70 km joins the Arabian Sea through the Aguada bay near Panaji. Its width at confluence region is 3.2 km, while at upstream it narrows down to 0.25 km and is fed by monsoon precipitation from the discharges of a catchment area of ~ 1150 sq km (Shetye *et al*., 2007). The Mandovi basin has an area of 1530 sq km and constitutes about 42% of the land area of the State (Shetye *et al*., 2007). Its pre- and post-monsoonal flows are also regulated by the semidiurnal tide of 1.0-2.5 m range. Along its course, Mandovi has number of tributaries and islands with narrow bends and shallow depth. It is connected with Zuari estuary through a canal called Cumbarjua canal having a length of 17.0 km and an average width of 0.5 km. It is a natural course connecting the two estuaries.

Status of Mangroves:

Mangrove vegetation in the world has been declining at the assumed rate of 2 to 8% per year or 0.6 % of all inland forests (Spalding, 1997). The total area of mangroves in the year 2000 was 1,37,760 sq km in 118 countries and territories in the tropical and subtropical regions of the world; approximately 75% of world's mangroves are found in just 15 countries and only 6.9% are protected under the existing protected areas network (Giri, *et al.*, 2010). Indonesia has the highest mangrove cover of 22.6% of total global mangrove area, while India accounts for only 2.7%.

The Indian sub-continent harbours about 9700 sq km of mangrove area with major formations occur in the regions of the Indus, Sunderband, and Mahanadi deltas, the Gulf of Kutchchh, the Andaman and Nicobar group of islands, and a part of the West Coast and the Jaffana Peninsula in the north of Sri Lanka (Jagtap, *et al.*, 2007). Mangrove habitats of India have been facing tremendous threats due to indiscriminate exploitation of mangrove resources for various uses. In recent past, the mangrove vegetation in the world and particularly in Indian subcontinent has deteriorated, mainly due to their poor management (Jagtap, *et al.,* 1993; Khalil, 1999; Jayatissa, *et al.,* 2002). Pollution is major common occurrences that dwindled mangrove area (Jagtap, 1983). According to Government of India report (1981), there was a loss of 40% of mangrove forests during the last century (Kumar, 2000 a). The National Remote Sensing Agency (NRSA, 1983) recorded a decline of 59.18 sq km of mangrove between 1972-1975 and 1980-1982. Owing to these threats, more than 33% of the Indian mangrove areas have been lost within the last 15 years; East Coast has lost an area of about 28%, West Coast lost about 44% and Andaman and Nicobar Islands approximately 32% (Jagtap, 1983; Babukuttyand Chacko, 1992; Chakrabarti, 1995; Naskar, *et al.*, 1999; Elizabeth, *et al.*, 2006; De Souza, 2006; Naskar, *et al.*, 2008).

In the context of Goa, as well, there are concerns of the mangrove habitats being put under threat due to anthropogenic activities of various kinds. Mining, being a major industry in Goa is believed to be one of such activities, which have a potential to cause a considerable damage to their existence and in their conservation efforts.

III. METHODOLOGY

Mapping of mangroves along Mandovi estuary was done using cloud free satellite data (Febuary, 2011) of LISS III sensor of IRS-P6 series during the low tide period in order to obtain maximum coastal zone and exposure of vegetation. IRS LISS III provides data in four spectral bands; green, red, Near Infra Red (NIR) and Short Wave Infra Red (SWIR). Density-wise classification details are obtained from LISS III data with the resolution of 23.5 m at 1:25,000 Scale. Geometric correction was performed to improve the geolocation to a root mean square error of half a pixel, an accuracy needed for subsequent change analysis. Each image was normalized for variation in solar angle and earth–sun distance by converting the digital number values to the top of atmosphere reflectance. The images were not enhanced prior to unsupervised classification, and the thermal band (band 6) was excluded. Prior to classification, satellite images were subsetted to include only areas where mangrove forest is likely to occur. Subsetting an area of interest helped to increase overall classification accuracy by reducing the number of land-cover types and spectral

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variation. In addition, subsetting was done which helped to substantially reduce data size.

