Abstract—In the coastal environment, mangroves are various kinds of trees up to medium height and shrubs that grow in saline coastal sediment habitats in the tropics and subtropical tidal areas, including estuaries and shorelines. Mangroves form an essential part of the coastal environment as they act as a barrier against cyclonic storms, floods; they help avoid coastal erosion; mangroves prevent the extinction of distinct and vital species of flora and fauna thriving in their ecosystems; they improve the production of coastal fisheries; they balance the coral reef and sea grass bed ecosystems; they enable the recharge of ground water; they retain nutrients and filter sediments. The World’s mangroves span over 30 countries with a total area of 99,300 sq. km. World-wide mangroves are disappearing at an alarming rate. In some developing countries about 80% of mangroves were lost in the last three decades. In Tamil Nadu, mangroves are well developed in Pichavaram and Muthupet. The Pichavaram mangrove is a typical swamp, extending between Vellar and Coleroon estuaries. The areal extent of mangroves has changed over years and human activities continue in the Pichavaram mangrove environment. As per that analysis of changes have been made using GIS, the possible causes of degradation are aqua culture, use as fuel and fodder and socio-economics. Assessing the health of the mangroves and the intertidal areas in which they live, is also very important in assessing the overall ecological health of Pichavaram coast for the purpose of future developmental activities. In this paper, mangrove health assessment and change detection of Pichavaram is done by taking into consideration the various important health indicators such as canopy cover, defoliation, waterway obstruction, mangrove vegetation pattern, human habitation, erosion / accretion. These indicators are mapped using pre – monsoon , post – monsoon and multi – temporal remote sensing data of Pichavaram coast for the years 2005, 2007 and 2012 by GIS analysis rather than field data. Weightage analysis of all indicators is done using the maps to obtain the mangrove health map showing areas of healthy, unhealthy and degrading and degraded mangroves.

Keywords—Pichavaram mangroves, Mangrove Health Assessment, Change detection of mangroves, GIS Analysis of Mangroves, Mangrove Health Indicators.

I. INTRODUCTION

An easy way to comply with the conference paper formatting requirements is to use this document as a template and simply type your text into it. Mangroves are coastal wetland forests established at the intertidal zones of estuaries, backwaters, deltas, creeks, lagoons, marshes and mudflats of tropical and subtropical latitudes. Approximately one fourth of the world’s coastline is dominated by mangroves that are distributed in 112 countries and territories comprising a total area of about 181,000 square kilometers. Mangrove ecosystems dominate the coastal wetlands of tropical and subtropical regions throughout the world.

Pichavaram is home to the second largest Mangrove forest in the world, and it is one of the unique eco-tourism spots in South India. Ecological studies carried out in the Pichavaram mangrove wetlands that unscientific management practices followed in the past are the main causes of degradation. In the Pichavaram mangrove wetland, a system of management called “coupe-system” was followed from 1935 to 1970. Under this system of management, healthy mangrove forest was clear-felled in coupes by rotation every 20 to 25 years for revenue generation. This triggered a chain reaction, leading to development of hyper-saline conditions in the coupe-felled area, and preventing natural regeneration of mangroves. Since nearly 80% of the volume of the mangrove surface soil is made up of water, exposure of this soil to the sun due to clear felling caused evaporation of soil water. This in turn led to subsidence of sediment in the clear felled area, on account of which the topography of the coupe-felled area became trough shaped.
As a result, tidal water entering into these “troughs” during high tide became stagnant; evaporation of stagnant tidal water led to increase in salinity, which is lethal to any mangrove plant. An estimate indicates that coupe-felling is responsible for nearly 65% of degradation in the Pichavaram mangroves. Grazing is another important factor. So finding the changes taking place in the mangrove plantation and modelling the health assessment of the mangroves using minimum field survey and more of remote sensing data and GIS is necessary for improved accuracy in results and for carrying out developmental activities.

II. STUDY AREA

Pichavaram mangrove ecosystem (latitude 11º 25’ N and longitude 79º 47’ E) is a shallow estuarine complex sandwiched between two prominent estuaries, the Vellar estuary in the north and Coleroon estuary in the south with a total area of 1100 ha. It has 15 islets ranging in size from 10 m to 2 km square separated by intricate waterways, that connect the Vellar estuary in the north and the Coleroon estuary in the south (Ramanathan, 1997 Avicennia marina is the most dominant mangrove species followed by Avicennia officinalis, Excoecaria agallocha, Rhizophora apiculata and Rhizophora mucronata. Uppanar River and Khan Saheb Canal contributes the discharge during monsoon season. The anthropogenic input from nearby agricultural, domestic and industrial sources through Khan Saheb Canal has made this pristine ecosystem vulnerable for heavy metal contamination.

