International Journal of Ecology and Environmental Sciences 39 (3): 147-157, 2013
ISSN: 0377-015X (Print); 2320-5199 (Online)

Monitoring Mangrove Forest Reclamation Using Geospatial Tools in Can Gio Mangrove Biosphere Reserve, Viet Nam

SARNAM SINGH *[1], NGUYEN VIET LUONG [2] AND TRUONG THI HOA BINH [3]

[1] *Indian Institute of Remote Sensing, ISRO, 4 Kalidas Road, Dehradun 248001, India*
[2] *Remote Sensing Application Department, Space Technology Institute (STI), Vietnam Academy of Science and Technology (VAST), Hanoi, Viet Nam*
[3] *Center for Satellite Reseach and Development, Vietnam National Satellite Center (VNSC), Vietnam Academy of Science and Technology (VAST), 18 Hoang Quoc Viet Street, Cau Giay Dist., Hanoi, Viet Nam*
* Corresponding author; *Email: sarnam.singh@gmail.com*

ABSTRACT

We have studied the vegetation cover and land use dynamics of mangrove ecosystem in last one decade to monitor the improvement due to reclamation. Three dates SPOT HRV satellite data (1999, 2004 and 2009) were used. Post classification comparison approach was followed. The classification scheme was uniform and the mapping accuracy was over 82.78 to 87.78% for 1999, 2004 and 2009. The total area considered in this study was 74,048.75 ha. During 1999 to 2009, the dense mangrove forest increased by 10,456.13 ha from 1999 to 2004 and 4,150.56 ha from 2004 to 2009. During 1999 to 2004, the area of open mangrove forest decreased by 6,912.57 ha because much of the open mangrove forest got converted to dense forest. However, from 2004 to 2009 the open mangrove forest increased by 1,755.64 ha. From 1999 to 2004 and 2004 to 2009 most of young forest/shrub areas decreased by 6,921.57 ha and 2,620.45 ha respectively, due to protection and reclamation. Over the years, from 1999 to 2009, most of the agricultural land area decreased, and it was maximum in the period from 2004 to 2009. The water body of area changed very little because the shrimp ponds area did not expand. From 1999 to 2004, the barren land area changed a little; however, from 2004 to 2009, the barren land has greatly decreased (1,076.16 ha). The study indicates that monitoring of the mangrove forests resources using satellite data is significant to understand the impact of anthropogenic pressures as well as management action.

Key Words: Satellite Data, SPOT HRV, Mangrove, Pesticide, Herbicides, Shrimp Cultivation, Ecosystem Restoration.

INTRODUCTION

Vietnam has rich coastal natural resources including mangroves. It has eight International Biosphere Reserves, of which seven lie along the coasts. The mangrove ecosystems play an important role in the coastal regions by its functions and services which include supplying food and fuel wood for humans, providing niche for wildlfe, and natural protection against erosion and reducing impact of storms, cyclones, tsunami, and carbon sequestration (Iverson et al. 1993, Kathiresan and Rajendran 2005, Forbes and Broadhead 2007, Barbier, 2008, Alongi 2008), sea level rise etc. and therefore, it acts as bioshield (Kamthonkiat et al. 2011). Because of their importance and key coastal ecosystems, Mangrove forests have drawn attention increasingly world over in view of the global warming and possible impact. The impact of large scale land use change for agriculture, e.g. shrimp culture, has led to environmental problems in the mangrove ecosystems (Graaf and Xuan 1998, Johnston et al. 2002). Attempts have been made to assess the impact of anthropogenic activies such as impact of pesticides, herbicides, shrimp cultivation, etc, on mangrove forests of Vietnam using multidate satellite images (Tong et al. 2004). Thus, the management, protection and development for this coastal natural resources are very essential. However, mangrove management is quite complex because of its unique geographic conditions, inaccessibility, dynamisms, productivity, etc. Therefore, satellite data are more amenable.

Multi-date satellite remote sensing images are used widely to monitor the land use and land cover (LULC) world over particualry mangroves (Dwivedi et al. 1999, Gao 1999, Phinn et al. 2000, Reddy et al. 2007, Binh et al. 2008a,b). Several approaches are available to monitor the changes using satellite data; some of the most common ones are image differencing, ratioing (Normalised Difference Vegetation Index), Principal Component Analysis, Post Classification Comparision, Image Regression, Vector Change Analysis, etc. (Singh 1989, Malingreau and Belward 1992, Green et al. 1998, Tong et al. 2004, Gupta et al. 2005, Reddy and Roy 2008, Kamthonkiat et al. 2011). The basic assumption using digital satellite data-based analysis is that there has to be a significant difference in reflactance. Therefore, sufficient precaution is required for deciding a threshold for change (Fung and LeDrew 1988). Each one of these may have its own advantages and disadvantages in terms information extraction but most significant factors are availability of satellite data from same sensor and season for vegetation analysis. To minmize misinterperetation and to have high accuracy it is important to have uniformity in terms of pixel size, radiometry, reflectance, phenology, etc. A vegetation index, now called the generic Normalized Difference Vegetation Index (NDVI), developed by Rouse et al. (1974), is also frequently used for such studies (Running et al. 1994, Huete et al. 1997). Townshend et al. (1992) looked at the impact of mis-registration by looking at difference in NDVI values for two dates. Green et al. (1994) found image differ-encing of a single band to work better than differences in a vegetation index. Howarth and Wickware (1981), Coppin and Bauer (1994) and Singh (1989) proposed several procedures for LULC change detection. However, Blasco et al. (1998) observed that there is no standard image processing method that can be applied for the identification and delineation of coastal eco-systems. For management and effective decision making, it is not sufficient to know the change or area alone but most important is the direction of change, i.e. from which land use/land cover to which land use/land cover; therefore, post classification comparison approach has been followed by Gupta et al. (2006), Panigrahy et al. (2010) is adopted here.

Can Gio Mangrove forest in Ho Chi Minh City in Vietnam was selected for the study because it is a well-developed mangrove habitat and is currently reclamed in-spite of the serious damage suffered during the Vietnam War (Ross 1975) and are rich in species composition (Tong et al. 2004). At present, it is being protected and developed and on January 21, 2000, MAB/UNESCO committee recognized Can Gio mangrove forest as an International Biosphere Reserve. There are some 68,213 people living within the biosphere reserve boundaries, 54,000 of which live in the transition area. The application of remote sensing technology in forest study in Vietnam is mostly limited to mapping of LULC. But, the application of this technology to monitor the growth, the development and the inner change of species association structure of flora are still wanting. Since most of mangrove forest was lost due to spray of pesticides and herbicides by US Army until 30 April 1975, therefore, it is necessary to study the current status and imapct of management, conservation, rehabilitation/restoaration and development of Can Gio Biosphere Reserve.

