ENVIRONMENTAL SENSITIVITY INDEX (ESI) MAPPING FOR OIL SPILL HAZARD - A CASE STUDY FOR KAKINADA COAST

Sriganesh. J[1], Kankara. R. S.[2], and Venkatachalapathy. R[3]
[1]Centre for Remote Sensing and Geoinformatics, Sathyabama University, Sholinganallur, Chennai, Tamil Nadu
[2]Integrated Coastal Marine Area Management Project Directorate, Pallikkaranai, Chennai, Tamil Nadu
[3]Centre of Advanced Study in Marine Biology, Faculty of Marine Science, Annamalai University, Parangipettai, Tamil Nadu

Abstract

The recent oil spill incidents such as oil rig blow up on 20th April, 2010 at Gulf of Mexico and ship accident on 7th August, 2010 at Mumbai has drawn attention of coastal managers to adopt proactive approach to manage the oil spills in marine environment. The oil spill in marine water has direct impact on coastal resources and community. Preparation of Environmental Sensitivity Index (ESI) map is the first step to assess the potential impact of an oil spill and minimize the damage of coastal resources. In this paper an attempt made to prepare an ESI map for sensitivity to oil spills of Kakinada coast. The Kakinada coast is subjected to high threaten to oil spill because of port, off shore oil exploration, dense mangrove forest and many industrial activities. Mapping the coastal resources, shoreline and coastal structures was carried out using Satellite images and GIS technology. The dataset used for the study include high resolution CARTOSAT-1 PAN (2007) image of 2.5 m resolution and LANDSAT ETM (2001) image of 30 m resolution. The Digital Image Processing software (ERDAS) & GIS software (ARCGIS 10) used for the satellite image processing and feature extractions. The coastal features classified into three major categories as: Biological, Human and Habitat. Mapping carried out upto 2 km into the land from shoreline. Coastal resources identified, mapped and extracted from satellite image by Supervised Classification technique with 83% accuracy. The important resources classified into mangrove, mudflat, coastal structure (Break Water, Jetty and Port), sandy beach, saltpan, tidal flats, etc. The sensitivity of shore was ranked as low to high (1 = low sensitivity; 10 = high sensitivity) based on geomorphology of Kakinada coast using NOAA standards (sensitivity to oil, ease of clean up, etc). The ESI map prepared at 1:25,000 scale and digital database have been generated for the Kakinada coast. The ESI maps are useful to the oil spill responders, coastal managers and contingency planners.

Keywords: Coastal, Contingency, Geomorphology, Supervised Classification.

Introduction

Though there is a reduction in the ship accidents in the past few decades, but still some accidents caused oil spills in the navigational channels of world coastal waters. There are countless opportunities for oil to get out of control. Many are due to mechanical failure of the equipment, or due to human carelessness and mistake. Since the world's main petroleum producing areas do not coincide with the areas of greatest consumption, the transportation of petroleum has increased with consumption. This increasing movement and storage of products has also increased the risk of inland water contamination. The recent oil spill incidents such as oil rig blow up on 20th April, 2010 at Gulf of Mexico and ship accident on 7th August, 2010 at Mumbai has drawn attention of coastal managers to adopt proactive approach to manage the Oil Spill in marine environment. Though many spill models available, the common widespread trajectory Oil Spill modeling is known as GNOME (Beegle-Krause, 2001).

The oil spills are the major environmental issues for coastal and marine environment which can change coastal ecosystems, valuable fishing grounds, long recreational and tourist beaches. Many environmental resource areas are located along and/or near the coast, "A sensitive Sea Area is the area of the coastal line which is vulnerable and in need of special protection due to ecological, social, economical, educational reasons and or scientific reasons in face of natural causes or human actions, especially marine navigational activities and requires special protective measures." (Danehkar, 2002). Many factors, such as local currents, weather, water temperatures and the composition of the oil itself, among others, affect the degree of long term environmental damage from oil spills. The potential threat from operational and accidental spills events evoke visions of deposited coasts, oiled birds/turtles and economic losses from the ruined fisheries, closure of cooling water intakes/ power plants.

