study of cobalamine synthesis gene clusters (cob/cbi), where a multitude of potential cobalt transporters belonging to various families (ABC family, NiCoT family, etc.) have been identified[8], we performed comparative genome analysis of eight different bacterial species employed in this study. This *in silico* approach allowed us to identify high-affinity cobalt transporters in the bacterial species used in this study. Genome-wide analysis of radiation-resistant bacterium, *Deinococcus radiodurans*[9] revealed the presence of three putative cobalt transporter genes (unpublished data). Genetic engineering strategies to overexpress these transporters in *D. radiodurans*[10] would be the next ideal step to increase the overall cobalt removal efficiency from a margin of 40–90%, and such a recombinant strain could be more promising for bioremediation.

1. Gadd, G. M., Influence of microorganisms on the environmental fate of radionuclides. *Endeavour*, 1996, **20**, 150–156.
2. Lloyd, J. R. and Lovley, D. R., Microbial detoxification of metals and radionuclides. *Curr. Opin. Biotechnol.*, 2001, **12**, 248–253.
3. Rashmi, K., Naga Sowjanya, T., Balaji, V., Maruthi Mohan, P. and Venkateswaran, G., Bioremediation of $^{60}Co$ from spent decontamination solutions. *Sci. Total Environ.*, 2004, **328**, 1–14.
4. Kobayashi, M. and Shimizu, S., Cobalt proteins. *Eur. J. Biochem.*, 1999, **261**, 1–9.
5. Jeter, R., Escalante-Semerena, J. C., Roof, D., Olivera, B. and Roth, J., Synthesis and use of vitamin $B_{12}$ in *Escherichia coli* and *Salmonella typhimurium*. In *Cellular and Molecular Biology* (eds Magasanik, B. and Schaechter, M.), American Society for Microbiology, Washington DC, 1987, pp. 551–556.
6. Watson, R. J., Heys, R., Martin, T. and Savard, M., *Sinorhizobium meliloti* cells require biotin and either cobalt or methionine for growth. *Appl. Environ. Microbiol.*, 2001, **67**, 3767–3770.
7. Komeda, H., Kobayashi, M. and Shimizu, S., A novel transporter involved in cobalt uptake. *Proc. Natl. Acad. Sci. USA*, 1997, **94**, 36–44.
8. Rodionov, D. A., Vitreschak, A. G., Mironov, A. A. and Gelfand, M. S., Comparative genomics of the vitamin $B_{12}$ metabolism and regulation in prokaryotes. *J. Biol. Chem.*, 2003, **278**, 41148–41159.
9. White, O. *et al.*, Genome sequence of the radio-resistant bacterium *Deinococcus radiodurans* R1. *Science*, 1999, **286**, 1571–1577.
10. Hassan, B. and Daly, M. J., Engineering *Deinococcus radiodurans* for metal remediation in radioactive mixed waste environments. *Nature Biotechnol.*, 2000, **18**, 85–90.

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# Assessment and monitoring of mangroves of Bhitarkanika Wildlife Sanctuary, Orissa, India using remote sensing and GIS

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**The present study deals with periodic assessment and monitoring of the mangroves of Bhitarkanika Wildlife Sanctuary, Orissa, India using remote sensing and Geographic Information System techniques. Satellite data of Landsat MSS for 1973, IRS-1A LISS II for 1988 and IRS-P6 LISS III for 2004 along with other spatial and non-spatial data were used to find out the changes that occurred in mangrove and other land-cover categories during the last 30 years. It was found that the sanctuary is occupied by agriculture (51.76%), followed by dense mangrove (21.77%), water bodies (20.19%) and open mangrove (2.73%). A loss of 1534 ha mangrove area and an increase of 2436 ha agriculture area clearly depict anthropogenic activities by local villagers. A significant increase of 270 ha plantations illustrates plantation activities taken up by the Orissa Forest Department to protect the coastal shoreline.**

**Keywords:** Bhitarkanika Wildlife Sanctuary, Geographic Information System, mangrove, multi-spectral data, remote sensing.

MANGROVE forest is a vegetation community formed by a variety of salt-tolerant species growing in the inter-tidal areas and estuary mouths between the land and the sea. Mangrove forests are one of the most productive wetlands on earth. They provide critical habitat for diverse marine and terrestrial flora and fauna. Yet, these unique coastal, tropical forests are among the most threatened habitats in the world. Traditionally, local communities in mangrove ecosystems collected fuelwood, harvested fish and other natural resources[1,2]. However, in recent decades, many coastal areas have come under intense pressure from rapid urban and industrial development, compounded by a lack of governance or power among environmental institutions. Mangroves have been overexploited or converted to various other forms of land use, including agriculture, aquaculture, salt ponds, terrestrial forestry, urban and industrial development and for the construction of roads and embankments[3,4]. Mangroves are affected by several different activities simultaneously, or over time as land-use patterns change[5].

