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Abstract

Mangroves are coastal wetland forests established in the intertidal zones of estuaries, backwaters, deltas, creeks, lagoons, marshes and mudflats of tropical and subtropical latitudes. World-wide mangroves are disappearing at an alarming rate. Mangroves form one of the most important ecosystems of coastal areas. In real sense, mangrove is the Kalpvriksh (divine tree which fulfills all the desires) for the coastal communities. It nurtures and safeguards the local ecology of the coastal areas and provides livelihood options to the fishermen and pastoral families. Amongst the maritime States of India, Gujarat has the second highest mangrove cover after West Bengal. Additionally, during last three decades Gujarat has more than doubled its mangrove cover. In Gujarat State, mangroves are well developed in Lakhpat taluka (block) situated in Kachchh district. In recent past, Gulf of Kachchh experienced both natural and anthropogenic changes which made it a distinctive site to analyze how natural processes and anthropogenic activities determine the changes in mangrove vegetation density and health of mangroves in coastal areas.

Multi-temporal Landsat TM data covering Lakhpat taluka (block) of February-1995, February-2017and Sentinel-2 multi-spectral data (spatial resolution 10 m) of April-2017 was analysed. The mangrove vegetation around the coastal areas was identified and classified into dense and sparse density classes based on Normalized Difference Vegetation Index (NDVI) thresholding approach. The health assessment of mangroves in Lakhpat taluka was attempted using Multi Criteria Decision Making (MCDM) approach including various parameters like mangrove density based on NDVI, Distance of mangroves from human settlement, Distance of mangrove from Industries and Ports which have direct impact of growth and health of mangroves, Erosion/ Accretion over the period of last 22 years and availability of Saline water flow during the high tide for good mangrove growth. The buffers layers of various distances for example, 0 to 10 km, 10 to 20 km and 20 to 35 km were generated from the existing mangroves using Sentinel-2 multi-spectral image in GIS environment.

The results indicate that the NDVI which is single parameter indicating the mangrove stand / vigour, growth condition and resulting health of mangroves in the area. This factor has been given highest weightage as compared to other parameters. The major anthropogenic factors like human Pressure and presence of Industries and Ports have negative impact on the mangrove health. Therefore, it was observed that presence of human settlements and Industries and Ports with the buffer region of 0 to 10 km distances from mangroves are unhealthy or prone to degradation in this region. The results of health assessment are very useful for sustainable planning and management of mangroves in the coastal areas of Lakhpat Taluka. The mangrove restoration and regeneration activity needs to be carried out as suggested by Upadhyay et al., 2015 with active participation of Community Based Organizations (CBOs) to increase the mangrove density as well as mangrove health in this region.

Keywords: Mangroves, Multi-temporal Landsat TM data, Vegetation Indices (VIs), Multi Criteria Decision Making (MCDM) approach, Mangrove health assessment

1. Introduction

Mangroves are coastal wetland forests established in the intertidal zones of estuaries, backwaters, deltas, creeks, lagoons, marshes and mudflats of tropical and subtropical latitudes. It is often highly saline and frequently inundated by the tidal action. Mangroves form one of the most important ecosystems of coastal areas. World-wide mangroves are disappearing at an alarming rate (Quoc et al., 2013). In some developing countries about 80% of mangrove cover has reduced in the last three decades. Indian coast harbours rich biodiversity and critical habitats like coral reefs and mangroves. Mangroves form one of the most important ecosystems of coastal areas. In real sense, mangrove is the Kalpvriksh (divine tree which fulfills all the desires) for the coastal communities. It nurtures and safeguards the local ecology of the coastal areas and provides livelihood options to the fishermen and pastoral families.