Satellite data of LISS III sensor of IRS-P6 series for the February 2011 with spatial resolution 23.5 m was used for the purpose of this study. Whereas, data of IRS-1C LISS III of year 1997, IRS-1D LISS III of the year 2001 and IRS-P6 LISS III of the year 2006 were used. Scales of various images are depicted in the respective maps. Images of above mentioned years (Fig. 2) available with the National Institute of Oceanography, (CSIR-NIO), Dona Paula, Goa were acquired. They were geo-corrected to match the real world coordinate using an already geo corrected image of LISS III image of 2006 image to image registration procedure using ERDAS 9.1 software. Images were projected to UTM (Universal Transverse Mercator) projection and WGS84 datum. Area of interest was separated using subset method and then subjected to unsupervised classification. From the results obtained, mangrove classes were visually separated and grouped into one common class. Google map was used as reference for confirmation of the classified area. These images were later opened in Arc Map 9.3 environment to spatially assess change detection in mangrove habitat (Figure 6.2). Ground truth information was used to match the classified images to check the accuracy of the result and for the production of final maps.

IV. RESULTS

Satellite imaginaries (Fig. 2) of the four years, namely 1997, 2001, 2006 and 2011 showed various spectral reflectances in the different bands. Mangroves as well as terrestrial vegetation and the agricultural fields showed maximum spectral reflectance to the NIR (Near Infra Red) band. The lowest spectral reflectance was to the red band. The water bodies, barren lands, built-up lands, mud flats and mudflats showed the highest spectral reflectance to the green band and the lowest to the NIR band. The sandy beaches showed similar reflectance in all three bands.

It is found that the mangrove vegetation during the period from 1997 to 2011 has shown tremendous improvement with an increase of 116.68%, particularly from 2006 to 2011 (Table 1). From 1997 to 2001, a growth was noted from 5.563 sq km to 7.783 sq km thereby, registering an increase of 39.90%. However, a decline in the mangrove vegetation was noted between the period from 2001 to 2006 and the mangrove vegetation declined from 7.783 sq km to 6.806 sq km respectively during this period. This period showed negative growth of 12.52% in mangrove plantation. Between the period 2006 and 2011, mangrove vegetation increased to 12.054 sq. km from 6.808 sq. km in 2006, resultantly, showing much more healthy growth of 77.05%. Thereby, over the period of time from 1997 to 2011, a cumulative growth of 116.68 % was recorded in mangrove vegetation along the Mandovi estuary.

V. DISCUSSION

RS data in combination with GIS offers possibilities for effective and efficient analysis of detailed mangrove communities allowing qualitative and quantitative assessments of inaccessible area and is also able to retrieve, transform and display spatial data (Jensen, 1986; Davis and Quinn, 2002). GIS has been used with RS and field data to map and monitor regional and global environments, including the extent and dynamics of mangrove communities (Chaudhury, 1991; Hussain *et al.*, 1999). Numerous researchers have carried out study on various aspects of mangroves in India (Jagtap, 1985; Banerjee and Gosh, 1998; Singh, 1998; Naskar and Mandal, 1999; Nayak and Bhuguna, 2001; Singh, 2002). To arrive at the clear picture of status of mangroves, Kumar (2000 b) worked extensively on the status of natural regeneration in mangroves of Goa through sample surveys in all the estuaries and compared observations with Untawale *et al.* (1982).

Upper reaches of the bank of Mandovi estuary is amidst of intense mining activities for considerable time. It has > 27 mines in its catchment area and 12 loading points on its bank or on the bank of its tributaries. About two third of mining operations are confined in its catchment area (Pathak *et al.*, 1988) generating a reject of ~ 1500 to 6000 tonnes/day by each mine in this area (Nair, *et al.*, 2003). Ore loading platforms are constructed along the bank of the rivers from where it is loaded on the barges and transported to Mormugoa harbour. Thus, the estuarine bed and associated mangrove of the Mandovi are exposed to an influx of metal affluent from ferromanganese mining (Attri and Kerkar, 2011).

Mangrove cover in Goa was estimated to be around 20 sq km according to one mapping (Untawale, *et al.*, 1982; Jagtap, 1985 and Jagtap, *et al.*, 2003). As per the report of Forest Survey of India (1999), the State had five sq km areas under mangroves, which appears to be an under-estimate (Singh, *et al.*, 2004). In the context of the presently study, it is revealed that there is an increase of 116.68% in mangrove vegetation from an area of 5.563 sq km to 12.054 sq km during the span from 1997 to 2011 along the Mandovi estuary. Whereas, from 1997 to 2001, a growth was noted from 5.563 to 7.783 sq km thereby, registering an increase of 39.90%. According to one study (Singh, *et al.*, 2004), an increase in the mangrove vegetation in the important estuaries has been found during 1994 to 2001. During this period, the mangrove habitat increased by