It is important to show all the coastal information in one map. Because, during a spill event, the responders should take the decision with a matter of time to minimize damage. So the first priority should be more on the high sensitive resource region. Mapping the coastal resources can be achieved using Satellite images, GPS surveying & GIS technologies (IMO 2010).

Prediction of the behavior and persistence of oil in intertidal habitats is based on an understanding of the dynamics of the coastal environments, not just the substrate type and grain size. The intensity of energy expended upon a shoreline by wave action, tidal currents, and river currents directly affects the persistence of stranded oil. The need for shoreline cleanup activities is determined, in part, by the slowness of natural processes in removal of oil stranded on the shoreline. The potential for biological injury, and ease of cleanup of spilled oil, are also important factors in the ESI ranking. Generally speaking, areas exposed to high levels of physical energy, such as wave action and tidal currents, and low biological activity rank low on the scale, whereas sheltered areas with associated high biological activity have the highest ranking. There is no single best possible approach for coastal habitat discrimination and mapping (Edwards, 2000; Seto and Fragkias, 2007). Some of the variables to consider when determining the appropriate methodologies are: i) Desired end product; ii) Extent of the study area; iii) Accuracy; iv) Time; v) Cost; vi) Field work (e.g. accessibility) Logistics. Remote sensing was used here as it constitutes a cost-effective approach for the synoptic sampling and mapping of resources of large areas over time, for land planning and monitoring purposes (Dahdouh-Guebas, 2002; Giri et al., 2008; Mumby and Edwards, 2000; Mumby et al., 2000; Thu and Populus, 2007). A systematic and effective coastal resource mapping carried out from the satellite images of LANDSAT ETM (2001) (for technical information http://eros.usgs.gov/products/satellite/landsat7.html) and CARTOSAT (2007). With all the above information an attempt made to prepare ESI map for sensitivity to oil spills of Kakinada coast.

Study Area Details:

Kakinada situated in the Andhra Pradesh state in the East Godavari district. Kakinada port is one of the intermediate ports in Andhra Pradesh located at latitude 16.9738ºN and longitude 82.2774ºE along the East Coast of India. Construction of deep-water port, establishment of fishing harbour and construction of breakwater are some of the events that have taken place in the recent years. Significant changes in the beaches on the east coast of India are expected. This coastal city is witnessing rapid growth of a Special Economic Zone (Presence of mangroves). It is a core to all the exploratory activity in the region due to its deep-water sea port and its proximity to the gas fields. The presence of a small island called Hope Island about 5 km from Kakinada coast makes Kakinada a natural harbor. Mangrove channels in the Godavari delta, one of India's largest estuarine systems.

The study area lies between the latitude of 16.73ºN to 17.02ºN and longitude of 82.2ºE to 82.36ºE. The area was restricted with 2 km to 5 km from the shoreline covering the entire Godavari mangroves (figure 1).

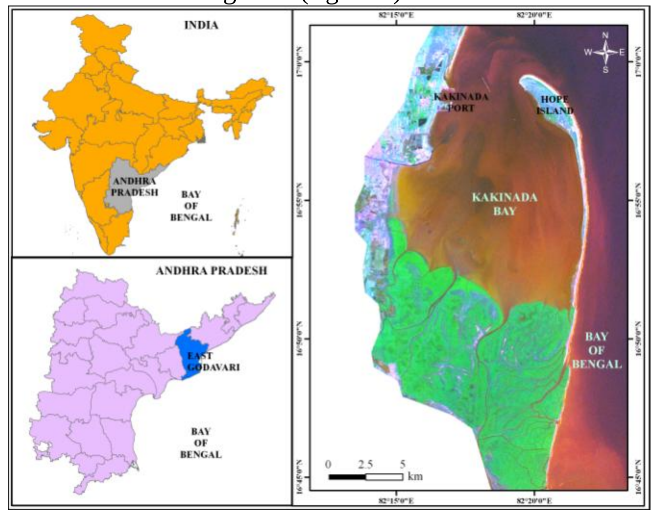

Figure 1. Research Area - Kakinada Coast, Andhra Pradesh, India

Materials & Methodology:

The research area is situated in the Andhra Pradesh, along the East Coast of India, The Kakinada boundary of this research shown in figure 1. The boundary was fixed by 2 km buffer in the northern region and 2 to 5 km in the southern region to cover the Coringa mangrove forest. LANDSAT ETM and CARTOSAT-1 (PAN) images (figure 2) were used for the mapping of coastal resource, shoreline & coastal structures. The common environmental classification was followed based is on http://response.restoration.noaa.gov/.

Satellite image classification technique (Supervised) was used to identification and mapping the coastal resources (Foody G.M, 2002). Field verification was carried out for the training sites. The resources were imported into the GIS environment for the preparation of Environmental Sensitive map with different map scale. The shoreline and coastal structures were digitized from the CARTOSAT 1 in ArcGIS 10 and were ranked based on the NOAA ESI 2002 guidelines. All the coastal information brought down into three types; 1. Shoreline Type, 2. Biological Resources, 3. Human-use-Resources.

Shoreline Type:

The boundary between land and coastal water knows as “shoreline". It is difficult to survey all along the coast to identify the type of shore (Michel, J., et al 1978). The satellite image interpretation is a simple way to map the large area in a short time. Here we used image classification technique to classify the sandy beaches, vegetative beaches etc...

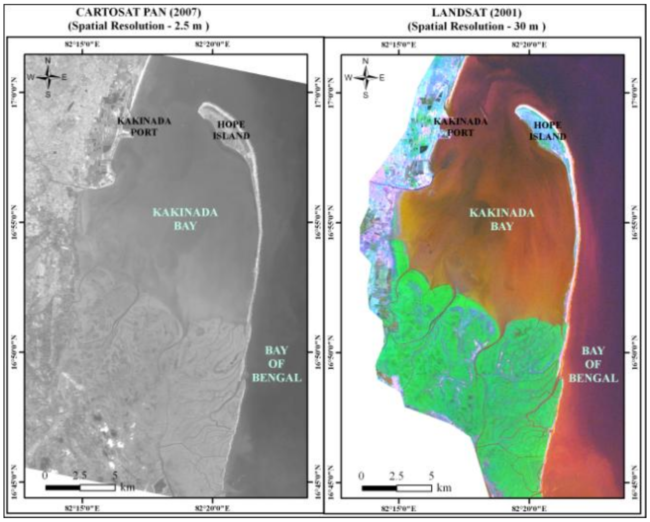

Figure 2. Satellites Images used for the Study. Left:Cartosat1 & Right: Landsat ETM.

Biological Resources & Sensitive groups:

The distribution of biological resources is shown using many different conventions. The major convention is an icon associated with a point, line, or polygon that shows the species' areal distribution. In the map, importance is placed on the following order:

- Rare, threatened, endangered, and special concern species (Turtle Beach)
- Commercial and recreational species
- Species of significance to the local community (Fish)
- Areas of high concentration
- Areas where sensitive life-history stages or activities occur (Nesting Beach)

When evaluating protection strategies, it is important to consider which species are most likely to be adversely effected to oiling at the time the spill occurs. Seasonality plays a significant role in where members of a particular species will congregate, and what life stages will be found. The ESI maps not only show the probable location and extent of various species, they also have supporting data tables that indicate the monthly presence and abundance. All the biological resource are organized into five major groups: 1. Birds, 2. Mammals, 3. Fish, 4. Reptiles, 5. Invertebrates and 6. Rare/endangered plants and special habitats. All these features are indicated by an icon placed in the general area (figure 3)

Human Use Resources & Features:

Human use resources are those that might be sensitive to oil, useful during response operations, or may be vulnerable during response activities. These may include:

- High-use recreational and shoreline access areas
- Officially designated natural resource management areas
- Resources extraction sites
- Cultural resources