MATERIALS AND METHODS

Study Area

Can Gio mangrove forest lies entirely within the Can Gio district of Ho Chi Minh City. The area lies in geographic co-ordinate between 10° 22' 14" and 10° 40' 00" N Latitudes and 106° 46' 12" and 107° 00' 59" E Longitudes. It shares its boundary with Nha Be district in the North, with East Sea in the South; with Dong Nai and Ba Ria–Vung Tau Provinces in the East and with Long An and Tien Giang Provinces in the West. From 1964-1970, Can Gio District, like many other mangrove areas, was sprayed heavily with herbicides: 665,666 gallons of Agent Orange, 343,385 gallons of Agent White and 49,200 gallons of Agent Blue. As a result, 57% of the mangrove forest in this district was destroyed (Ross 1975). In some areas large trees of *Rhizophora, Sonneratia*, and *Bruguiera* were killed by the herbicides spraying and in many areas the vegetation was completely destroyed. Only *Avicennia* and *Nypa* were able to survive and regenerate and later also replanted. And new plants such as *Phoenix paludosa* Roxb. and *Acrostichum aureum* L., a fern which presently dominates elevated land, have expanded since then. Some individual trees of *Avicennia officinalis* L. and *Excoecaria agallocha* L. are now found only as shrubs. After many years of chemical spraying, the degraded land still has only scattered small trees of *Avicennia*, *Ceriops, Lumnitzera, Thesphesia, Pluchea,* or *Sesuvium* *portulacastrum* (L.) L. and *Paspalum vaginatum* Sw. Since 1978, a vast programme of reforestation had been undertaken by Ho Chi Minh City Forestry Department with the main species being *Rhizophora apiculata* Blume. Until now, reforestation efforts have brought vast ecological improvements to the environment. Wild animals such as monkeys, otters, pythons, wild boars, crocodiles and various kinds of birds have returned to the artificially regenerated mangrove forests. Since 1991, the Can Gio mangrove forest has been declared an "Environmental Protection Forest" by the Council of Ministers (Decree No. 173 CT/H date May 29, 1991).

Topographically, the Can Gio mangrove forest forms a basin with an altitude range of 0.0 m–1.5 m in the northeastern sector of the forest, with downward inclines from the east, south and west. The Can Gio mangrove forest developed out of a comparatively recent brackish swamp, as the alluvium from the Sai Gon and Dong Nai rivers created the soil foundation. Four main soil types can be found here are: saline soil; saline soil with low alum content; saline soil with high alum content and soft sandy soil with mud deposits at the seashore. High humidity and temperatures, in general, characterize the climate of Can Gio mangrove forest. There are two seasons and the area is affected by equatorial monsoons, rainy season from May to October and dry season from November to April. The Can Gio mangrove forest lies in a zone with a bi-diurnal tidal regime (i.e. two ebb and flow tides per day). Tidal amplitudes range from about 2 m at mean tide to 4 m during spring tides. Precipitation in Can Gio is the lowest in the Ho Chi Minh City area, with an average range of 1300 – 1400 mm per annum. Prior to April 30th 1975 Can Gio mangrove forest covered an area of 40,000 ha; the canopy was dense, with trees over 25 m tall and 25–40 cm diameter. About 108 plant species belonging to 48 genera were found here. *Rhizophora apiculata* Blume constitutes the main part of the flora, together with other assemblages of *Sonneratia alba* J.E. Smith, *Avicennia alba* Blume, *Rhizophora mucronata* Lam., *Bruguiera* spp., *Xylocarpus* spp., *Lumnitzera* spp., *Phoenix paludosa* Roxb., *Excoecaria agallocha* L. etc. The dominant mangrove species are: *Aegyceras corniculatum* (L.) Blanco, *Avicennia alba* Blume, *Avicennia lanata* Ridley, *Ceriops* spp., *Excoecaria agallocha* L., *Hibiscus tiliaceus* L., *Lumnitzera littorea* (Jack) Voigt, *Lumnitzera racemonsa* Willd., *Rhizophora apiculata* Blume *and Sonneratia alba* J.E. Smith. In 1917, forest regulations were such that land exploitation was issued. Because of desperate circumstances of unemployment and poor transportation, exploitation was rampant due to market demand for *Rhizophora apiculata* Blume, *R. mucronata* Lam. and *Ceriops* spp., the forest became exhausted, the structure and the nature of the indigenous tree assemblages changed until they were quite different from those of the original forest.

After 32 years of rehabilitation and development by the hard efforts of Ho Chi Minh city committee and people, Can Gio forest become the largest replanted mangrove area in Viet Nam with a beautiful natural landscape and diversity of both flora and fauna.

Data

In this study three-time data were used and these were from Système Probatoire de l'Observation de la Terre satellite: SPOT-4 1999 (March), SPOT-5 2004 (April) and SPOT-5 2009 (March) (Figure 1a,b,c). SPOT (HRV) with 1, 2 and 3 bands has 20 m spatial resolution. Considering the issues (season, sensor characteristics, etc.) and related errors involved in the change detection analysis appropriate near-ideal conditions for monitoring the SPOT satellite data of three-times of same season were used. As tree leaves reflect differently due to phenology and age and temperatures disparities, their reflectance varies from season to season particularly during transition period when older leaves are already senescent, drying and shedding and younger leaves are different stages of drying. The preprocessing of satellite data were done for removing radiometric and geometric distortions. First order radiometric corrections were done by dark pixel subtraction technique (Lillesand and Kiefer 1999). The common uniformly well distributed 25 ground control points (GCPs) were considered for rectification of geometric distortions and the images were resampled using first order nearest neighbors interpolation model with an error of less than half pixel. To avoid mis-registration, all the data sets were then co-registered for further analysis (McManus 1992, Townshend et al. 1992). Normalization of the all the images using histogram matching was performed to circumvent the errors in digital change detection procedures. A uniform classification scheme in conformity with forestry practices in Vietnam was taken. Classification scheme land covers as: (a) Level 1 have two classes: Forest and Non-forest and (b) Level 2 have six classes: Dense forest (canopy of forest >75%, height of tree >10 m, and diameter of tree from 20-40 cm), Open forest (canopy of forest <75%, height <10 m and diameter of tree from <20 cm), Scrub, Agriculture land, Water Body and Barren soil.

Mapping of Mangroves and Land Use/Land Cover

The standard procedure of supervised classification approach was followed and maximum likelihood classification algorithm was used for forest cover density mapping for all the datasets of 1999, 2004 and 2009. Handheld GPS (Garmin 12 channel) was used to record the geo-locations and for image analysis and classification ERDAS IMAGINE 9.2 and ArcGIS 9.2 were used. Reconnaissance survey and ground truth were done in the entire study area. Training sites were identified in homogenous areas in each class covering the spectral variability. The training site statistics was evaluated and sites were modified accordingly. A uniform classification scheme was adopted and forests were classified into dense mangrove forest (dense forest), open mangrove forest (open forest), young forest/shrub, agriculture land, water body and barren land. Attempts were made to follow similar classification scheme. Fifty-four locations were considered as ground check for accuracy assessment.