44.90% as a result of increased protection and consequent regeneration. The plantation of mangrove species has been raised to 8.76 sq km during the period 1985 to 1997 by the State Forest department, further mangrove cover increased from 5.93 to 9.08 sq km between 1994 and 2001 along the entire stretch of Mandovi estuary, showing 53.11% increase. As per the study of Nagi (2008), there is an increase of about 36.50% of mangrove cover along the entire stretch of Mandovi estuary. The predominant increase was witnessed in Mandovi, Chapora and Sal estuaries, adding about 5.38 sq km with respect to data of 1973 (Jagtap,1985) over the span of three decades. In accordance with the National Wetland Atlas (2009), there are 84 numbers of wetlands of mangrove in North Goa District covering about 15.87 sq km. The composition of mangroves species along the bank of the three regions of the study area of Mandovi estuary (GOG, 1983) are: 1) Pilgao (St. # 1): *Sonneratia caseolaris* (70%), *Acanthus illicifolius* and *Aegiceras corniculatum* (20%) and others (10%); 2) Old Goa (St. # 2): *Avicennia officinalis* (30%), *Sonneratia alba* (30%), *Porterasia coaretata* (20%) and others (20%); 3) Verem (St. # 3): *Sonneratia alba* (80%), *Rhizophora mucronata* (10%) and others (10%).

Such habitants are being subjected to a tremendous stress owing to wide range of anthropogenic activities and natural calamities all over the world including Indian sub-continent. In 1976, the Government of India set up the National Mangrove Committee in the Ministry of Environment and Forests to advise the Government on mangrove conservation and development. The need to conduct survey on the extent of existing mangrove areas, identification of selected mangrove areas for conservation, preparation of management plan, promotion of research, adaptation of multidisciplinary approaches involving State Government, Universities, researchers, institutions and local organizations have been recommended (MoEF, 1987). Towards this endeavour, the Goa government declared about 1.78 sq km of the best mangrove area at Chorao Island as reserved forest under the Indian Forest Act, 1927 to protect and conserve the mangrove forest. Subsequently, in 1988, this area was declared a bird sanctuary under the Wildlife (Protection) Act, 1972). The Goa State Forest Department initiated afforestation works to restore degraded mangrove areas in 1985 in all the estuaries and by 1997, an area of 8.76 sq km was planted (FSI, 1999 b). In 1988, The Government of Goa formed a State Level Steering Committee to oversee the improvement and conservation of the mangrove forest. In 1990, the State Government set up Multidisciplinary Project Formulation Team to facilitate the preparation of a Comprehensive Action Plan for the development of the mangrove ecosystem. In the same year, the government decided that no construction or development work would be allowed in the area earmarked by the Forest Department for mangrove conservation and declared that mangrove species should not be felled for a period of ten years. A five-year Mangrove Management Plan for Goa was prepared in 1991-1992 and implemented with financial assistance from the Government of India and one sq km of mangroves were planted each year as planned. The increase in the mangrove habitat in the study region can also be attributed to conservation and restoration mechanism initiated by the forest department of the State government and their well organized awareness programmes. As per the latest released India State of Forest report (2011) by government of Goa, the State has 22 sq km areas under mangrove cover and there has been increase in mangrove habitat in North Goa by 5 sq km over last two years.

Ground truth observations revealed that mudflats due to the mining operations in the catchment region of Mandovi estuary provide a suitable substratum for the mangrove vegetation for its growth (Plate 1 a). Besides the increase in mangrove habitat could also be attributed to the reduction in agriculture activity in the area adjacent to mangrove plantation which is infested by mangrove (Plate 1 b). Further, Ground truth observations revealed that new mangrove formations have taken place, particularly in the area on the recently deposited mudflats between the existing mangrove and open mudflats along the waterways. More recently, an expansion of recently developed isle (Plate 1 c) was noticed in the mid stream of Mandovi estuary at Ribandar, close to station # 2, perhaps due to deposition of heavy sediments. The primary reason can be attributed to the flow of mining rejects from mining operations located along the bank of Mandovi estuary on its upper region. Spilling of ores from the barges while being transported from loading points situated either along its bank or its tributaries to Mormugoa harbour is also a contributing factor. Such types of new isles provide a good substratum for the growth of mangroves. This has proved to be blessing in disguise for the profusion of mangroves. Plantation efforts of the State forest department also assisted in a major way for the increase of mangrove cover. All these could be possible reasons of tremendous improvement of mangrove vegetation along the Mandovi estuary. Here, one side there is a heavy deposition of sediments in the Mandovi river and gets affected to such an extent that a small island of sort being formed whereas, on the other side, the sediments deposition acts as a good substratum for the growth of mangroves. Therefore, to conclude that there is no effect of mining operations on marine environment of Mandovi river on the basis of tremendous growth of mangroves in Mandovi river and along its bank would be erroneous and far from facts. The effects of mining pollutants on aquatic ecosystem of Mandovi estuary needs to be judged from the study of various marine hydrological parameters.