These resources should be considered from a variety of perspectives. Some of these resources may be sensitive to oiling; others may be even more vulnerable to damage from cleanup equipment or responder traffic. Still other resources may be useful in determining possible access or staging locations. All together, the resources mapped on the ESI provide a very good starting point for planners and responders in the event of a spill. However it is important to remember the data reflect the conditions that existed at the time the maps were made. All of these resources have the potential to change. The important human use resources were classified into 1. Airport, 2. Archaeological site, 3. Historical site, 4. Industrial Site, 5. Marina, 6. Park, 7. Beach, and 8. Port. Like biological resources these resources also indicated by an icon placed in the general area (figure 3)

Results:

Classification of coast based on landforms using Image Processing Technique. The satellite images used for the study area were acquired and relevant bands were selected and stacked (Landsat). Georeferencing carried out with second order polynomial transformation of 10 Ground Control Point (GCP) collected from the field data collection using ARCPAD GPS with which the RMS error was minimized to 0.5. The projection set to Universal Transverse Mercator (UTM) and Datum WGS-84. The CARTOSAT-1 was used for the training area identification and also rectified with reference to the LANDSAT 7 in the same projection. Image fusion of high resolution (PAN) with multispectral (MSS) in the case of LANDSAT 7 the color distortion is much more significant even if greater operator have been employed (Yun Zang 2002). The image was then subjected to level-I classification to identify the coastal resource such as beaches, mudflats, mangroves, settlements, water bodies, saltpan, aquaculture, etc. The image processing for the coastal resource identification was done using the "guided clustering" technique which involves training area polygons (for salt pans, mangroves and settlement) being delineated from the CARTOSAT-1 as well as from LANDSAT-7 (marsh lands, agricultural lands and vegetation). The classification procedure as follows:

a) Training site extraction for classes (LANDSAT-7, CARTOSAT-1).
b) ISODATA-clustering using the training site (an automatic training site is extracted for the clustered image).
c) Maximum Likelihood Classification using the extracted training sites.
d) Recoding of the assorted pixels.
e) 3×3 filtering window used to minimize the bias.

The final classification output with 12 classes of the coastal resources was generated (table 1). The overall classification accuracy was derived from the classified data and the ground verified for the 12 classes resulted 83% in which the Overall Kappa Statistics = 0.8005

Table 1. Kakinada Coastal Resources

S.No	Resources	Total Area (sq. km)
1	Mangroves	115.34
2	Beach with Vegetation	2.78
3	Aquaculture	8.39
4	Barren Land	6.02
5	Beach	4.21
6	Saltpan	0.44
7	Agriculture	4.05
8	Coastal Structures	0.09
9	Mudflats	8.67
10	Settlements	11.21
11	Shrubs	4.36
12	Water Body	10.57

Shoreline, Coastal Structures Mapping & ESI ranking:

Shoreline & Coastal structures were mapped using digital images. The Costal structures like breakwater, sea wall, and jetty were identified and shoreline types were identified and shoreline classified in to 5 types (table 2) based on NOAA classification. The sensitivity of shore was ranked as low to high (1 = low sensitivity; 10 = high sensitivity) based on geomorphology of Kakinada coast using NOAA standards (sensitivity to oil, ease of clean up, etc).
The shoreline is ranked on a scale from 1 to 10 based on sensitivity to oiling determined by:
1. Relative exposure to wave and tidal energy
2. Biological productivity and sensitivity
3. Substrate type (grain size, mobility, penetration and trafficability)
4. Shoreline slope
5. Ease of cleanup
6. Ease of restoration