RESULTS

Land Cover Mapping

(a) Land cover map of 1999

The land cover map based on supervised classification of SPOT 1999 is shown in Figure 2 and the area analysis of LULC is given in Table 1. The dense forest area is 12.89%, open forest is 23.73%, young forest/shrub is 15.83%, agriculture land is 2.76%, water body is 41.67% and barren land is 3.11%. The overall accuracy is 83.89% and average accuracy of 81.95%. Kappa statistics (K^) is 0.7894.

(b) Land cover map of 2004

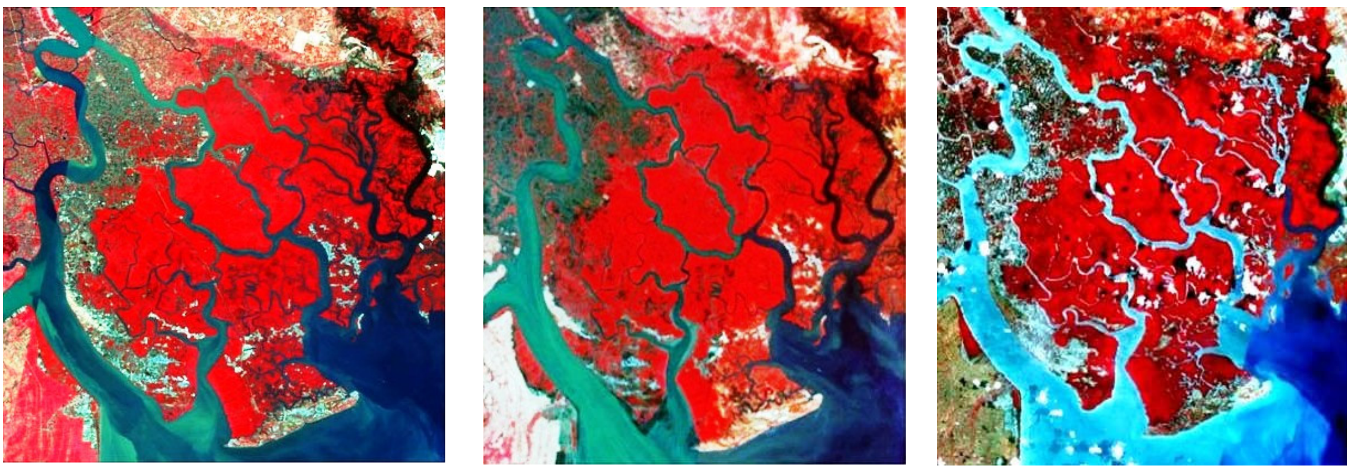
The land cover map based on supervised classification for 2004 is given in Figure 3. The area statistics for LULC of 2004 is given in Table 1. Dense forest is 27.01%, open forest is 14.38%, young forest/shrub is 14.53%, agriculture land is 1.26%, water body 39.65% and barrens land is 3.16%. The overall classification accuracy of mapping using confusion matrix is 87.78% and average accuracy of 82.90%. Kappa statistics (K^) is 0.82%.

(c) Land cover map of 2009

The land cover map based on supervised classification for the 2009 is shown in Figure 4. The area statistics for LULC of 2009 is given in Table 1. Dense forest is 32.62%, open forest is 16.90%, young forest/shrub is 10.84%, agriculture land is 1.48%, water body 36.45% and barren land is 1.71%. The overall accuracy assessment of mapping 82.78% and average accuracy of 70.00%. Kappa statistics (K) is 76.09%.

Analysis

The post classification comparison method was followed to find the changes from 1999 to 2004 and from 2004 to 2009. The result of the change from 1999 to 2004 is shown in Figures 5a and 5b. The analysis indicates that the area with no change is 56.02%, while the area with negative change (loss of forest) is 31.52% and the area



(a) (b) (c)

Figure1. SPOT HRV False Colour Composite (a) 1999, (b) 2004 and (c) 2009.

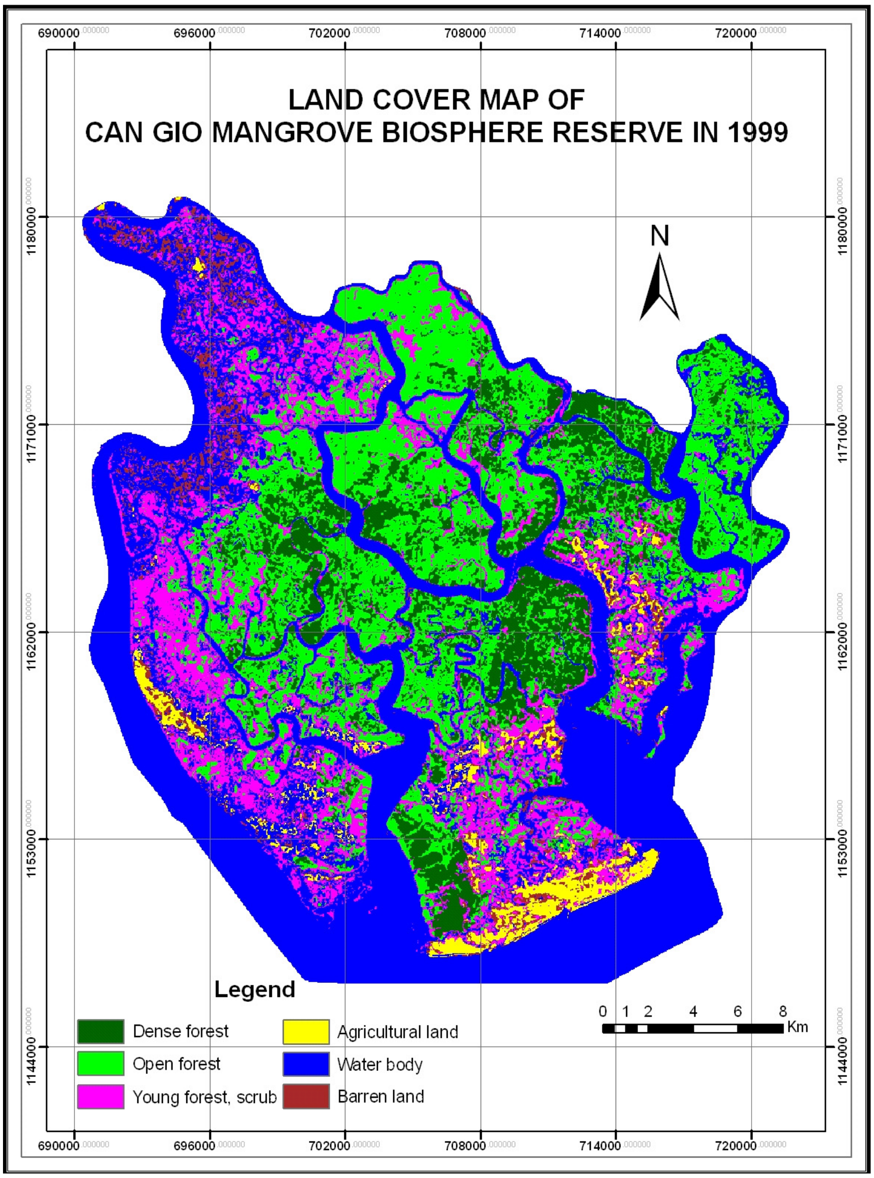


Figure 2. Mangrove and LULC map (1999)