India has a total area of 4461 sq. km under mangroves, which is 0.14% of the country's total geographic area. It

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account for about 5% of the world's mangrove vegetation[6]. Nearly 57% of the mangroves is found along the east coast[7]. The National Remote Sensing Agency (NRSA), Hyderabad, India recorded[8] a decline of 59.18 sq. km of mangrove between 1972–75 and 1980–82. According to the Government of India report (1987), India lost 40% of its mangrove area during the last century[9]. Mangroves have not received proper attention and they have been subjected to over-exploitation and encroachment, and hence there is a need for conservation and management of mangrove forests. Recognizing the environmental, social and economic importance of mangrove ecosystems, a National Mangrove Committee was set up under the Department of Environment, Forests and Wildlife in 1976, for a close monitoring of these valuable coastal resources and to evolve a management plan for the protection of mangroves[10]. Several floristic studies have been done in Bhitarkanika Wildlife Sanctuary, Orissa, India by several botanists from time to time[11–18]. However, reliable and timely information on the nature, extent, spatial distribution pattern and temporal behaviour of mangrove forests (which is prerequisite for restoration and management) is not available. Satellite-based remote-sensing techniques have proved successful in providing comprehensive, reliable and up-to-date information on land use, land cover and change dynamics periodically in the most cost-effective manner[19,20]. This communication describes the use of remote sensing to evaluate changes in mangrove vegetation and other land-cover categories in the Bhitarkanika Sanctuary area from 1973 to 2004. It is hoped that the results of the study would be useful in effective development and management of mangroves.

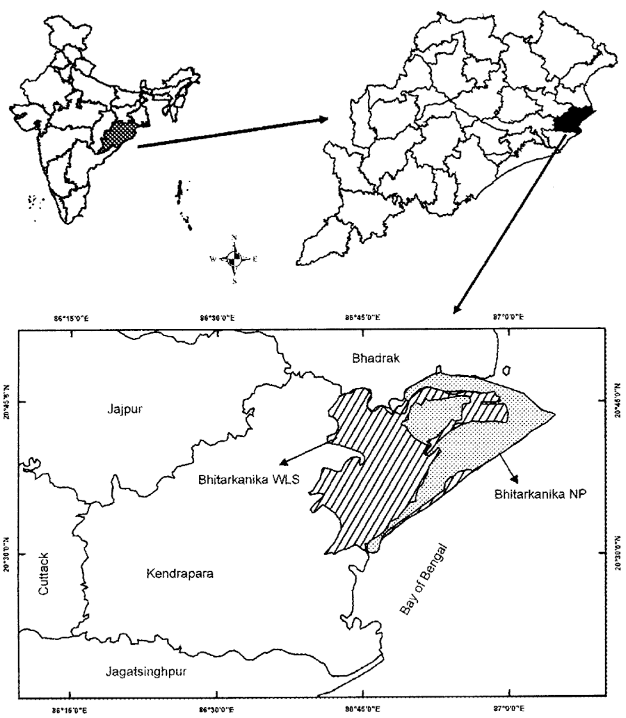


**Figure 1.** Location map of the study area.

Bhitarkanika Wildlife Sanctuary is a rich, lush green, vibrant ecosystem lying in the estuarine region of Brahmani, Dhamra and Baitarani rivers in the northeastern corner of Kendrapara District, Orissa, east coast of India (Figure 1). It covers an area of 672 sq. km extending between 86°48′–87°03′E long. and 20°33′N–20°47′N lat. It is surrounded by the Bay of Bengal in the east, villages of Kendrapara District in the west, Baitarani and Dhamra rivers in the north and the Mahanadi delta in the south. The area is intersected by a network of creeks with Bay of Bengal on the east. Salt-water crocodiles (*Crocodylus porosus*) and a variety of other wildlife inhabit in this ecosystem, which forms one of the most spectacular wildlife areas in Asia. The Government of Orissa declared this area as a sanctuary in 1975 for better protection of the habitat. Later, the core area (145 sq. km) of the sanctuary was declared as a National Park in the year 1998. The total mangrove area is a mixture of 13 protected reserve forests (PRF), 12 protected forests (PF) and one newly formed island[21]. Due to its rich diversity in flora and fauna, this mangrove area has been declared as a Ramsar site in 2002, being a wetland of international importance.

This area experiences tropical warm and humid climate, with no distinct season. Rain occurs due to the southwest monsoon from May to September, and the northeast monsoon from November to December. The average rainfall is about 1642 mm, bulk of which is received during June to October[17]. The maximum temperature recorded is 41°C and the minimum is 9°C during May and January respectively. Mean relative humidity ranges from 70 to 85% throughout the year. Soils of the mangrove areas are fine-grained silt or clay, formed by the sedimentation of Mahanadi and Brahmani rivers.