1.1. Mangrove Ecosystem

Mangroves are considered as one of the fragile ecosystem in coastal areas. Mangroves are unique plants capable of surviving under extreme saline environment. Mangroves are evergreen trees and shrubs that grow in saline coastal waters mainly in tropics and also sometimes in subtropics, mainly between 25°N and 25°S. They cover up to 75% of the tropical and subtropical shorelines. Mangroves growing within equatorial regions achieve their maximum biomass. These favorable conditions enable an optimal lush growth, with tree canopies reaching a height of 30–40 m (Kuenzer et al., 2011).The mangrove ecosystem is highly productive and plays critical role in economic and social development. Mangroves not only have environmental benefits like purifying water, they act as a buffer zone between land and sea and protect land from erosion and play an invaluable role as nature's shield against cyclones, ecological disasters and a protector of shorelines. Mangroves also provide indirect benefits through its impact on up-gradation of coastal and marine eco-system. It is well known that coastal population succumbs to disasters of cyclones and Tsunamis', incurring heavy losses to their properties and live-stock. Mangrove plantation along the coast serves as a barrier to cyclones and Tsunamies and protects the people living in Coastal areas. The endangered mangrove ecosystem has been accepted as a unique biological setup which needs protection and conservations. Mangroves harbor variety of life forms and economically, Mangroves are a good source of timber, fuel and fodder and hence are the main source of income generation for shoreline communities like fisher folk (Patel et al., 2014).

Mangrove distributions within their ranges are strongly affected by temperature (Duke, 1992) and moisture (Saenger and Snedaker, 1993). Large-scale currents may also influence distributions by preventing propagules from reaching some areas (De Lange and De Lange, 1994).

Indian mangrove forests account for about 3% of world's mangrove vegetation supporting around 4011 diverse biological species including globally threatened species in the coasts of the country (FSI 2011 & Kathiresan, 2010). Amongst the maritime States of India, Gujarat has the second highest mangrove cover of 1103 sq km after West Bengal that is 2097 sq km as on 2013. Additionally, in around three decades Gujarat has more than doubled its mangrove cover. In the coastal areas of Gujarat state, mangroves are well developed in Lakhpat taluka (block) situated in Kachchh district. Assessment of mangroves health and the intertidal area are very important for assessing the overall ecology of Lakhpat mangroves. In recent past, Gulf of Kachchh has experienced both natural and anthropogenic changes which made it a distinctive site to analyze how natural processes and anthropogenic activities have impact on mangrove vegetation density and health of mangroves in coastal areas. Mangroves plantation development is largely dependent not only the proper selection of site but also the selection of planting species and planting method. Kachchh district has a large inter-tidal mudflat which is the potential site for mangroves plantation but all these inter-tidal mudflats are not suitable. A study was carried out to provide a preliminary overview of the coastal segment which was suitable for mangroves plantation. The suitable sites for mangrove plantation are identified based on four variables: coastal land use and land cover, coastal geomorphology, mean tidal range and significant wave height (Mahapatra et. al., 2013).

1.2. Health Assessment of Mangroves

Despite the ecological and economic significance of mangroves they are considerably under pressure from human activities. Its area has declined by 30- 50% in the past 50 years, a higher rate than most other biomes (Balmford et al., 2002). Reduction in the quantity and periodicity of fresh water flowing into mangrove wetlands affects the density as well as diversity of the mangroves through increasing water and soil salinity. The other major threats to this ecosystem are reclamation of mangrove areas for human habitation, aquaculture, agriculture, port and industrial and other developmental. One of the major human induced threats to mangrove ecosystem is its

reclamation for shrimp aquaculture ponds (Ajai and Chauhan, 2017). These various anthropogenic factors and natural processes lead to destruction and degradation of mangrove health. Therefore, period assessment of mangrove health is very important to necessary steps for protection of mangroves.