Table 1. Area statistics (ha) of three-times LULC

LULC Class	1999		2004		2009	
	Area (ha)	Percent	Area (ha)	Percent	Area (ha)	Percent
Mangrove Dense forest	9546.93	12.89	20003.06	27.01	24153.62	32.62
Mangrove Open forest	17570.80	23.73	10649.23	14.38	12513.72	16.90
Mangrove Young forest	11724.88	15.83	10758.08	14.53	8028.78	10.84
Agriculture land	2045.64	2.76	936.06	1.26	1095.22	1.48
Water body	30855.51	41.67	29361.03	39.65	26992.28	36.45
Barren land	2304.99	3.11	2341.29	3.16	1265.13	1.71
Total	74048.75	100.00	74048.75	100.00	74048.75	100.00

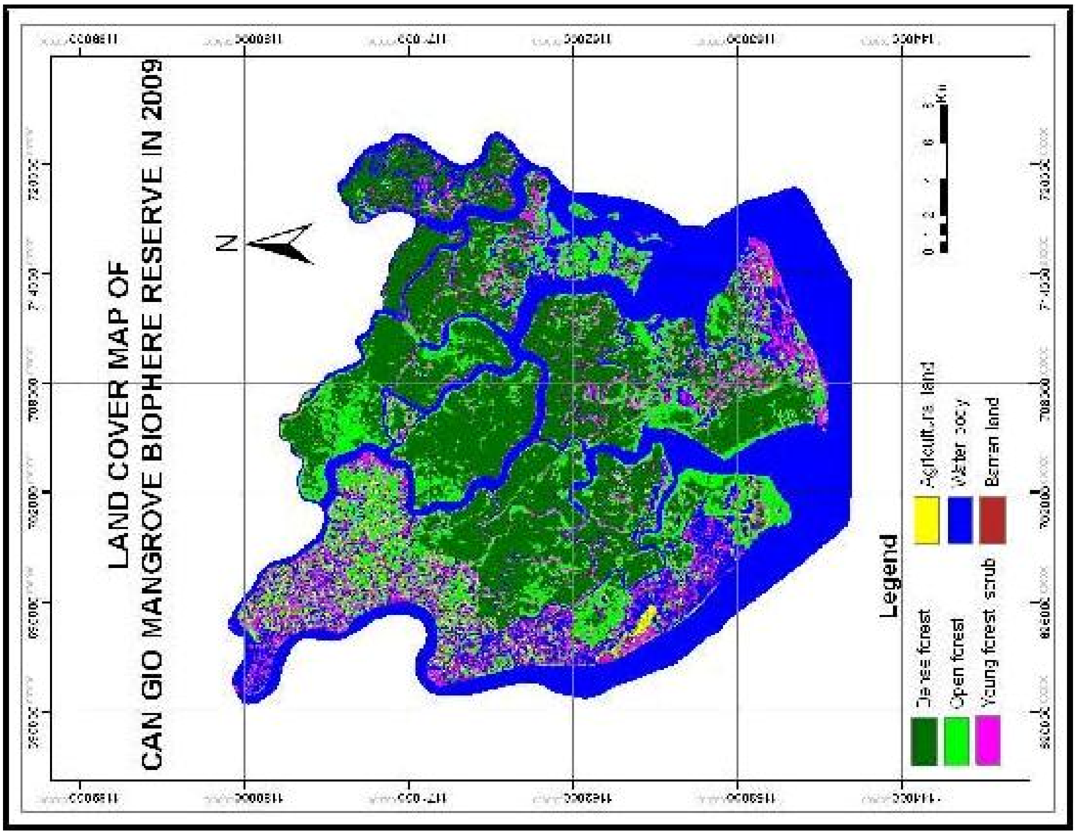


Figure 3. Mangrove and LULC map (2009)

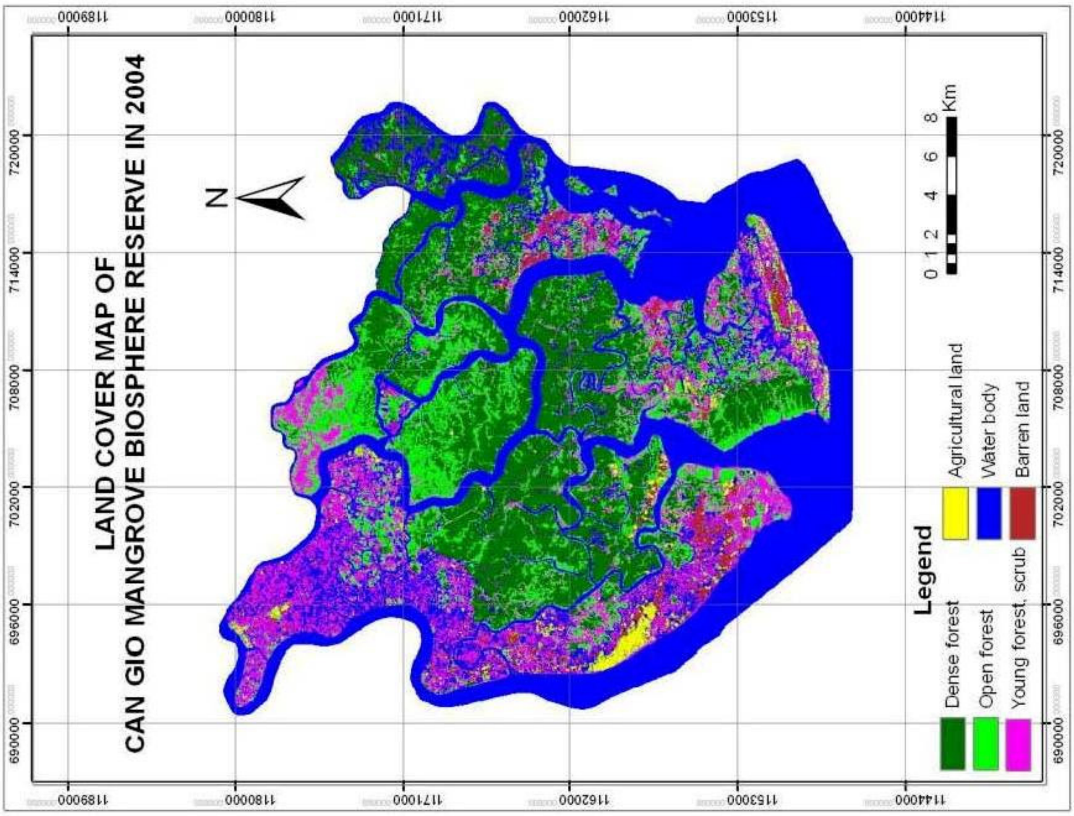


Figure 3. Mangrove and LULC map (2004)