The analysis is based on a multi-temporal satellite imagery study that included the mangroves of Bhitarkanika and the adjacent area, the extent of which was analysed over time. As a result of the analysis, classified thematic maps were prepared to obtain a land-cover map. The following satellite data and materials were used for the present study. Landsat multi-spectral scanner (MSS), Indian Remote Sensing satellite 1A (IRS-1A), Linear Imaging

**Table 1.** Details of remote sensing data used

| Satellite-sensor | Path-row | Date of acquisition |
|---|---|---|
| Data used | | |
| Landsat-MSS | 142/46 | 17–03–1973 |
| IRS-1A LISS II | 19/53 | 17–12–1988 |
| IRS-P6 (Resourcesat) | 107/58 | 13–01–2004 |
| Reference data | | |
| Landsat-TM | 139/46 | 21–11–1990 |
| IRS-P6 (Resourcesat) | 107/58 | 18–04–2004 |

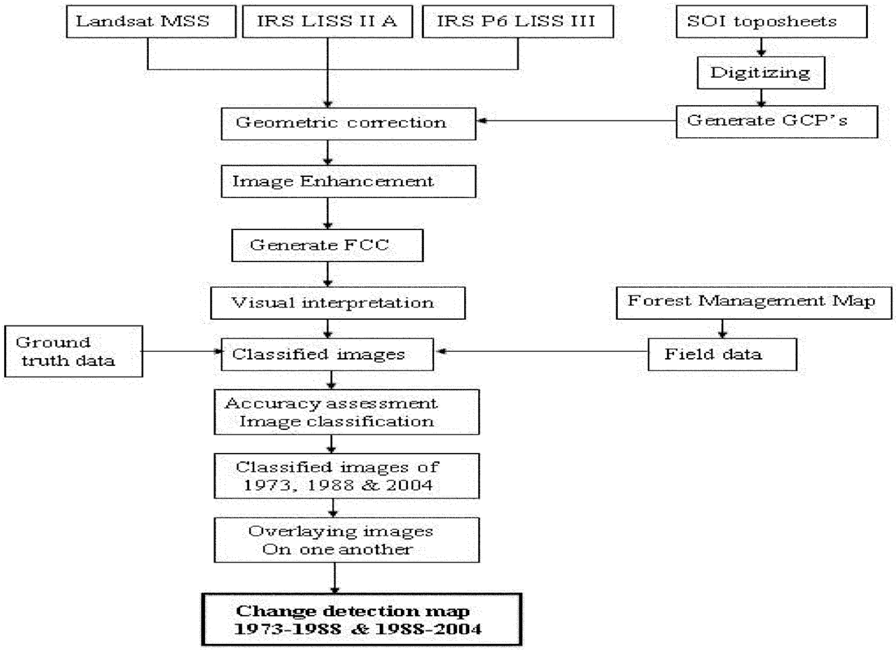


**Figure 2.** Flow chart indicating the methodology used to prepare mangrove change detection map.

**Table 2.** Image interpretation key for mangrove and other land-cover mapping

| Land-cover class | Tone | Texture | Shape | Pattern | Description |
|---|---|---|---|---|---|
| Mangrove | Dark red | Medium | Varying | Smooth | Tall dense trees |
| Freshwater swamp | Light red | Medium | Regular | Smooth | Moist and dry deciduous species |
| Mangrove scrub | Greyish | Coarse | Varying | Rough | Low vegetation density |
| Littoral scrub | Dark tan | Coarse | Regular | Rough | Scattered vegetation with exposed ground surface |
| Grasslands | Dark grey | Coarse | Varying | Smooth | Medium-sized grasses with little herb species |
| Plantation | Dark brown | Coarse | Regular | Rough | Patchy vegetation along the coastal belt and river beds |
| Mudflat | Pale blue | Medium | Irregular | Scattered | River sedimentation on the bank |
| Sand | Whitish | Fine | Regular | Smooth | Mound of sands with sparse vegetation |
| Water body | Dark or light blue | Smooth | Irregular | Scattered | Rivers and tanks |
| Agriculture with habitation | Light green or pinkish | Smooth | Regular | Smooth | Crops with current fallow lands |

Self Scanner (LISS II), IRS P6 (Resourcesat) LISS III (January) and Survey of India (SOI) toposheets nos 73 L/10, 73 L/13, 73 L/14, 73 L/15, 73 P/1, 73 P/2 of 1 : 50,000 scale. In addition, Landsat Thematic Mapper (TM) and IRS-P6 LISS III (April) data were used as reference (Table 1). All the images were recorded during approximately the same season between December and January, which corresponds to the wet season in this region. All these datasets were geometrically corrected. For geo-referencing, the IRS-P6 LISS III data were co-registered to SOI topographic maps at 1 : 50,000 scale using ground control points. All the datasets were brought into WGS 84 datum and UTM projection. These satellite data were visually interpreted on-screen on a Silicon Graphics Workstation using ERDAS IMAGINE version 8.7 image processing software. Ancillary data like SOI toposheets and forest management maps were also used to complement the results of the classification. A flow chart representing the research methodology used here is given in Figure 2.