III. SOFTWARE USED

- Erdas IMAGINE 10
- ArcGIS 9.1

IV. METHODOLOGY

The health assessment model of the literature uses field observation data. Whereas, this thesis uses remote sensing data for mangrove health assessment. The methodology involves three main stages. The three main stages are health indicator identification, setting criteria for indicators, mangrove health calculation.

A. Data Collection

For this study, IRS 1 - C satellite images of Pichavaram coast, TamilNadu were acquired for the years 2005, 2007 and 2012. All these satellite images were obtained from Institute of Remote Sensing, Anna University Collected Satellite Images
  - Pre monsoon, post monsoon and multi temporal IRS - 1C LISS III remote sensing data of Pichavaram Coast for three years – 2005, 2007, 2012
  - Toposheet of Pichavaram Coast (scale 1:50000)
  - Google image download

B. Health Assessment Model

a) Indicators Affecting Health Of Mangroves

The indicators which affect the health of mangroves as per their importance are

i. Canopy cover – (mapped using standard methods of analysing remote sensing data)

ii. Obstruction to natural flow of tidal and freshwater of tidal and freshwater is mapped using pre and post monsoon remote sensing data for the presence of any obstruction across waterways

iii. Anthropogenic pressure such as pollution, dredging, grazing and reclamation
iv. Change in vegetation – changes such as dense mangrove to open mangrove, open mangrove to sparse mangrove, sparse mangrove to non-mangroves will be mapped using temporal RS data.

v. Erosion and/or accretion – Temporal Google earth data will be used to map erosion/accretion.

In the final output, Health of mangroves is assessed as a map showing values from 1 to 100 (healthy to unhealthy) and can be graded as:
1. Mangroves in pristine health
2. Mangroves vulnerable to degradation
3. Mangrove degrading
4. Mangrove degraded

b) Indicators Criteria

1) Canopy Cover

The mangrove area was clipped from the satellite data for the year 2005 and 2012 and Normalized Differential Vegetation Index (NDVI) was calculated for both the images. Histogram was generated for the NDVI images. Based on the histogram statistics, maximum and minimum ndvi values are identified for the image corresponding to mangroves. Natural breaks (jerks) classification has been used to divide the entire image into four bands based on the histogram statistics. The band classified image is converted into vector file to create the final canopy cover map, the flowchart for which is shown in figure 2.

2) Obstruction to Natural Flow

The LISS III satellite data for the year 2011 and 2012 along with the reference Google Earth image was used to create the waterway obstruction map. The waterways in the image, which indicated visual color change from blue to black or sand formation in the waterway was interpreted visually with the help of the pre monsoon and post monsoon satellite images for the year 2011 and 2012 along with validation from the Google Earth image. The identified waterways are digitized and obstruction attribute is assigned to create the waterway obstruction map.
Formation of sandbars across river mouths/ estuaries – Unhealthy
Formation of sandbars/ deposition across rivers/ creeks and canals – unhealthy change in water color from black or dark blue to light blue (barrages) - Unhealthy.
Obstruction for than or equal to 6 months
Obstruction for less than or equal to 3 months
No obstruction

3) Anthropogenic Stress

The IRS LISS III satellite images for Pichavaram are taken and the human habitation area i.e. Village present in close proximity with the mangroves are identified and digitized. The boundary of the mangrove area was separately digitized and buffer analysis was done. Buffers corresponding to various distances of the human habitation from the mangrove area were created as per the proximity of the village from the mangrove boundary.

4) Change in vegetation pattern

The IRS LISS III satellite images for the year 2005 and 2012 were taken and supervised classification was carried out for each image and the four types of mangrove classes were identified and subclasses were created for each main class and merged. The supervised classified images were converted into vector data and union analysis was carried out with both supervised classified images as input as shown in figure 5.