Optimally, the priority would be to protect the shorelines ranked with the higher values, as these are the more sensitive areas and the areas where oil would be more apt to persist and cleanup, if even possible, would be the most difficult. Mangrove forests are to be considered as the most important resource in the Kakinada coast. The groups of protected animals are of equal importance in the evaluation of protected areas of the Kakinada coastal area. The most important of these is the “Coringa Wildlife Sanctuary” in the back shore area, and the “Turtle Nesting Beach” in the coastal shore area. Amongst the recognized side effects, hydrologic forms, in particular estuaries are considered as a more important protective factor than other coastal genus. Amongst the various coastal resources, followed by mud flats, play a more important role than other mangroves. Mangrove coast was ranked as 10D which is considered as high economic importance and need to be protected first at the time of a spill event. The inter-tidal regions which are exposed during low tide and oil may strand on mudflats which is of high biological resource region ranked (9) next to mangroves followed by sheltered structures (8). The Coastal structures like seawall, port area and concrete jetties were ranked as 1 due to low biological resources and also these areas are easy to clean moreover oil cannot accumulate on the seawalls because of wave actions.

Table 2. Kakinada Shoreline Classification with ESI Rank

S.No	Shore type	ESI Rank	Length (km)
1	Riprap structures (Break Water)	6	1.14
2	Sheltered coastal structures	8	0.22
3	Coastal structures (Sea Wall)	1	3.72
4	Fine grained sandy beach	3	57.73
5	Mangroves	10D	25.58

Environmental Sensitive Map:

Environmental Sensitive Map was generated in the GIS environment. The ESI map prepared with all the information's covering the entire Kakainada coast with 1:150000 scale figure 3. The ESI maps with clear information about the coast of 1:25000 scale also prepared. This will be more useful for planning purpose at the time of oil spill event and also for environmental planning (figure 4).