Visual interpretation of satellite imagery and reconnaissance survey of the area have been carried out for obtaining patterns of vegetation and other land features during June 2004 to September 2005. Ground truth was collected with the help of false colour composite (FCC) hard copy prints of the study area during 1973, 1988 and 2004 (Figure 3 *a–c*), SOI toposheets, Global Positioning System (GPS) and magnetic compass. The satellite imageries were interpreted and different land-use and land-cover categories were delineated on the basis of tone, texture, colour, pattern, etc. Based on reconnaissance survey of the ground details and signatures, an interpretation key has been developed to enable information extraction from the image (Table 2). Visually interpreted maps of 1973, 1988 and 2004 were generated. The classified map of 2004 was corrected and finalized after thorough ground check (Figure 4). Three maps were overlaid on each other to find out the net change in area of mangroves and other land-cover classes between 1973 and 2004 using ARC INFO

(9.0) GIS software. The output maps showing positive as well as negative changes are given in Figure 5 *a* and *b*. The overall distribution of areas in mangrove cover and other land-cover categories (1973, 1988 and 2004) and the net changes in area (1973–2004) are estimated (Table 3).

To determine the accuracy of the thematic map obtained using visual interpretation from the latest 2004 image, an accuracy assessment was carried out. Doubtful areas

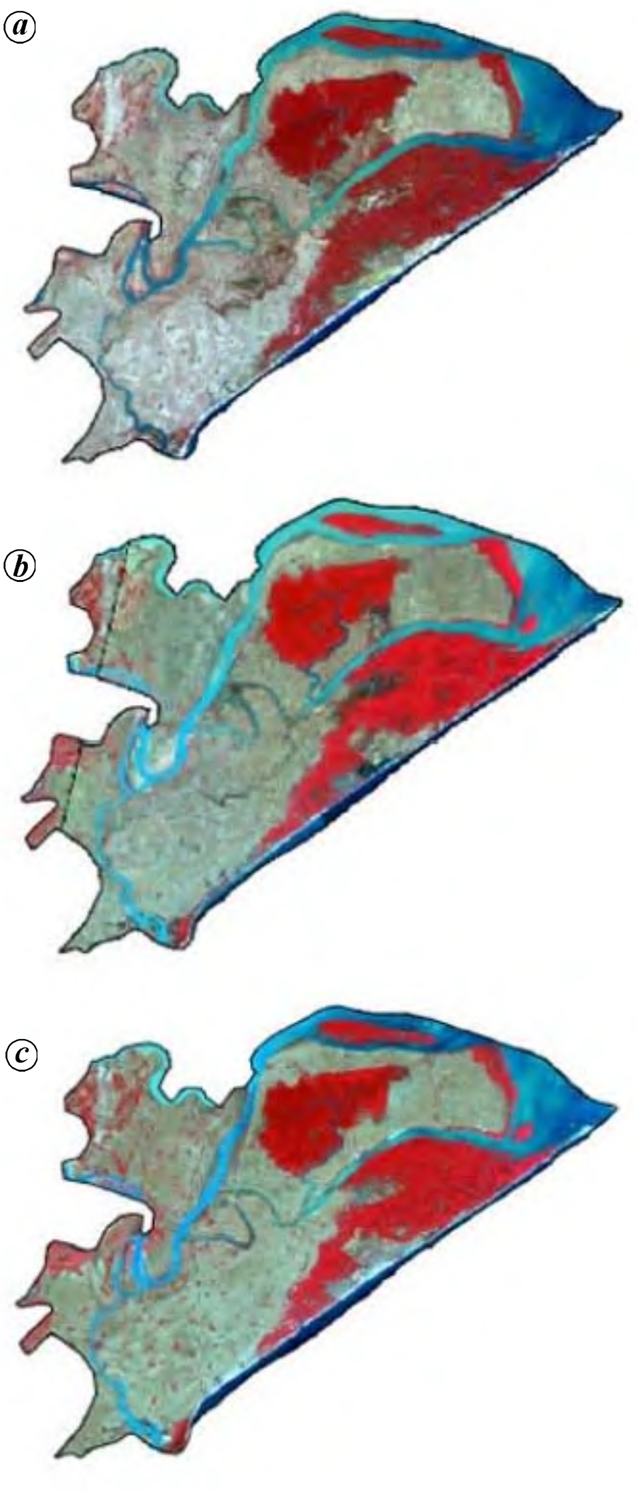

**Figure 3.** Multi-temporal FCC image of Bhitarkanika Wildlife Sanctuary, Orissa. ***a***, Landsat MSS, 17 January 1973. ***b***, IRS-1A LISS II, 17 December 1988. ***c***, IRS-P6 LISS III, 13 January 2004.