One estimate suggests that on an average about 25 to 30 million tonnes of mining rejects per year is generated in the regions around Mandovi and Zuari estuaries. Along the basin of Mandovi estuary itself, an average reject amounting to 1500-6000 tonnes/day/mine is generated and about 27 major mines are located in the area (Nair, *et al.*, 2003). Luxuriant growth of mangroves particularly in the Mandovi is attributed to favourable ecological conditions and substratum deposition (Jagtap, 1985). However, a study by Jagtap *et al*., (2007) revealed that an excess of sediments to a tune of > 9-12 cm thick per year due to natural and human activities has potential to threaten mangroves by way of clogging and ultimately may result in their deaths besides retarding new formations. Therefore, this parameter needs to be investigated regularly as a part of monitoring of mining to understand the impact on the mangrove habitats.

Nevertheless, this work throws a light on healthy situation with regard to mangrove ecosystem and its potential for further growth and its conservation along the bank of the Mandovi estuary provided the various measures initiated by the government are continued further and if possible, strengthen the same. This study gives an updated geospatial database of these natural resources, which is the pre-requisite for the management and conservation planning.

Hence, to draw a conclusion that the mining pollutants do not exhibit visible impact on mangrove vegetation along the bank of Mandovi estuary is difficult to conclude, as there are multiple reasons for its growth as discussed above. However, various initiatives and mitigation steps taken by the government towards the conservation and protection of mangrove vegetation did help in yielding the desired result including steps taken to prevent the pollutants from mining operations reaching mangrove ecosystem.

Summary and Conclusion:

The anthropogenic activities worldwide along with natural disturbances in the past have yielded varied results. Mining was the backbone of Goa's economy till recent past; however, illegal mining in the past decade has caused severe damage to the ecology, hydrology and agriculture. This study was aimed to understand possible effects of mining on mangrove ecosystem along the course of Mandovi estuary of Goa. The present study reveals that there was an overall increase of 116.68% in mangrove cover from an area of 5.563 sq km. to 12.054 sq km during the span from 1997 to 2011 along the Mandovi estuary. However, a decline in the mangrove vegetation was observed from 2001 to 2006 registering negative growth of 12.52% and the mangrove vegetation declined from 7.783 sq km to 6.806 sq km, further from 1997 to 2001, registered an increase of 39.90%. To conclude that mining activities do not have any tangible effect on mangrove ecosystem along the bank of Mandovi estuary is difficult to arrive at due to increase of its cover. It is observed that the proliferation of mangroves is greatly helped by the aforestration efforts of the State forest department's initiatives. Further, mudflats due to mining operations in the Mandovi estuary provides a substratum for the mangrove vegetation for its growth, besides the increase in mangrove habitat could be attributed to the reduction in agriculture activity in the area adjacent to mangrove plantation, which is infested by mangrove. Ground Truth Observations revealed that new mangrove formations have taken place, particularly in the area on the recently deposited mudflats between the existing mangrove and open mudflats along the waterways. Besides, of late formed isle within the mid stream of Mandovi river, close to St. # 2, was noticed with more proliferation with mangroves due to the deposition of sediments of mining rejects from mining operations and also spilling of ores from the barges while being transported from loading points to Mormugoa harbour. Besides, mangroves have inherent characteristics to withstand pollutions to certain extent due to its robust nature. All these could be the possible reasons of tremendous improvement of mangrove vegetation along the Mandovi estuary. As such, mining activities may not affect mangrove distribution (area, content and canopy cover) to greater extent but, its associated biological, hydrological and sedimentological features could get adversely affected. The present work will form a baseline data on mangrove habitats to monitor the changes in near future.

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REFERENCES

[1] Ajana, A. M.1980. Fishery of the Mangrove Oyster, Crassostrea gasar Adanson (1757), in the Lagos Area, Nigeria; *Aquaculture*; **21**: 120-137.

[2] Attri, K. and Kerkar, S. 2011. Seasonal Assessment of heavy metal pollution in the tropical mangrove sediment (Goa, India). *Jour. Biotechnology*, **3**: 9-15.

[3] Babukutty Y. and Chacko J. 1992. Trace Metals in an Estuarine Bivalve from the Southwest Coast of India, *Ambio*, **21(4)**: 292-296.