To develop a "mangrove health assessment model", the first step is to identify environmental indicators of the mangrove ecosystem health that need to be included in the multi-parametric health model. The choice of these of indicators and the weighting factors to be assigned to each of them, may differ from one mangrove zone to the other depending on the biological, ecological, environmental and geomorphic setup. The above health models based on a single parameter such as the vegetation vigour/canopy density (represented by NDVI) are not robust and may not work in certain conditions, specially, when mangroves are stressed due to anthropogenic or natural causes. On the other hand multi-parametric health models, accounting for the mangrove vigour/canopy, the weather, hydrology, stress factors, environment etc may be more robust. Such multi parameter 'Mangrove health assessment model' has been developed for the selected mangrove zones of India (Ajai et al., 2013). This model uses a number of environmental indicators which are generated using both, satellite data and field survey/ measurements. The health assessment and change detection of mangroves at Pichavaram was carried out taking into consideration the various important health indicators such as canopy cover, defoliation, waterway obstruction, mangrove vegetation pattern, human habitation, erosion/accretion, etc. 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. Weightage analysis of all indicators was carried out using the maps to obtain the mangrove health map showing areas of healthy, unhealthy and degrading and degraded mangroves (Kannan, 2014).

Spatial multi-criteria decision making (MCDM) is a process where geographical data are combined and transformed into a decision where

decisions made based on analysis of criteria and since this method is to determine the best alternative from a number of alternatives based on certain criteria. Criteria are usually in the form of measures, rules or standards used in decision making (DoriRachmawania et al., 2016). Multi-criteria decision making involves input data, the decision maker's preferences and manipulation of both information using specified decision rules. In special MCDM, the input data are geographical data. Spatial MCDM is more complex and difficult in contrast to conventional MCDM, as large numbers of factors need to be identified and considered, with high correlated relationships among the factors a spatial decision problem is the difference between the desired state in a geographical system and an existing state in real world (Malczewski, 1999). Many spatial decision problems give rise to the GIS-based multicriteria decision analysis (GIS-MCDA). These two distinctive areas of research, GIS and MCDA, can benefit from each other (Laaribi et al. 1996, Malczewski 1999, Thill 1999, Chakhar and Martin 2003).

The mangrove spatial vulnerability modeling that takes into consideration environmental and socioeconomic criteria, in spatial and non-spatial formats has been attempted in parts of western Niger delta by Omo-Irabor et al., 2011. These parameters and their effects on mangrove vulnerability were selected and weighted by experts in the related fields. Criteria identification and selection were mainly based on effects of environmental and socioeconomic changes associated with mangrove survival. The results obtained revealed the dominance of socioeconomic criteria such as population pressure and deforestation, with high vulnerability index of 1.75. The environmental criteria were broadly dispersed in the study area and represents vulnerability indices ranging from 0.00–0.75.

1.3. Mangroves Health Assessment using Remote Sensing

Remote sensing technique due to its synoptic, multi-temporal, coverage and multi-spectral

ability in whole range from visible to microwave wavelengths can effectively act as tool par excellence providing advance and reliable information on mangrove extent and status of its growth along the coastal area (Patel et al., 2014). It is an indispensable tool for assessing and monitoring land use/ land cover changes especially in forests, because the hilly or swampy terrain in inaccessible and vast in area and supports in planning appropriate conservation measures. Mapping the distribution of species and vegetation communities in coastal wetlands is important to provide wetland inventories, assess change over time and to map and quantify biodiversity. Remote sensing has an essential role to provide a fast and efficient method of ecosystem baseline mapping and subsequent monitoring in mangrove areas which are temporarily inundated and sometime inaccessible. Mangrove environments often grow in remote and inaccessible areas and field-survey and airborne data acquisition is difficult and time consuming.