**Figure 4.** Classified land-use/land-cover map of Bhitarkanika Wildlife Sanctuary (2004).

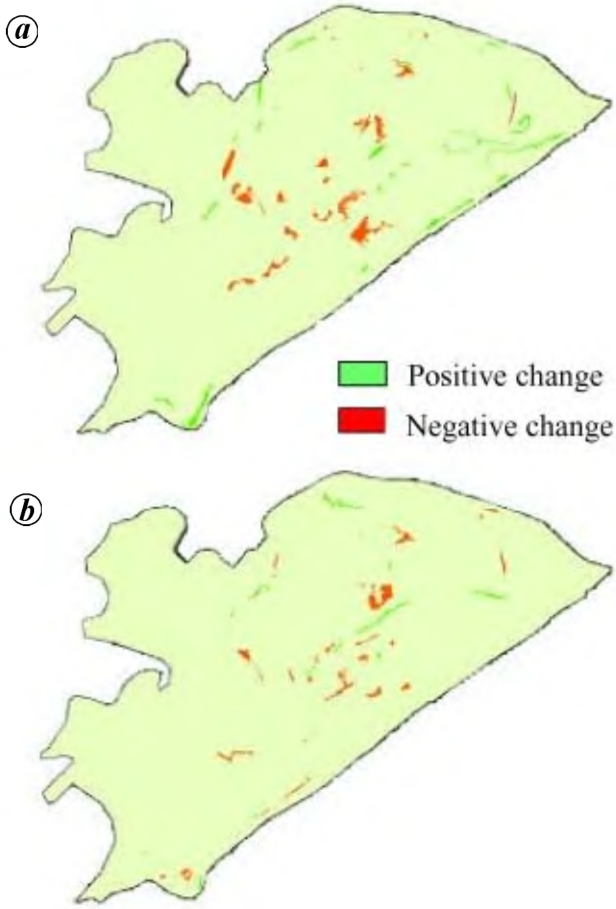


**Figure 5.** Mangrove and other land-cover changes in the sanctuary area during (***a***) 1973–88 and (***b***) 1988–2004.

**Table 3.** Distribution of areas in mangrove and other land-use categories (ha) in Bhitarkanika Wildlife Sanctuary from 1973 to 2004

| Category | Area (ha) 1973 | 1988 | 2004 | Percentage of total area (2004) | Change (ha) (1973–2004) |
|---|---|---|---|---|---|
| Dense mangrove | 14,646 | 14,532 | 14,630 | 21.77 | –16 |
| Open mangrove | 3350 | 3333 | 1832 | 2.73 | –1518 |
| Freshwater swamp | 103 | 103 | 103 | 0.15 | 0 |
| Littoral scrub | 0 | 0 | 48 | 0.07 | 48 |
| Grassland | 28 | 28 | 28 | 0.04 | 0 |
| Plantation | 0 | 237 | 270 | 0.40 | 270 |
| Mudflat | 2298 | 1661 | 1219 | 1.81 | –1079 |
| Sand | 664 | 464 | 723 | 1.08 | 59 |
| Water body | 13,767 | 13,344 | 13,568 | 20.19 | –199 |
| Agriculture | 32,346 | 33,501 | 34,782 | 51.76 | 2436 |
| Total | 67,202 | 67,202 | 67,202 | 100.00 | |

**Table 4.** Accuracy assessment of the study area

| Classified data | 1973 UA* | 1973 PA** | 1988 UA | 1988 PA | 2004 UA | 2004 PA |
|---|---|---|---|---|---|---|
| Dense mangrove | 85.7 | 100 | 100 | 100 | 80 | 100 |
| Open mangrove | 66.6 | 80 | 60 | 75 | 80 | 100 |
| Freshwater swamp | 100 | 100 | 100 | 100 | 100 | 100 |
| Littoral scrub | – | – | – | – | 100 | 100 |
| Grassland | 100 | 100 | 100 | 100 | 100 | 100 |
| Plantation | – | – | 100 | 100 | 100 | 98.7 |
| Mudflat | 60 | 60 | 60 | 100 | 80 | 99 |
| Sand | 80 | 100 | 100 | 83.3 | 100 | 100 |
| Water body | 100 | 100 | 100 | 100 | 100 | 98.3 |
| Agriculture | 90 | 75 | 87.5 | 70 | 100 | 62.5 |
| Overall accuracy (%) | 86 | | 90 | | 94 | |
| Kappa statistics | 0.83 | | 0.88 | | 0.93 | |