[4] Banerjee, L. K. and Gosh, D. 1998. Species diversity and distribution of mangroves in India, An Anthology of Indian Mangroves. *ENVIS*, **2(1)**: 22-24.

[5] Chakrabarti, P. 1995. Coastal Zone Management in Hooghly Estuary – An Operational Approach, *Indian Journal of Earth Sciences*, **22(3)**: 125-134.

[6] Chaudhury, M. U. 1991. Monitoring the ecological status of mangrove forests of Sunderbans in Bangladesh- classification and change detection with Landsat and Spot. In: Murai, S. (ed.): 286 – 291.

[7] Davis, B. E. and Quinn, Norman; online http://www.gisdevelopment.netacrs/2002/czm/088.pdf .

[8] De Souza, R. J. S. 2006. Remote Sensing and GIS Tools for Integrated Coastal Zone Management – Goa State; A Ph.D. Thesis Submitted to Goa University. Resources, Govt.of Goa and Central Ground Water Board, Bangalore: 6-

[9] FSI. 1999. State of Forest Report 1999, Summary, Forest Survey of India, Ministry of Environment and Forest, Government of India, Dehradun: 4.

[10] Elizabeth McLeod and Rodney V. Salm. 2006. Managing Mangroves for Resilience to Climate Change. The World Conservation Union (IUCN), Gland Switzerland, E. V. M. 2003. Safe upper levels for vitamins and minerals, London: food standard agency.

[11] Filho, P. M. W.; Martins, E. S. F. and da costa, F. R. 2006. Using Mangroves as a Geological Indicator of Coastal Changes in the Braganca Macrotidal Flat, Brazilian Amazon: A Remote Sensing Data Approach*; Ocean & Coastal Management*: **49**: 462-475.

[12] Giri, C.; Ochieng, E.; Tieszen, L. L.; Zhu, Z.; Singh, A.; Loveland, T.; Masek, J. and Duke, N. 2010. Status and distribution of mangrove forests of the world using earth observation satellite data, *Global Ecology and Biogeography*: 1-6.

[13] GOG. 1983. Mangroves of Goa. Dept. of Forest, Government of Goa: 13-17.

[14] GOI. 1981. Eco-development Plan for Goa (Report of Task Force on coastal area planning), Government of India: 42.

[15] Hussain, Y.; Zuhair, H. and Weir, M. 1999. Monitoring mangrove forests using remote sensing and GIS. Asian Conference on Remote Sensing, Hong Kong. Poster Session 5, Online at: http://www.gisdevelopment.net/aars/acrs/1999/ps5/ps512pf.htm.

[16] Jagtap T. G., 1983, Metal Distribution in Halophila beccarii (Aschers) and Surrounding Environment along the Central West Coast of India; *Mahasagar Bulletin of the National Institute of Oceanography*, **16(4)**: 429-434.

[17] Jagtap, T. G., 1985. Ecological studies in relation to the mangrove environment along the Goa coast, India. A Ph.D. Thesis submitted to Shivaji University, Kolhapur.

[18] Jagtap, T. G., 1986. The mangroves; *Proceedings of national symp. on Biol. utilization andconservation of mangroves,* November 1985: 183-195.

[19] Jagtap, T. G.; Chavan, V. and Untawale, A. G. 1993. Mangrove ecosystems of India: a need for protection. Royal Academy of Sciences, *Ambio*. **22**: 252-254.

[20] Jagtap, T. G.; Desai, K. and Rodrique R. 2003. Coastal Vegitation: Pattern in a Tourism region;[In Coastal tourism, Environment and Sustainable Local Development (Eds.) Noronha, L. *et al*.,]; New Delhi; 221-150.

[21] Jagtap, T. G., and Nagle, Vinod L. 2007, Response and Adaptability of Mangroves Habitants from the Indian Subcontinent to Changing Climate, Royal Academy of Sciences, *Ambio* Vol. **36**, No. **4:** 328-334.

[22] Jensen, J. R., 1986. Introductory Digital Image Processing: A Remote Sensing Perspective, Prentice Hall, Englewoods Cliff, NJ.

[23] Jayatissa, L. P.; Dandough-Guegas, F. and Koedam, N. 2002. A review of the floral composition and distribution of mangroves in Sri Lanka. *Bot. J. Linn. Soc*. **138**: 29-43.

[24] Kathiresan, K., 2000. A review of studies on Pichavaram mangrove, south east India. *Hydrobiologia*, **430**: 185-205.

[25] Khalil, S.1999. Economic valuation of the mangrove ecosystem along the Karachi coastal areas. In: The Economic value of the Environment: Case of South Asia. Hecht, E. (ed) IUCN publ. online http://www.incnus.org/publications.html.