The mangrove regeneration was monitored using multi-temporal Indian Remote Sensing Satellite (IRS) LISS-III and LISS-IV digital data covering Gulf of Kachchh region. The multi-temporal IRS LISS-III data covering Gulf of Kachchh of October-2005, November-2011 and LISS-IV data of April-2014 was analyzed and mangrove status in terms of status of regenerated mangrove density and mangrove area in different talukas was estimated. The taluka-level mangrove areas were estimated and changes in the areas were monitored during the period of six years from 2005 to 2011. The results indicated that the areas where mangrove regeneration activities was carried out mangrove density as well as mangrove area has substantially increased in the Gulf of Kachchh region (Upadhyay et al., 2015). Indian Remote Sensing Satellite (IRS) data have been extensively used to map mangroves and other coastal vegetation for the entire country's coastline. In one such study, on the Marine National Park, in the Gulf of Kachchh, mangrove areas were monitored for the last 25 years. The degradation of mangroves continued up to 1985 and the condition significantly improved due to the adoption of conservation measures. This has helped in planning various management actions to conserve this vital ecosystem (Nayak and Bahuguna, 2001).

High-spatial resolution multi-spectral optical sensors are well-suited technologies for detailed coastal ecosystem mapping, such as mangroves, and are also cost-effective when compared to traditional air photo interpretation (Muhammad and Stuart, 2011; Simav et al., 2013). In the field of monitoring, scientists have developed various vegetation indices for qualitative and quantitative assessment using spectral measures. The various satellite-derived indices such as Normalized Difference Vegetation Index (NDVI) and Ratio of NIR & Red wavelengths can also be effectively used to monitor the vegetation status and condition of mangrove ecosystem (Patel et al., 2014; Direk et al., 2012). Above indices were generated, evaluated and compared for assessing its suitability for discrimination of mangroves and other terrestrial vegetation. Spectral indices, such as normalized difference vegetation index and band ratios can be effectively used to distinguish mangrove forests from water, mud flats and sand beach. However, terrestrial vegetation and water-vegetation mixed pixels may complicate mangrove forest identification by using these spectral indices (GAzioğlu, et al., 2014; Tiezhu et al., 2016). The mangrove density distribution in Pongok Island was analyzed using the Normalized Difference Vegetation Index (NDVI) computed from Landsat data (Umroha, et al., 2016). The results of this study indicated that the mangrove density could be classified into three classes i.e. spares (NDVI range: -1 – 0.33; equal with <1,000 Trees/Ha), moderate (NDVI range: 0.33-0.42; equal with 1,000 to <1,500 Trees/Ha), and dense (NDVI range: 0.42-1; equal with 1,500 Trees/Ha).

1.4. Objectives
The major objectives of study on Mangrove health assessment using Geo-informatics technology in Gulf of Kachchh area in Gujarat State are as follows:

❖ Identification of various indicators like human pressure on the mangrove ecosystem, mangrove density, availability of water flow affecting health of mangroves, erosion/accretion, distance of human settlement and port and industries from mangroves etc. using multi-date satellite data in GIS environment.

❖ Mangrove density classification based on Normalized Difference Vegetation Index (NDVI) and health assessment

❖ Computation of Weightage and Rank for each criteria

❖ Mangrove health assessment using criteria based analysis of various factors using multi criteria decision making approach (MCDM)

2. Study Area

The Gulf of Kachchh (GOK), a large marine ecosystem in the state of Gujarat, has unique ecosystems like coral reefs and mangroves at its southern coast and mangroves at selected locations along the northern coast. The region was notified as a Marine National Park and Sanctuary (MNPS) in 1982. Lakhpat-Abdasa coast comprises of coastal corridor, agriculture area, habitation and mining area. Part of the coast has been declared as a Chinkara Wildlife Sanctuary. There is one fishing settlement, namely Narayan Sarovar. The main industries along the Lakhpat- Abdasa coast are mining, cement industries etc.

In order to support these industries, there are power plants and desalination plants on the coast. Developmental activities like construction of ports and human interventions like mining of corals, destruction of mangroves to expand the salt-pan activities etc., have extensively damaged the corals and the mangroves in the region (Upadhyay et al., 2015). In the present study Lakhpat taluka (block) in the Kachchh district is selected for health assessment of Mangroves using Remote Sensing satellite data along with other important parameters affecting the mangrove growth in this region. The location map of the study area in Kachchh district is given in Figure 1.