*UA, User's accuracy (%); **PA, Producer's accuracy (%).

were identified and the geographic coordinates of these points were noted from the visually interpreted classified map. All these points were thoroughly checked in the field with GPS points. The overall accuracy assessment stands at 94% in 2004 (Table 4). Spatial changes in mangrove cover were assessed (Tables 3, 5 and 6). The change-analysis map showed that major changes were taking place in the proximity of agricultural lands due to high anthropogenic pressure. Changes also observed in the river creeks may be due to sedimentation or tidal inundation. Of the total study area, agriculture land with habitation is the major category (51.76%) followed by dense mangroves (21.77%), open mangroves (2.73%) and water bodies (20.19%) in 2004 (Table 3). The overall change area statistics of different land-cover categories from 1973 to 1988 and 1988 to 2004 is presented in Tables 5 and 6. The study area represents a rich repository of plant wealth[18]. The floristic diversity in each vegetation type and change dynamics in different land-cover categories of the study area are discussed below.

Dense mangrove forest is typically a closed evergreen forest of moderate height, composed of species specially adapted to survive on tidal mud, which is partially submerged with salt water or brackish water. A major area of the national park is covered by mangrove forests. *Heritiera fomes* occupies a major portion of the Bhitarkanika Reserve Forest (BRF) followed by *Excoecaria agallocha*, *Avicennia alba* and *Sonneratia apetala*. *E. agallocha* and *A. alba* occur as a pure community found on the offshore islands or in the fringes to the seaward side. *S. apetala* occurs along the creeks. It has been observed that from 1973 to 1988, around 473 ha of dense mangroves were converted to open mangroves (328 ha) followed by agriculture (89), water (37) and mudflats (2). An area of 299 ha mangrove forest has been gained from conversion of water body. Change from water to mangrove may be due to sedimentation, and formation of new islands or tidal impact. Whereas in 1988–2004, an area of 577 ha of dense mangroves was converted to open mangroves (126) followed by littoral scrub (48), water (85) and agriculture (286). Similarly, an area of 98 ha mangrove forest has been gained from other land-use categories as a result of increased protection and consequent regeneration. The key to increase in mangrove area due to protection lies in

**Table 5.** Change area matrix from 1973 to 1988 (area in ha)

| Land-cover class | Dense mangrove | Open mangrove | Freshwater swamp | Littoral scrub | Grassland | Plantation | Mudflat | Sand | Water body | Agriculture | Total (1973) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dense mangrove | 14,174 | 345 | 0 | 0 | 0 | 0 | 2 | 0 | 37 | 89 | 14,646 |
| Open mangrove | 52 | 2698 | 0 | 0 | 0 | 5 | 253 | 0 | 0 | 342 | 3350 |
| Freshwater swamp | 0 | 0 | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103 |
| Littoral scrub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grassland | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 28 |
| Plantation | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Mudflat | 0 | 121 | 0 | 0 | 0 | 0 | 1267 | 0 | 12 | 898 | 2298 |
| Sand | 0 | 19 | 0 | 0 | 0 | 155 | 0 | 464 | 0 | 26 | 664 |
| Water body | 299 | 133 | 0 | 0 | 0 | 38 | 20 | 0 | 13,277 | 0 | 13,767 |
| Agriculture | 7 | 17 | 0 | 0 | 0 | 39 | 119 | 0 | 18 | 32,146 | 32,346 |
| Total (1988) | 14,532 | 3333 | 103 | 0 | 28 | 237 | 1661 | 464 | 13,344 | 33,501 | 67,202 |

**Table 6.** Change area matrix from 1988 to 2004 (area in ha)

| Land-cover class | Dense mangrove | Open mangrove | Freshwater swamp | Littoral scrub | Grassland | Plantation | Mudflat | Sand | Water body | Agriculture | Total (1988) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Dense mangrove | 13,954 | 126 | 0 | 48 | 0 | 0 | 32 | 0 | 85 | 286 | 14,532 |
| Open mangrove | 336 | 1403 | 0 | 0 | 0 | 0 | 134 | 78 | 182 | 1200 | 3333 |
| Freshwater swamp | 0 | 0 | 103 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 103 |
| Littoral scrub | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Grassland | 0 | 0 | 0 | 0 | 28 | 0 | 0 | 0 | 0 | 0 | 28 |
| Plantation | 19 | 0 | 0 | 0 | 0 | 218 | 0 | 0 | 0 | 0 | 237 |
| Mudflat | 10 | 58 | 0 | 0 | 0 | 0 | 1007 | 176 | 151 | 259 | 1661 |
| Sand | 0 | 0 | 0 | 0 | 0 | 16 | 0 | 380 | 53 | 15 | 464 |
| Water body | 255 | 34 | 0 | 0 | 0 | 35 | 39 | 13 | 12,969 | 0 | 13,344 |
| Agriculture | 57 | 210 | 0 | 0 | 0 | 0 | 7 | 76 | 128 | 33,022 | 33,501 |
| Total (2004) | 14,630 | 1832 | 103 | 48 | 28 | 270 | 1219 | 723 | 13,568 | 34,782 | 67,202 |

the wise management and use of mangrove habitat, and in the enforcement of existing rules and regulations by the State Forest Department.