[26] Kumar, R. 2000 (a). Distribution of mangroves in Goa, *Indian Journal of Forestry,* **23(4)**:360-365.

[27] Kumar, R. 2000 (b). Status of natural regeneration in mangroves of Goa, *Indian Journal of Forestry,* **23(3)**: 342-348.

[28] Lillesand, T. M., Keifer, R. W. and Chipman, J. W. 2004. Remote Sensing and Image Interpretation; 5th edition; John Wiley and Sons (Asia), Private Ltd., Singapore: 763.

[29] MoEF. 1987. Government of India. Mangroves in India – Status Report, Ministry of Environment Forest, New Delhi: 52-55.

[30] Murali, R. M.; Vethamony, P.; Saran, A. K. and Jayakumar, S. 2006. Change Detection Studies in Coastal Zone Features of Goa, India by Remote Sensing; *Current Science*; **91**(6): 816-820.

[31] Nagi Hisham, M. H. 2008. Environmental Studies on Mangrove Cover in Goa and its Resident Crassostrea population; A Ph. D. Thesis submitted to Goa University, Goa.

[32] Nair, M.; Joseph, T.; Balachandran K. K. and Nair, K. K. C. 2003. Arsenic Enrichment in Estuarine Sediments- Impact of Iron and Manganese Mining 2003 (Int. symp. On Fate of arsenic in the environment, Dhaka Eds. by Ahmed, M. F.; Ali, M. A.; Adeel, Z. L.): 57-67.

[33] Naskar, K. R. and R. N., Mandal. 1999. Ecology and Biodiversity of Indian Mangroves, Daya Publishing House, New Delhi, India.

[34] Naskar, K. R. and Mandal, R. N. 2008. Diversity and classification of Indian mangroves: a review. Tropical Ecology, ISSN 0564-329549(2): 131-146.

[35] Naskar, K. R. and Mandal, R. N. 1999. Ecology and Biodiversity of Indian Mangroves. Milton Book Company, Dehradun: 3-34.

[36] Nayak, S. and Bhuguna, A. 2001. Application of remote sensing data to monitor mangroves and other coastal vegetation of India, *Indian J. of Marine Sciences*, Vol. **30 (4)**: 195-213.

[37] NRSA. 1983. Mapping of forest cover in India from satellite imagery (1972-75 and 1980-82), Summary Report, National Remote Sensing Agency, Hyderabad: 5-6.

[38] Pathak, M. C.; Kotnala, K. L. and Prabaharan, N. 1988. Effect of bridge piers on tropical estuary in Goa, *India J. Coast Res*. **58**: 229-244.

[39] Shetye, S. R.; Suresh, I. and Sundar, D. 2007. Tide and sea level variability. In The Mandovi and Zuari estruaries, edited by S. R .Shetye, M. Dileep Kumar and D. Shankar, National Institute of Oceanography: 29-38.

[40] Shetye, S. R.; Shankar, D.; Neetu, S.; Suprit, K.; Michael, G. S. and Chandramohan, P. 2007. The environment that conditions the Mandovi and Zuari estuaries. In: The Mandovi and Zuari estuaries. Editors, S. R. Shetye, M. Dileep Kumar and D. Shankar, Special publication of NIO: 3-28.

[41] Singh, I. G.; Kushwaha, S. P. S.; Ashutosh S. and Singh R. K. 2004. *Journal of the Indian Society of Remote Sensing*, Vol. **32**, No. **2**: 167-174.

[42] Singh, R. K. 2002. Mangroves of Goa. Goa Forest Department, Research and Utilization Division publication, Aquem, Margao, Goa: 1-10.

[43] Singh, S. K. 1998. Mangroves of Tamil Nadu, Annals of Forestry, Dehradun, 6 (1): 44-46.

[44] Spalding, M. D. 1997. The global distribution of status of mangrove ecosystems in : Intercoast Network International Newsletter of Coastal Management), Mangrove Edition [Published Quaterly by the Coastal Resources Management Project of the University of Rhode Island's Resources Centre and the U. S. Agency for International Development (USAID), Narragansett, Rhode Island, USA]: 20-21.

[45] Untawale, A. G.; Wafar, S. and Jagtap, T. G. 1982. Application of Remote Sensing Techniques to Study the Distribution of Mangroves along the Estuaries of Goa; [In Wetlands: Ecology and Management (Proceedings of the First International Wetlands Conference), New Delhi, 10-17 Sep. 1980; (Eds.); Gopal, B.; Turner, R. E.; Wetzel, R. G. and Whigham, D. F.]; National Institute of Ecology and International Scientific Publications.