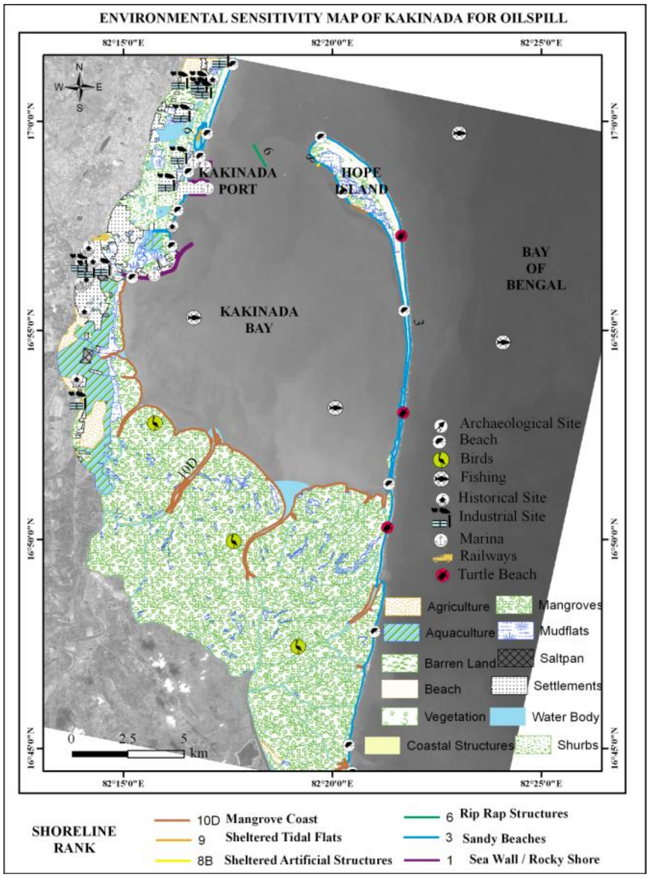

Figure 3. Classified Coastal Resources Overlaid on Cartosat 1 with ESI rank

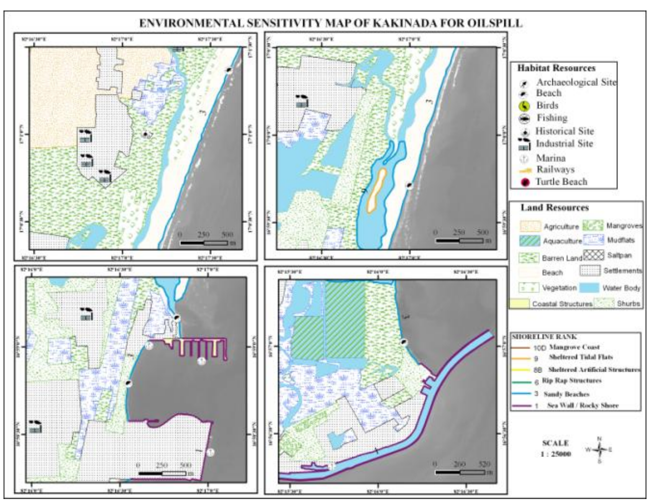

Figure 4. Environmental Sensitivity Maps for Oil Spill Hazard for Kakinada Coast.

Conclusion:

The Kakinada coast is subjected to high threaten to oil spill because of the presence of port, off shore oil exploration, dense mangrove forest and many industrial activities. Environmental Sensitive Map can be prepared easily in GIS environment and the shoreline can be classified into different classes using satellite image interpretation & classification technique. Their presence of long sandy beaches, huge mangrove eco system and intertidal regions made these regions to high threaten to oil spill. The Supervised classification technique is useful to identify and map the large coastal resources. The ESI maps are useful to the oil spill responders, coastal managers and contingency planners.

Acknowledgments

This work was carried out as part of Oil Spill Modeling Project in the 11th Plan Programme of ICMAM - PD under the Ministry of Earth Sciences, Government of India. The authors thank Dr. B. R. Subramanian, Former Director of ICMAM-PD, Chennai for his suggestions and encouragement. We also thank Dr. T. Balasubramanian, Former Director, CAS in Marine Biology, Faculty of Marine Science, Annamalai University, Portonova, for his support.

References

[1] Althausen, J. D. JR, C.G.ST.C. Kendall and Lakshmi. V, Alsharhan, A. S. Whittle, G. L. Using Satellite Imagery and GIS in the Mapping of Coastal Landscapes in an Arid Environment: Khor Al Bazam, Western Abu Dhabi, United Arab Emirates, Desertification in the Third Millennium, Ed. Alsharhan, A.S., et.al., Published by A.A. Balkema/Swets & Zeitlinger, Rotterdam, The Netherlands p.443-449, 2003.

[2] Beegle-Krause, CJ. (2001). General NOAA Oil Modeling Environment (GNOME): A New Spill Trajectory Model, Proceedings of International Oil Spill Confnference., Tampa, FL, 26 – 29 March 2001 St. Louis, MO: Mira Digital Publishing, Inc. vol. 2, pp. 865-871, 2001.

[3] Carvalho, M. & Gherardi, D. Mapping the environmental sensitivity to oil spill and land use/ land cover using spectrally transformed Landsat 7 ETM data, Brazilian. Journal for Aquatic Sciences and Technology, vol. 12, pp. 1-9, 2008.

[4] Foody, G.M. Status of land cover classification accuracy assessment. Remote Sensing of Environment, 80:185-201. 2002.

[5] Gad,A. & Shalaby, A. Assessment and mapping of desertification sensitivity using Remote Sensing and GIS Case study: Inland Sinai and eastern desert wadies, US–Egypt Workshop on Space Technology and Geo-information for Sustainable Development, Cairo, Egypt 14–17 June 2010, p. 6.

[6] Gundlach, E & Hayes, M. Vulnerability of coastal environments to oil spill impacts. Marine Technology Society, 12:18-27. 1978.

[7] IMO. Manual on Oil Spill Risk Evaluation and Assessment of Response Preparedness. 2010.

[8] Jayaraman, R. Status of GIS and Remote Sensing application in coastal resource management in India. 2006.

[9] Jensen, J.R.; Narumalani, S.; Weatherbee, O.; Murday, M.; Sexton, W.J. & Green, C.J., Coastal environmental sensitivity mapping for oil spills in the United Arab Emirates using remote sensing and GIS technology. Geocarto International, 2:5-13, 1993.