Open mangrove forest is of low average height, often 3–5 m in and represents the species of mangrove forest. With increasing pressure from biotic factors, the vegetation is rapidly decreasing; it is characterized by mixed mangroves. Even though there is no specific zonation pattern, *E. agallocha* and *A. alba* are the pioneering species found in degraded and scattered mangrove areas. Palm swamp vegetation is also found in drier areas within or outside the mangrove forests mixed with scrub areas on the landward side. Palm swamp shows typical representation of tufted palms (*Phoenix paludosa*) up to 3 m in height. This forest vegetation faces high anthropogenic pressure and change in landscape dynamics is clearly noticeable on the images. A net change of 1518 ha is observed due to conversion of open mangroves to other land-cover categories from 1973 to 2004. Freshwater swamp forest is purely localized and found above the tide level mainly in the BRF, and occupies an area of 103 ha. The ground is inundated by freshwater. Forest cover is fairly dense and biologically rich with a good number of plant species. *Diospyros peregrina* is the most dominant tree species, associated with several evergreen tree species and few deciduous elements. There is no appreciable change in the vegetation cover because of its geographic location.

Littoral scrub is a representative form of deforested mangrove landscape occurring in semi-arid or arid saline soils covering 48 ha of the study area. This was not found in 1973. After 1989, it was formed due to mass cutting of mangroves in Sunei Rupei Protected Forest area. *Tamarix troupii* and *Salvadora persica* are pioneering woody species found in these areas and often form pure *Tamarix* and *Tamarix–Salvadora* communities towards the landward zone. It is typically a shrubby formation about 2 to 4 m in height. The vegetation mostly represents exotic herbaceous species like *Parthenium histrophorus*, *Cleome viscosa*, *Croton bonplandianum*, *Hyptis suaveolens*, *Mimosa pudica* and *Scoparia dulcis*. Grasslands occupy an area of 28 ha in the BRF, found near freshwater swamp forest admixed with muddy substratum. Major portion of the area is covered by tall grasses. *Arundo donax*, *Chrysopogon aciculatus*, *Dicanthium pertusum* and *Imperata cylindrica* are some dominant grass species found in the area. Mudflat is a low-lying muddy land that is covered at high tide and exposed low tide. The vegetation seen in this area is of herbaceous type and generally referred to as mudflat (salt marshes) vegetation. Due to high moisture and salt content, halophytic species like *Suaeda* *maritima*, *Suaeda nudiflora*, *Suaeda monoica*, *Sesuvium portulacastrum* and *Arthocnemum indicum* grow predominantly. The sanctuary has a significant area under mudflats (1219 ha), which is the main substratum for mangrove regeneration and plantation activities. It has been observed that mudflat area had reduced from 1973 (2298 ha) to 2004 (1219 ha). Loose sand mounds along the coastal strip of the southeastern side of Bhitarkanika are well covered by the usual runners like *Ipomoea pes-caprae* and *Launaea sarmentosa*. *Spinifex littoreus*, *Hydrophylax maritima* and *Polycarpon prostratum* support the foreshore zone. It covers an area of 723 ha in the sanctuary. The Orissa Forest Department has raised plantation of *Casuarina equisetifolia* and *Rhizophora mucronata* in the coastal sand and riverbeds respectively. The plantation area was considerably increased from 237 (1988) to 270 ha (2004).

The land-cover system undergoes significant change according to the changes in socio-economic and natural conditions of the people. Agricultural practice is gradually increasing from 32,346 (1973) to 33,501 ha (1988) and reached 34,782 ha in 2004. A net change of 2436 ha area was observed due to conversion of dense and open mangrove forests to agricultural field by the surrounding villagers. Littoral scrub vegetation was formed due to mangrove deforestation. In the course of time, several exotic species spread over the area, and are affecting the native vegetation. The present study has shown that there is significant decrease of 1534 ha of mangrove forest from 1973 to 2004.