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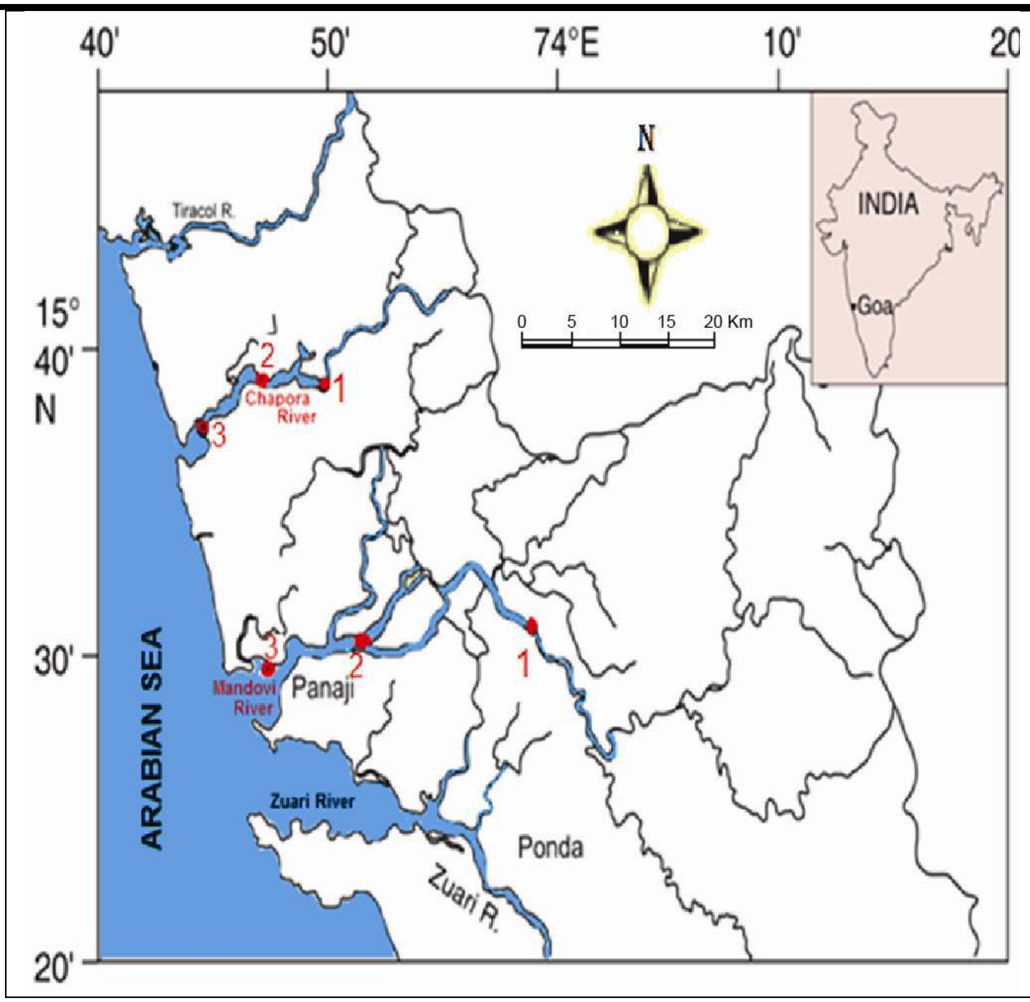

Fig.1: Study area-Mandovi estuary

Table.1: Change detection of mangroves (sq km) along Mandovi estuary

Estuary	Total Area	Mangrove extent in				% change (1997-2011)
		1997	2001	2006	2011	
Mandovi	348.480	5.563	7.783	6.808	12.054	116.680