3. Methodology

3.1. Remote Sensing Satellite Data Used

In this study, multi-temporal Landsat TM digital data (spatial resolution 30m) of February-1995, and February-2017 along with Sentinel-2 multi-spectral data (spatial resolution 10m) of April-2017 covering Kachchh region was downloaded from https:// earthexplorer.usgs.gov/. The details of Remote Sensing Satellite digital data acquired are given in Table-1.
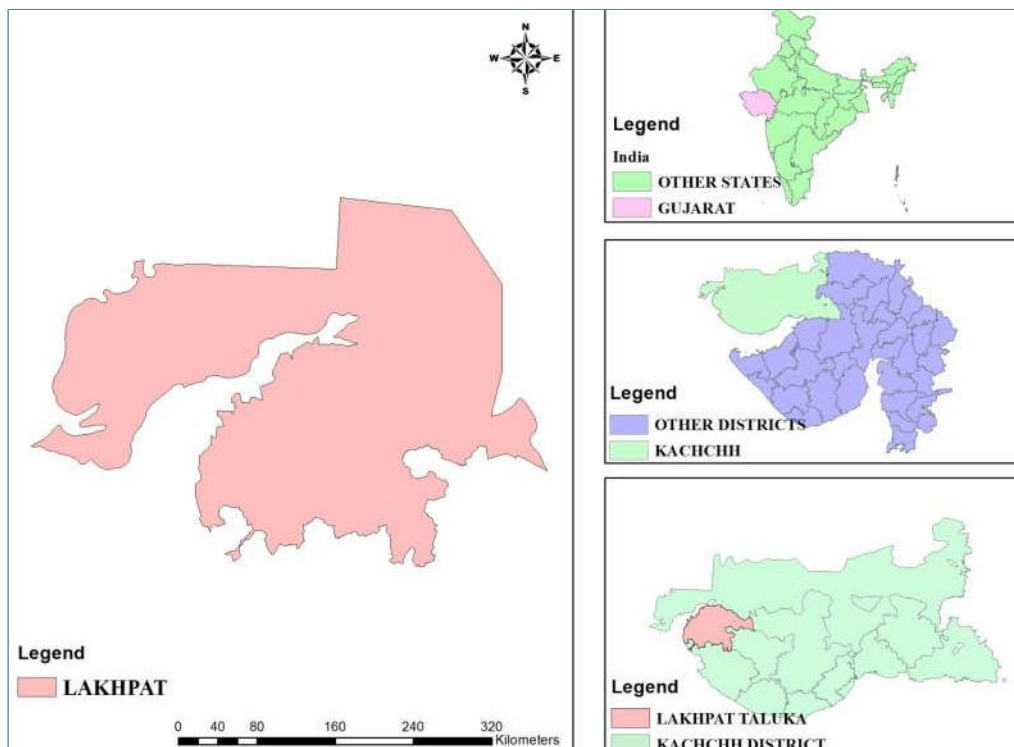