Remote sensing (RS) and Geographical Information System (GIS) are playing a major role in getting a synoptic view of the status of the present vegetation. A comparative study of the present and past conditions of mangrove vegetation brings out an overall picture, to convince forest officials, managers, decision makers and planners for further conservation and restoration activities. RS in conjunction with GIS technology can play a vital role in the monitoring and planning of mangrove forests, by multi-temporal interpretation of satellite data. The information generated for the Bhitarkanika Sanctuary area will aid in understanding the spatial distribution of mangrove forests and periodic changes over more than 30 years. This will help the Forest Department, Government of Orissa in further planning and taking appropriate decisions for sustaining the remaining mangrove cover.


1. Bandarnayake, W. M., Traditional and medicinal uses of mangroves. *Mangroves Salt Marshes*, 1998, **2**, 133–148.
2. Dahdouh-Guebas, F., Mathenge, C., Kairo, J. G. and Koedam, N., Utilization of mangrove wood products around Mida Creek (Kenya) amongst subsistence and commercial users. *Econ. Bot.*, 2000, **54**, 513–527.
3. Gang, P. O. and Agatsiva, J. L., The current status of mangroves along the Kenyan coast: A case study of Mida Creek mangroves based on remote sensing. *Hydrobiologia*, 1992, **247**, 29–36.
4. Das, P., Basak, U. C. and Das, A. B., Restoration of the mangrove vegetation in the Mahanadi delta, Orissa, India. *Mangroves Salt Marshes*, 1997, **1**, 155–161.
5. Dahdouh-Guebas, F., Verheyden, A., De Genst, W., Hettiarachchi, S. and Koedam, N., Four decade vegetation dynamics in Sri Lankan mangroves as detected from sequential aerial photography: A case study in Galle. *Bull. Mar. Sci.*, 2000, **67**, 741–759.
6. State of Forest Report 2003, Forest Survey of India, Ministry of Environment and Forests, Government of India, New Delhi, 2003, pp. 21–22.
7. Kathiresan, K., Conservation strategies for mangroves in India. *Botanica*, 2003, **53**, 61–75.
8. Mapping of forest cover in India from satellite imagery (1972–75 and 1980–82), Summary Report, National Remote Sensing Agency, Hyderabad, 1983, pp. 5–6.
9. Kumar, R., Distribution of mangroves in Goa. *Indian J. For.*, 2000, **23**, 360–365.
10. Mangroves of India, Status report, Ministry of Environment and Forests, Government of India, New Delhi, 1987, pp. 52–55.
11. Banerjee, L. K., Vegetation of the Bhitarkanika Sanctuary in Cuttack district, Orissa, India. *J. Econ. Taxon. Bot.*, 1984, **5**, 1065–1079.
12. Banerjee, L. K. and Rao, T. A. (eds), *Mangroves of Orissa Coast and their Ecology*, Bishen Singh and Mahendrapal Singh, Dehra Dun, 1990.
13. Biswal, A. K. and Choudhury, B. P., Bhitarkanika Wildlife Sanctuary: Exploitation and management. *Neo. Bot.*, 1993, **1 and 2**, 17–22.
14. Saxena, H. O. and Brahmam, M., *The Flora of Orissa*, *Vols I–IV*, Orissa Forest Development Corporation Ltd, Bhubaneswar, 1996.
15. Chadha, S. K. and Kar, C. S. (eds), *Bhitarkanika: Myth and Reality*, Natraj Publishers, Dehra Dun, 1999.
16. Dhal, N. K. and Rout, N. C., Few rare, endangered, vulnerable and threatened mangals from Orissa coast worth conserving. *Ecol. Environ. Conserv.*, 2001, **7**, 67–70.
17. Mishra, P. K., Sahu, J. R. and Upadhyay, V. P., Species diversity in Bhitarkanika mangrove ecosystem in Orissa, India. *Lyonia*, 2005, **8**, 73–87.
18. Reddy, C. S., Pattanaik Chiranjibi, Dhal, N. K. and Biswal, A. K., Vegetation and floristic diversity of Bhitarkanika National Park, Orissa, India. *Indian For.*, 2006, **132**, 664–680.
19. Ramachandran, S., Sundaramoorthy, S., Krishnamoorthy, R., Devasenapathy, J. and Thanikachalam, M., Application of remote sensing and GIS to coastal wetland ecology of Tamil Nadu and Andaman and Nicobar group of islands with special reference to mangroves. *Curr. Sci.*, 1998, **75**, 236–244.
20. Selvam, V., Ravichandran, K. K., Gnanappazham, L. and Navamuniyammal, M., Assessment of community-based restoration of Pichavaram mangrove wetland using remote sensing data. *Curr. Sci.*, 2003, **85**, 794–798.
21. Nayak, A. K., *Pictorial Guide to Mangrove Flora of Bhitarkanika*, Mangrove Forest Division (Wildlife), Government of Orissa, Rajnagar, 2004.


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