Any mangroves to others
Dense mangroves to open mangroves 40
Sparse mangroves to open mangroves 40
No change in open mangroves 40
Dense mangroves to sparse mangroves 60
Open mangroves to sparse mangroves 60
No change in sparse mangroves 60
Open mangroves to dense mangroves 100
Sparse mangroves to dense mangroves 100
No change in dense mangroves 100
5) Erosion / accretion

The Google earth images for the year 2005 and 2012 were taken and were checked for High Tide level and Low Tide Level as per the date and time the images were captured. If both images were together found to be in the same tidal level with minimal tidal variation, the shorelines for both images was digitized from the Google earth images and the resulting kml files were imported into ArcGIS and converted into vector files and erosion accretion attributes were assigned. Union analysis was done by taking both the files as input and the final erosion accretion map was created as per the flowchart shown in figure 6.

![Flowchart for Erosion and Accretion Map](image)

**Fig 6 Flowchart for Erosion and Accretion Map**

- **Erosion** – erosion of mangrove stands along shore/ river banks
- **Accretion** – accretion of mangrove stands along shore/ river banks
  - Erosion of mangroves (tide dominated mangroves) over a period is unhealthy and accretion of mangroves along the shore is healthy.
  - Accretion of sand inside mangrove stand is unhealthy.

<table>
<thead>
<tr>
<th>S.NO</th>
<th>PARAMETER</th>
<th>WEIGHTAGE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Canopy</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>Obstruction to nature water flow</td>
<td>4</td>
</tr>
<tr>
<td>3</td>
<td>Anthropogenic stress</td>
<td>3</td>
</tr>
<tr>
<td>4</td>
<td>Change in vegetation pattern</td>
<td>2</td>
</tr>
<tr>
<td>5</td>
<td>Erosion and Accretion</td>
<td>1</td>
</tr>
</tbody>
</table>

C. MANGROVE HEALTH CALCULATION

Map of each parameter (Rank) x weightages / sum of weightages (15)* = MH

The sum of weightages is done here to bring the values in the range of 1-100

Thus MH =

<table>
<thead>
<tr>
<th>Status</th>
<th>MH</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mangroves in pristine health</td>
<td>80.1-100</td>
</tr>
<tr>
<td>Mangroves vulnerable to degradation</td>
<td>40.1-80</td>
</tr>
<tr>
<td>Mangrove degrading</td>
<td>10.1-40</td>
</tr>
<tr>
<td>Mangrove degraded</td>
<td>1-10</td>
</tr>
</tbody>
</table>

Working with thematic maps of Mangrove wetland using the above calculation by ArcGIS.
V. RESULTS AND DISCUSSION

A. Creation Of Indicator Maps For Mangrove Health Assessment Model

The parameters affecting the health of mangroves include canopy cover, floral density, defoliation, change in vegetation pattern, obstruction to natural water flow, erosion / accretion, sedimentation pattern, anthropogenic stress and sedimentation pattern.

For the given study area, the most important parameters that are considered for creating the indicator maps using satellite data are:

- Canopy cover
- Obstruction to natural water flow
- Change in vegetation pattern
- Anthropogenic stress
- Erosion / accretion

a) Canopy Cover

For the purpose of creating canopy cover map, Normalized Difference Vegetation Index (NDVI) has been generated for all the corrected satellite images. This is done in order to differentiate the vegetation features from the other features in the image so that they are more prominently visible. The NDVI of Pichavaram for the year 2012 is shown in figure 8. The NDVI high and low values are 0.394737 and -0.538462. From histogram statistics, the minimum, maximum, mean and standard deviation values are -0.54, 0.39, 0.15 and 0.18.

Canopy cover or density for instance is considered as a surrogate for stand density, biomass, crown bulk density and an inferential measure of productivity, nutritional value, stand health and stand micro-climate. Canopy cover is one of the easiest measurable biophysical properties of mangroves. In relation to remote sensing, canopy cover is a key spatial variable that governs scene brightness and controls the fraction of over-storey and understory visible to the sensor. The canopy cover map that has been generated as per the above mentioned methodology is shown in figure 9.
b) Obstruction to natural water flow

Obstruction to natural water flow is caused by formation of sandbars and deposition across river mouths, estuaries, rivers, creeks and canals. This is indicated in the satellite data by a visual abrupt change in water color from black or dark blue to light blue (barrages). The obstruction to natural water flow map is shown in the figure 10.

![Obstruction to natural water flow map](image1)

Fig 10 Obstruction to natural water flow map for Pichavaram mangroves

---

c) Anthropogenic stress

Human induced stresses include clearing of land, agricultural practices, cutting of trees, grazing in the mangrove patches, dredging, pollution as well as construction and other activities of the area that is in proximity to the mangroves. Human habitation nearest to the mangrove patch is identified and anthropogenic stress map is created as shown in the figure 11.