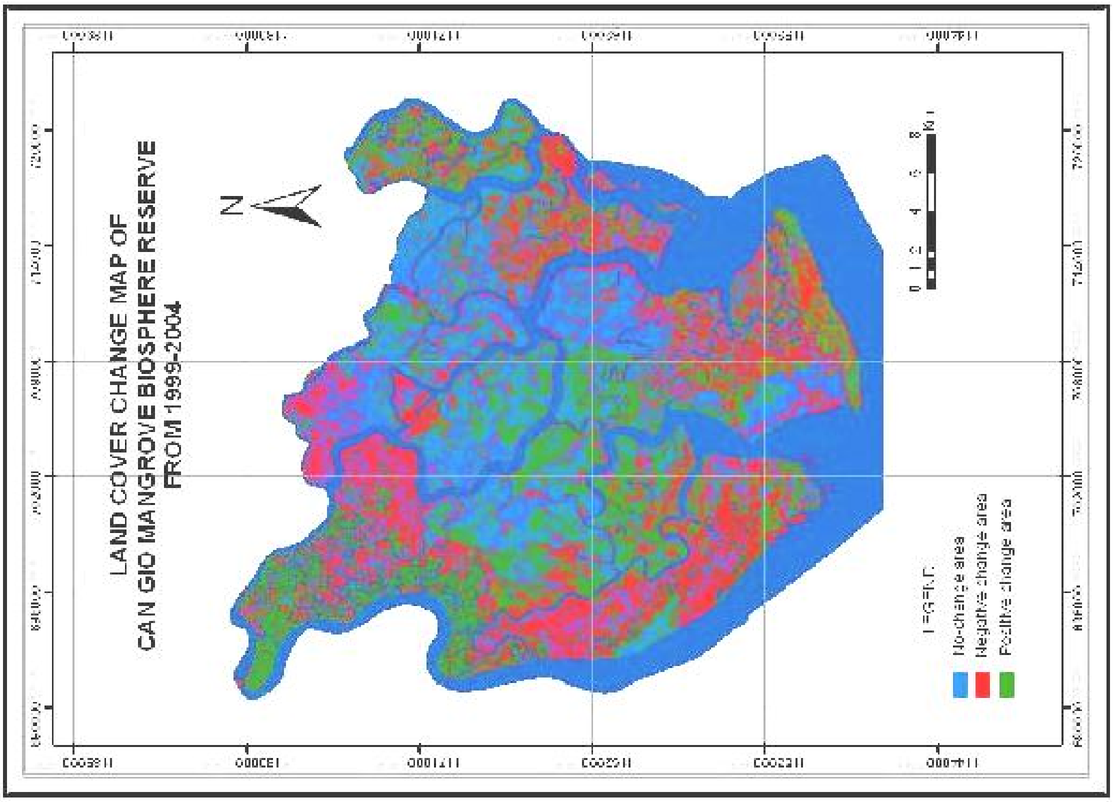


Figure 5 b. Land cover change map reclassified for simplification

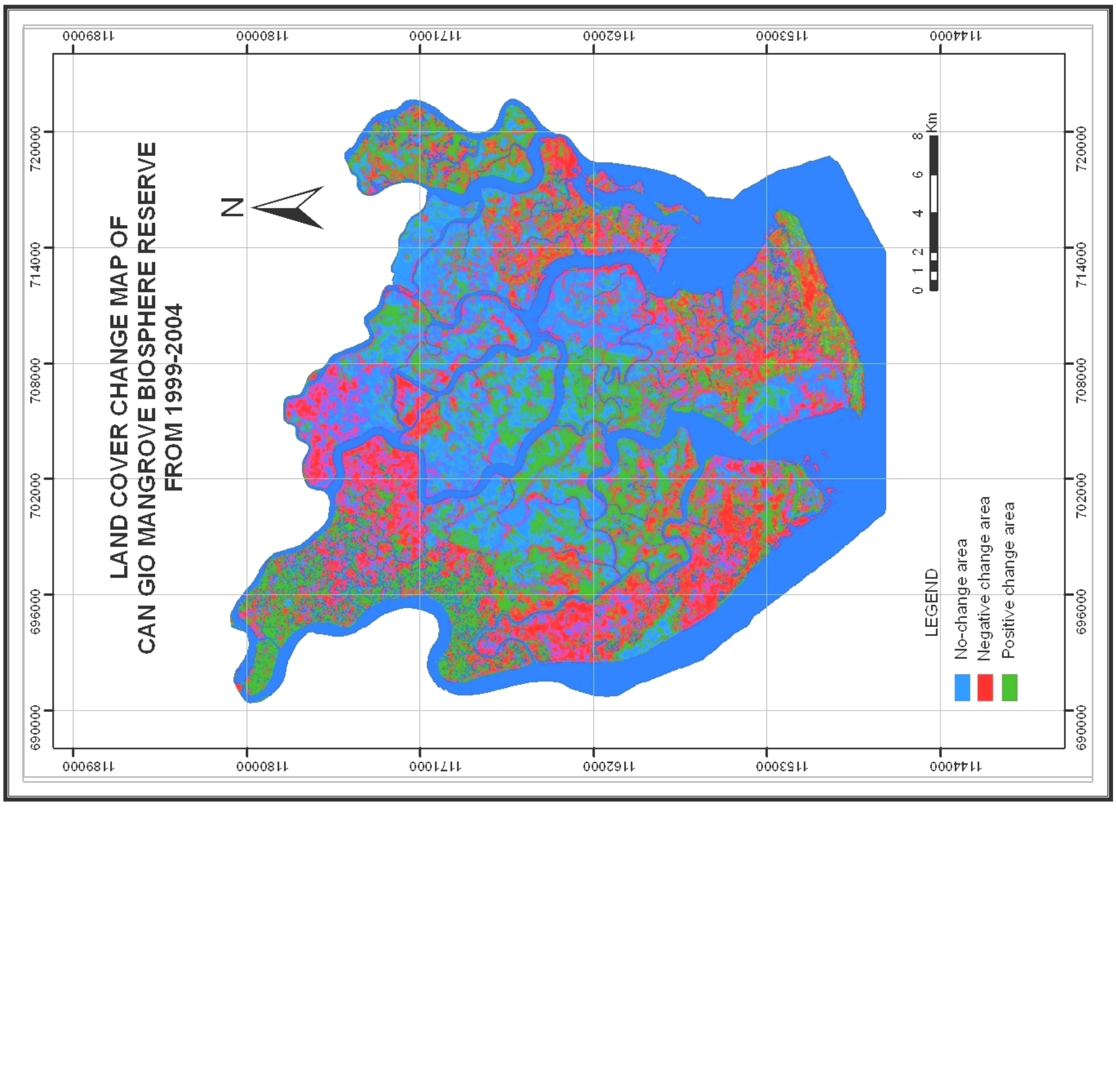


Figure 5a. Land Use Land Cover change map from 1999 to 2004

Table 2. Area change matrix for the period 1999 to 2004 (units: ha)