[10] Jensen, J. R,. Joanne, N,. Halls, and Jacqueline Michela. Systems Approach to Environmental Sensitivity lndex (ESI) Mapping for Oil Spill Contingency Planning and Response, photogrammetric engineering and remote sensing,p.1003-1013. 1998.

[11] Kankara, R. S. and Subramanian, B. R Oil Spill Sensitivity Analysis and Risk Assessment for Gulf of Kachchh, India, using Integrated Modeling, Journal of Coastal Research, 23(5),p.1251-1258. 2007.

[12] Kosmas, C.S., Poesen, J. and Briasouli, H. Key indicators of desertification at the ESA scale, In C.Kosmas, M. Kirkby and N. Geeson (eds), The Medalus Project. Mediterranean desertification and land use: manual on key indicators of desertification and mapping environmentally sensitive areas to desertification, 11-30. European Union, dir. 1882, 1999.

[13] Michel, J., M.O. Hayes, and P.J. Brown. Application of an oil spill vulnerability index to the shoreline of lower Cook Inlet, Alaska. Environmental Geology(2)2:107-117. 1978.

[14] Michel J. and Hayes M. O. Chapter 3: Sensitivity of Coastal Environments to Oil. In An Introduction to Coastal Habitats and Biological Resources for Oil Spill Response. Prepared for NOAA, Hazardous Materials Response and Assessment Division, 83 pp., Seattle, Washington. 1992.

[15] NOAA Environmental Sensitivity Index Guidelines, Version 3.0. NOAA Technical Memorandum NOS OR&R 11, Hazardous Materials Response Division, Office of Response and Restoration, NOAA Ocean Service, 2002.

[16] NOAA Desktop GIS for Environmental Sensitivity Index Mapping. Office of Response and Restoration, NOAA Ocean Service,. 1997.

[17] Nayak Shailesh and Bahuguna Anjali. Application of remote sensing data to monitor mangroves and other coastal vegetation of India, Indian Journal of Marine Science, vol. 30(4), p.195-213, 2001.

[18] Pineda-Bello, J,. Liceaga-Correa, A.M., HernAndez-Nunez, H. and Ponce-hernandez, R. Using aerial video to train the supervised classification of Landsat TM imagery for coral reef habitats mapping, Environmental Monitoring and Assessment, p.145-164.,2005.

[19] Santos, C. F and Andrade, F. Environmental Sensitivity of the Portuguese Coast in the Scope of Oil Spill Events-Comparing Different Assessment Approaches, Journal of Coastal Research,p.885-889, 2009.

[20] Zhang, Y. Problems in the fusion of commercial high resolution satellite images as well as Landsat 7 images and Initial solutions, in International Archives of Photogrammetry and Remote Sensing (IAPRS), 34, Part 4, ISPRS, CIG, SDH Joint International Symposium on "GeoSpatial Theory, Processing and Applications", Ottawa, Canada., July 8-12, 2002.

Biographies

JEYAGOPAL SRIGANESH received his Bachelor of Science degree in Geology during 2003 from University of Madras, Chennai, Tamil Nadu. He received his Master of Science degree in Applied Geology during 2005 from Anna University, Chennai, Tamil Nadu. He completed his Master of Philosophy degree in Geology during 2006 from University Madras, Chennai, Tamil Nadu with distinguished. Now he is working as a Scientist at Centre for Remote Sensing and Geoinformatics at Sathyabama University, Chennai, Tamil Nadu. J.Sriganesh may be reached at sriganeshgeo@gmail.com

DR.R.S.KANKARA is a Scientist F works at Integrated Coastal and Marine Area Management Project Directorate which is under the Ministry of Earth Sciences at Chennai, Tamil Nadu. He is specialized in mathematical modeling, GIS applications for coastal/nearshore, hydrodynamics, Oil Spill modeling and management plan. He may be reached at kankara@icmam.gov.in

DR.R.VENKATACHALAPATHY is a Professor of Physics works at Centre for Advanced Study in Marine Biology of Annamalai University at Parangipettai, Tamil Nadu. He may be reached at venkatr5@rediffmail.com