![Anthropogenic stress map](image2)

Fig 11 Anthropogenic stress map for Pichavaram mangroves

---

d) Change in vegetation pattern

Change in vegetation pattern of mangroves is caused by variation in the soil nutrient composition, moisture variation, accumulation of sediments and silt in the places of mangrove growth accompanied by various climatic and biological conditions. The change in vegetation pattern map is shown in figure 12.

![Change in vegetation pattern map](image3)

Fig 12 Change in vegetation pattern map for Pichavaram mangroves

---

e) Erosion / Accretion

Erosion and accretion of mangrove stands occurs along shore/river banks. Erosion of mangroves (tide dominated mangroves) over a period is considered as unhealthy and accretion of mangroves along the shore is considered healthy. Whereas accretion of sand inside mangrove stand is unhealthy. The erosion accretion map for Pichavaram shoreline is shown in figure 13.

![Erosion & Accretion Map](image4)

Fig 13 Erosion and Accretion Map for Pichavaram mangroves

---

B. MANGROVE HEALTH ASSESSMENT

Organized by Department of Civil Engineering, SRM University, Ramapuram Campus, Chennai, INDIA.
Health Assessment Modeling for Pichavaram mangroves is done by overlaying the five indicator maps and by applying the above mentioned mangrove health assessment calculation to finally obtain the mangrove health map shown in figure 14.

**Fig 14 Mangrove Health Map of Pichavaram**

### C. GROUND TRUTH VERIFICATION AND VALIDATION

Ground truth allows the mangrove health image data to be related to real features and materials on the ground. The collection of ground-truth data enables calibration of remote-sensing data, and aids in the interpretation and analysis of what is being sensed. The correctness of the Health Map is verified and validated with ground truth verification. The field photograph of mangroves in pristine health is shown in figure 15 and mangroves that are moderately healthy is shown in figure 16. The field images of mangroves that are degrading and have already degraded are shown in figure 17 and 18.

**Fig 15 Field image of Mangroves in pristine health**

**Fig 16 Field image of Mangroves that are moderately healthy**

**Fig 17 Field image of Mangroves that are degrading**

**Fig 18 Field image of Mangroves that have degraded**

Out of the 100 points that have been verified via handheld Global Positioning System (GPS), 76 percent of the observed mangrove health condition coincides with the expected mangrove health condition as obtained in the generated mangrove health map. The health condition of mangroves at few points that were not reachable in the mangrove forest has been verified using Google earth image. The correctness of the mangrove health at various points according to the latitude and longitude information along with the expected and observed conditions.
V. CONCLUSION

The Mangrove Health Map for the part of Pichavaram area in Tamil Nadu is modeled for the year 2012 using multi-temporal optical data (IRS-P6 LISS-III). The mangrove health indicator maps are prepared using the optical data, Normalized Difference Vegetation Index (NDVI) values of the optical data, Google earth images and ground truth verification of the study area. This model reveals that the mangrove health increases with adequate and not an oversupply of water followed by places with no erosion, minimal obstruction to flow of water, less accretion and decreased anthropogenic stress.

Field visit in the Pichavaram forest indicates that the major causes of degradation in the mangroves are obstruction to water flow among the swamps as well as cutting down of mangroves for the purpose of fuel as compared to the impact of erosion at the shoreline.

- This study recommends the following points to control the degradation process and to improve the mangrove health of the land:
  - Conducting checks in timely intervals to ensure regular spacing between mangrove trees, roots and stems as well as the sediment deposition over the mangroves in order to ensure adequate supply of wave currents to all parts of the forest.
  - Establishment of protective and regulatory measures to minimize the cutting down of mangroves for fuel purpose.

ACKNOWLEDGEMENT

Mr. M. Shanmugam, Scientist C, Institute of Remote Sensing is thanked for her continuous support and technical guidance for this study. Dr. K. Srinivasa Raju, Associate Professor, Institute of Remote Sensing and Dr. M. Ramalingam, Director, Institute of Remote Sensing are thanked for valuable inputs in this research.

References


[3] Dhafer AL Garni., and Ayman S.H.Aguib., ” Application or Remote Sensing and GIS for locating suitable mangrove plantation sites along the Saudi Arabia coast”, Civil Engineering Department, King Saud University- Al Riyadh and Dr. Scot E. Smith, Geomatics Program, School of Forest Resources and Conservation, University of Florida.