	Dense forest	Open forest	Young forest/shrub	Agriculture land	Water body	Barren land	Total
Mangrove Dense forest	8313.65	760.08	288.59	2.07	180.78	1.76	9546.93
Mangrove Open forest	9729.94	4831.00	2120.74	37.34	779.49	72.29	17570.80
Mangrove Young forest	1401.37	3054.48	3905.14	177.11	2683.49	503.29	11724.88
Agricultural land	10.92	420.98	501.41	347.33	217.71	547.29	2045.64
Water body	522.81	1352.04	3186.22	220.68	24719.62	854.14	30855.51
Barren land	24.37	230.64	755.96	151.53	780.21	362.28	2304.99
Total	20003.06	10649.22	10758.06	936.06	29361.30	2341.05	74048.75

with positive change (gain of forest) area is 12.46%. During 5 years (1999-2004), the dense mangrove forest area increased by 10,456.13 ha. While the open forest area declined by 6,921.57 ha, young forest/shrub area decreased by 966.80 ha as it got converted into dense forest. The agriculture land area declined by 1,109.58 ha and the water body area decreased by 1,494.48 ha, but barren land area increased by 36.30 ha (Tables 2 to 4).

Table 3. Mangrove forest and LULC change during1999 to 2004)

LULC Classes	Area (ha) 1999	Area (ha) 2004	Change (ha)
Mangrove Dense forest	9546.93	20003.06	10456.13
Mangrove Open forest	17570.80	10649.23	- 6921.57
Mangrove Young forest	11724.88	10758.08	- 966.80
Agriculture land	2045.64	936.06	-1109.58
Water body	30855.51	29361.03	-1494.48
Barren land	2304.99	2341.29	36.30
Total	74048.75	74048.75	

Table 4. Area change distribution from 1999 to 2004

Class	Area (ha)	Percent (%)
No change	41479.02	56.02
Negative change	23343.56	31.52
Positive change	9226.17	12.46
Total	74048.75	100.00

The results of geospatial change maps from 2004 to 2009 based on post-classification comparison method are shown in Figures 6a and 6b. The analysis indicates that no change area is 58,867.88 ha (65.99%), the negative change area is 18,495.51 ha (24.98%) and the positive change area is 6,685.36 ha (9.03%). During the 5 years (2004-2009), the dense forest area increased by 4,150.56 ha and the open forest area increased by 1,864.48 ha (Table 6). While the young forest/shrub areas decreased by 2,729.30 ha, the water area declined by 2,368.75 ha and the barren land area decreased by 1,076.16 ha. Nevertheless, agriculture land area increased by 159.16 ha (Tables 5 to 7).

Table 5. Area change matrix for the period 2004 to 2009 based on supervised classification (units: ha)

	Dense forest	Open forest	Young forest/shrub	Agriculture land	Water body	Barren land	Total
Mangrove Dense forest	18391.66	823.11	668.75	28.54	86.01	4.99	20003.06
Mangrove Open forest	4181.21	4449.78	1241.64	167.30	503.25	106.05	10649.23
Mangrove Young forest	1378.21	4883.08	2390.10	521.30	1266.60	318.79	10758.08
Agricultural land	2.77	169.86	333.62	103.85	255.48	70.48	936.06
Water body	198.00	2018.88	2875.00	255.34	23390.74	623.07	29361.03
Barren land	1.77	169.01	519.67	18.89	1490.20	141.75	2341.29
Total	24153.62	12513.72	8028.78	1095.22	26992.28	1265.13	74048.75