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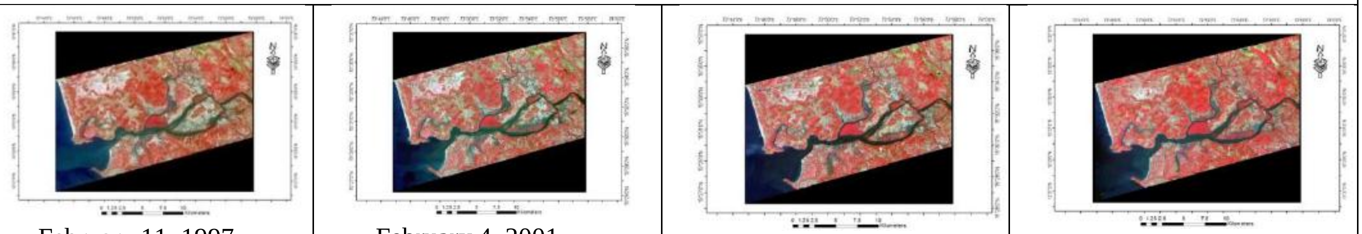
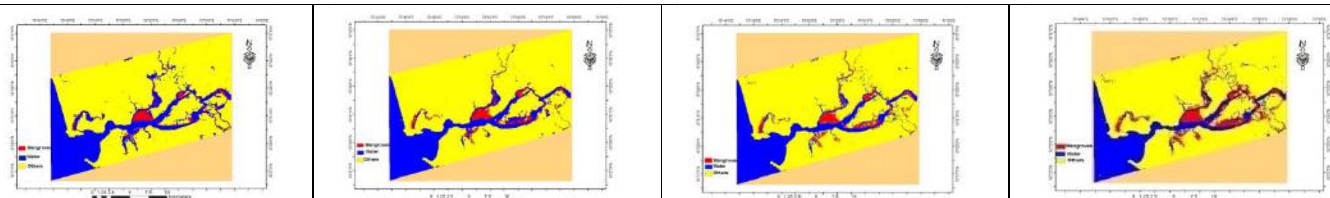
Satellite image of Mandovi estuary showing mangrove



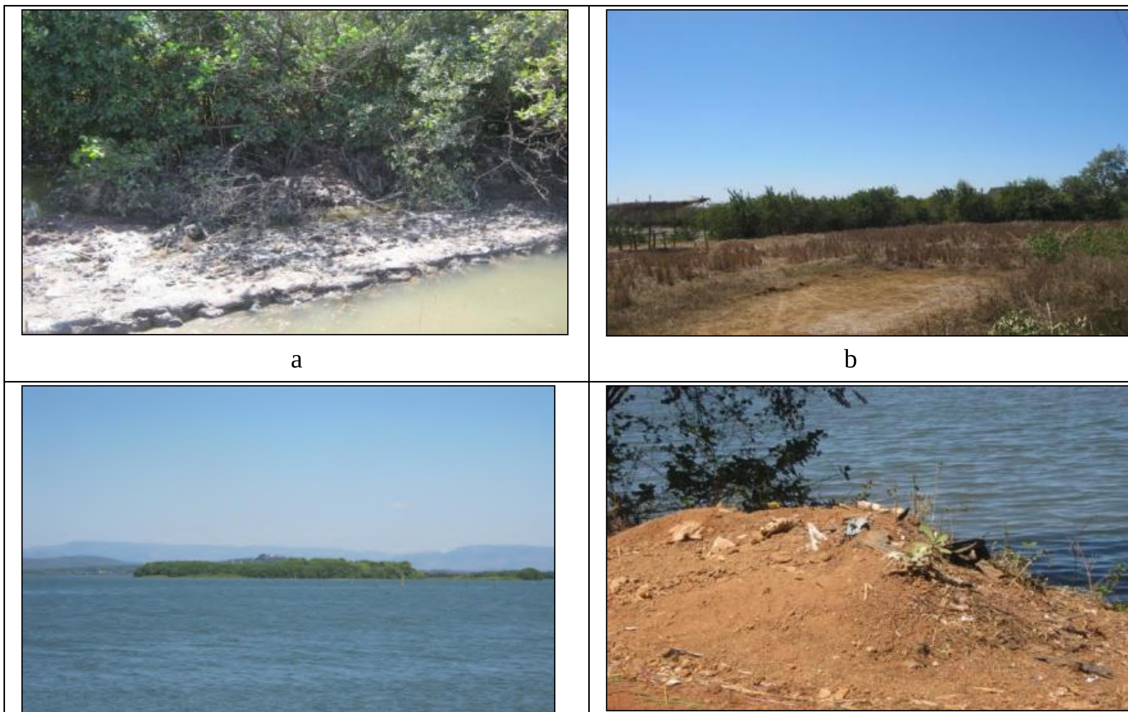
February 11, 1997	February 4, 2001	January 19, 2006	January 17, 2011

Land use land change along Mandovi estuary



February 11, 1997	February 4, 2001	January 19, 2006	January 17, 2011

Fig,2: Satellite images and land use land change of study area-Mandovi estuary during different years



a b c d

***Plate 1**: a. Mudflats providing substratum for the growth of mangroves, b. An abandoned agriculture field adjoining Mandovi estuary, c. A small island formed in the middle of Mandovi estuary, d. A freshly deposited reject along the bank of estuary*