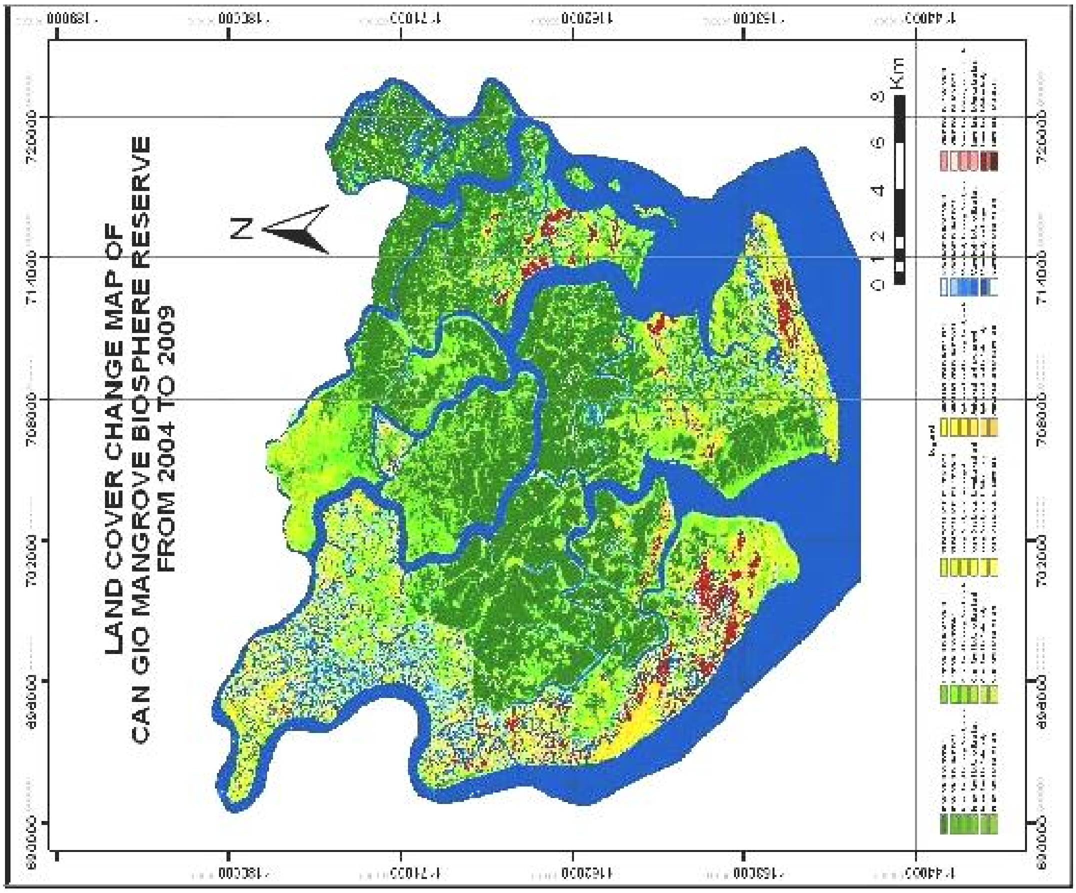


Figure 6 a. Land use/ land cover change map for 2004-2009

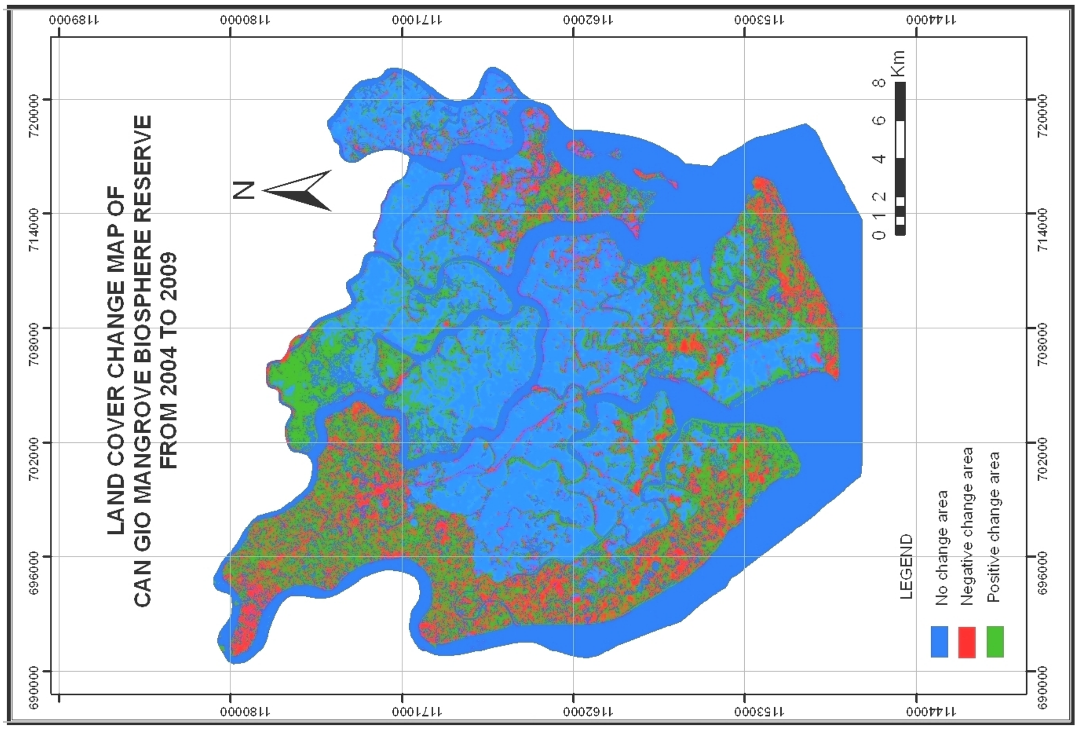


Figure 6 b. Land cover change map reclassified for simplification

Table 6. Change in land cover of mangrove forest during 2004 to 2009

Class	Area (ha) 2004	Area (ha) 2009	Change (ha)
Mangrove Dense forest	20003.06	24153.62	4150.56
Mangrove Open forest	10649.23	12513.72	1864.49
Mangrove Young forest	10758.08	8028.78	-2729.30
Agriculture land	936.06	1095.22	159.16
Water body	29361.03	26992.28	-2368.75
Barren land	2341.29	1265.13	-1076.16
Total	74048.75	74048.75	

Table 7. Area change distribution from 2004 to 2009

Class	Area (ha)	Percent (%)
No change	48867.88	65.99
Negative change	18495.51	24.98
Positive change	6685.36	9.03
Total	74048.75	100.00

DISCUSSION

The SPOT satellite images (1999, 2004 and 2009) demonstrated that efficient and effective use for mapping of mangrove vegetation and LULC with overall classification accuracy of 82.78% to 87.78%, respectively and also for monitoring their dynamics during this period data. The analysis indicates that during 1999 to 2009, the dense mangrove forest continuously increased by 10,456.13 ha (1999 to 2004) and 4,150.56 ha (2004 to 2009). However, from 1999 to 2004, the open mangrove forest decreased by 6,912.57 ha because much of these changed to dense forest due to protection, but during 2004 to 2009 the open mangrove forest increased 1,755.64 ha. Mangrove forest forest/shrub during 1999 to 2004 and 2004 to 2009 changed by 6,921.57 ha and 2,620.45 ha, respectively. Over the years, from 1999 to 2009, most of the agricultural land area decreased, and decrease was most during 2004 to 2009. For a Biosphere Reserve this is significant achievement. The water body area changed a little, because the shrimp ponds area were not allowed not to expand. From 1999 to 2004, the barren land area also changed a little; however, from 2004 to 2009 the barren land greatly decreased 1,076.16 ha. The study demonstrated that the remote sensing data can be effectively used for monitoring the status of the natural resources reclamation after a gap of 4-5 years. World over mangrove forests are under severe threat due to coastal development for commercial purposes. Following recommendations are made from this study:

- Management of mangrove forest may use satellite data for monitoring the mangrove forest every two years, preferable with high resolution.
- The dense mangrove forest area should to be thinned to allow more light to penetrate and facilitate increase in diameter. The barren land area needs to be replanted. The open mangrove forest and young mangrove forest area need to restored by protection.
- Research to build an economic, ecological and tourism model with sustainable development of mangrove ecosystems.

ACKNOWLEDGEMENTS

NYL is grateful to Director, Centre for Space Science Technology and Education in Asia and the Pacific (affiliated to the United Nations), Dehradun, India for allowing him to take up Master's programme. He is also highly grateful to the President, Vietnam Academy of Science and Technology, Ha Noi, Vietnam for funding the VAST's project on "Assessment of area change of Mangrove forest using Remote Sensing Technology and GIS", in whose framework the satellite data and facilities for field work and data analyses were provided.

REFERENCES

Alongi D.M. 2008. Mangrove forests: resilience, protection from tsunamis, and responses to global climate change, Estuarine, Coastal and Shelf. Science 76 (1): 1–13, doi:10.1016/j.ecss.2007.08.024.

Barbier, E. B. 2008. In the wake of tsunami: Lessons learned from the household decision to replant mangroves in Thailand. Resource Energy Economics 30: 229–249.

Binh, T.T.H.; Luong, N.V.; Hoa, P.V.; and Thoa, P.K. 2008a. Using multi-temporal remote sensing data to manage the mangrove for coastal environmental protection. Remote Sensing and Spatial Information Sciences 37(Part B8): 709-711.

Binh, T.T.H. and Luong, N.V. 2008b. Changed detection analysis of Hoang Sa Archipelago and Truong Sa Archipelago, Vietnam using Remote Sensing and GIS technology. Vietnam.

Blasco, F.; Gauquelin, T.; Rasolofoharinoro, M.; Denis, J,, Aizpuru, M.; and Caldairou, V. 1998. Recent advances in mangrove studies using remote sensing data. Marine and Freshwater Research 49(4): 287–296.

Coppin, P.R. and Bauer, M.E. 1994. Processing of multitemporal Landsat TM imagery to optimize extraction of forest cover change features. IEEE Geoscience and Remote Sensing 60(3): 287-298.

Dwivedi, R. S.; Rao, B. R. M., and Bhattacharya, S. 1999. Mapping wetlands of the Sundarban delta and its environs using ERS-1 SAR data. International Journal of Remote Sensing 20(11): 2235-2247.

Forbes, K. and Broadhead, J. 2007. The Role of Coastal Forests in the Mitigation of Tsunami Impacts. FAO Report, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok. 37 pages.

Fung, T. and LeDrew, E.F 1988. The determination of optimal threshold levels for change detection using various accuracy indices. Photogrammetric Engineering & Remote Sensing 54(10): 1449-1454.

Gao, J. 1999. A comparative study on spatial and spectral resolution of satellite data in mapping mangrove forests. International Journal of Remote Sensing 20(14): 2823-2833.

Graaf, G.J. de and Xuan, T.T. 1998. Extensive shrimp farming, mangrove clearance and marine fisheries in the southern provinces of Vietnam. Mangroves and Salt Marshes 2(3):159-166.

Green, E. P.; Clark, C. D.; Edwards, A. J.; and Ellis, A. 1998. Remote sensing techniques for mangrove mapping. International Journal of Remote Sensing 19(5): 935-956.

Green, K.; Kempka, D. and Lackey, L. 1994. Using Remote Sensing to Detect and Monitor Land-Cover and Land-Use Change. Photogrammetric Engineering and Remote Sensing 60(3): 331-337.

Gupta, S.; Singh, S.; Agarwal, S. and Roy, P.S. 2006. Degradation of Tropical evergreen forests in Mokokchung, Nagaland, India – A geospatial approach. International Journal of Ecology and Environmental Sciences 32(4): 345-356.

Howarth, P.J. and Wickware G. M. 1981. Procedures for change detection using Landsat digital data. International Journal of Remote Sensing 2: 277-291.

Huete, A.R.; Liu, H.Q.; Batchily, K. and YanLeeuwen, W. 1997. A comparison of vegetation indices global set of TM images for EOS-MODIS. Remote Sensing of Environment 59: 440-451.

Iverson, L.R.; Brown, S.; Grainger, A.; Prassad, A. and Liu, D. 1993. Carbon sequestration in tropical Asia: an assessment of technically suitable forest lands using geography information system analysis. Climate Research 3(1-2): 23-38.

Johnston, D.; Lourey, M.; Van Tien, D.; Luu, T.T. and Xuan, T.T. 2002. Water quality and plankton densities in mixed shrimp-mangrove forestry farming systems in Vietnam. Aquaculture Research 33(10): 785–798.

Kamthonkiat, D.; Rodfai, C.; Saiwanrungkul, A.; Koshimura, S.; and Matsuoka, M. 2011. Geoinformatics in mangrove monitoring: damage and recovery after the 2004 Indian Ocean tsunami in Phang Nga, Thailand. Natural Hazards and Earth System Sciences 11: 1851-1862, doi:10.5194/nhess-11-1851-2011.

Kathiresan, K. and Rajendran, N. 2005. Coastal mangrove forests mitigated tsunami. Estuarine, Coastal and Shelf Science 65: 601–606.

Malingreau, J.P. and Belward, A.S. 1992. Scale considerations in vegetation monitoring using AVHRR data. International Journal of Remote Sensing 13(12): 2289-2307.

Lillesand, T.M. and Kiefer, R.W. 2004. Remote Sensing and Image Interpretation. John Wiley, New York. xiv-724 pages.

Panigrahy R.K.; Kale, M.P.; Dutta, U.; Mishra, A.; Banerjee, B. and Singh, S. 2010. Forest cover change detection of Western Ghats of Maharashtra using satellite remote sensing based visual interpretation technique. Current Science 98(5): 657-664.

Phinn, S.R.; Menges, C.; Hill, G.J.E.; and Stanford, M. 2000. Optimizing remotely sensed solutions for monitoring, modeling and managing coastal environments. Remote Sensing of Environment 73: 117-132.

Reddy, C.S.; Patnaik, C. and Murthy, M.S.R. 2007. Assessment and monitoring of mangroves of Bhitarkanika Wildlife Sanctuary, Orissa, India using Remote Sensing and GIS. Current Science 92(10): 1409-1415.

Reddy.; S and Roy, A. 2008. Assessment of three decade vegetation dynamics in mangroves of Godavari delta, India using multi-temporal satellite data and GIS. Research Journal of Environmental Sciences 2(2): 108-115.

Ross, P. 1975. The mangrove of South Viet Nam: the impact of military use of herbicides. Proceedings of International Symposium of Biology and Management of Mangroves, 8-11 October, 1974 (Gainesville. FL, USA): 695-709.

Rouse, J.W.; Haas, R.H.; Schell, J.A. and Deering, D.W. 1974. Monitoring vegetation system in the great plains with ERTS. Proceedings of the Third Earth Resources Technology Satellite-1 Symposium, Greenbelt, USA; NASA SP-351, 3010-3017 pages.

Running, S.W.; Justice, C.O.; Salomonson, Hall, D.; Barker, J.; Kaufmann, Y.J.; Strahler, A.H.; Huete, A.R.; Muller, J.-P.; Vanderbilt, V.; Wan, Z.M.; Reillet, P. and Carneggie, D. 1994. Terrestrial Remote Sensing Science and Algorithm Planned for EOS/MODIS. International Journal of Remote Sensing 15(17): 3587-3620.

Singh, A. 1989. Digital change detection techniques using remotely-sensed data. International Journal of Remote Sensing 10(6): 989-1003.

Tong, P.H.S.; Auda, Y.; Populus, J.; Aizpuru, M.; Al Habshi, A. and Blasco, F. 2004. Assessment from space of mangroves evolution in the Mekong delta, in relation with extensive shrimp-farming. International Journal of Remote Sensing 25(21): 4795-4812.

Townshend, J.R.G.; Justice, C.O.; Gurney, C. and McManus, J. 1992. The impact of misregistration on change detection, IEEE Transactions on Geoscience and Remote Sensing 30(5): 1054-1060.

Received 2 February 2013;
Accepted 4 June 2013