Fig. 1. Location Map of Study area in Kachchh District, Gujarat State

Table-1: Details of Remote Sensing Satellite data used

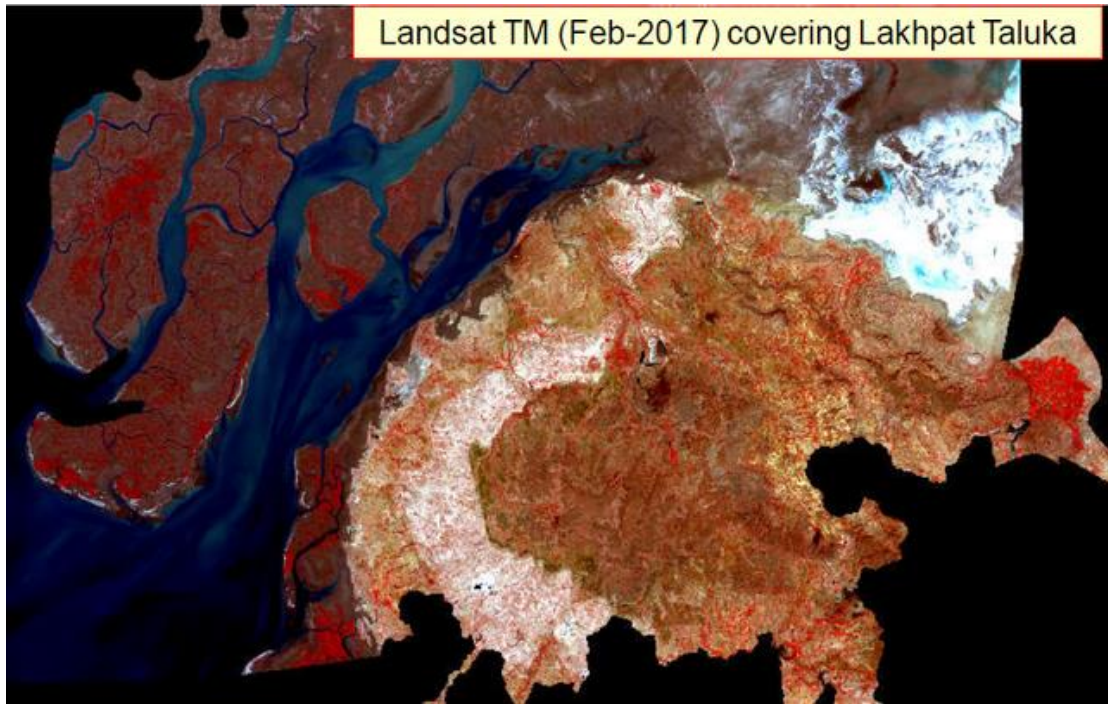| Sr. No.	Satellite	Sensor	Path/Row	Acquisition Date
1	Landsat-5	TM	151/44	24-Feb-1995
5	Landsat-8	TM	151/44	20-Feb-2017
6	Sentinel-2	MSI	L1C_T42QVM_A009383 _20170409T060223	09-Apr-2017

Fig. 2. Landsat TM data of Feb-2017 covering Lakhpat Taluka

Fig. 3. Sentinel-2 data of Apr-2017 covering parts of coastal area in Lakhpat

The Landsat TM data of Feb-2017 covering Lakhpat Taluka is given in Figure-2. The Landsat TM image of Feb. 2017 extracted using Lakhpat Taluka boundary is given in Figure-2 and the Sentinel-2 multi-spectral data of 9-Apr-2017 is given in Figure-3. The parts of coastal areas in Lakhpat Taluka extracted from Landsat TM data of Feb-1995 and Feb-2017 showing mangrove density are given in Figure-4.

3.2. Geographic Information System (GIS) data

The administrative boundaries like district, taluka and village boundaries of coastal villages were generated and used for extracting satellite data covering the study area in Kachchh District, Gujarat State. The satellite data covering study area extracted from multi-date Landsat TM and Sentinel-2 was used for monitoring mangrove vegetation density as generating other various thematic layers used for mangrove health monitoring in this study.

3.3. Ground Truth Data

Ground Truth (GT) data on mangroves in Lakhpat taluka was collected during first fortnight of June-2017, which coincided with flowering stage of Mangrove in this region. Large homogeneous sites of mangroves with different density classes, as well other aquatic and agricultural vegetations were identified using the Sentinel-2 False Colour.

Composite (FCC) in the field. The field observations like mangrove growth/vigour, mangrove density, availability of saline water to mangroves through creeks and during high-tide, location of habitation, ports, industries and their distance from mangroves, etc. were recorded for selected sites. The GPS measurements of selected sites in the dense and sparse mangrove along with field photographs were recorded. Some of the field photographs of dense and sparse mangrove vegetation cover are given in Figure-5.
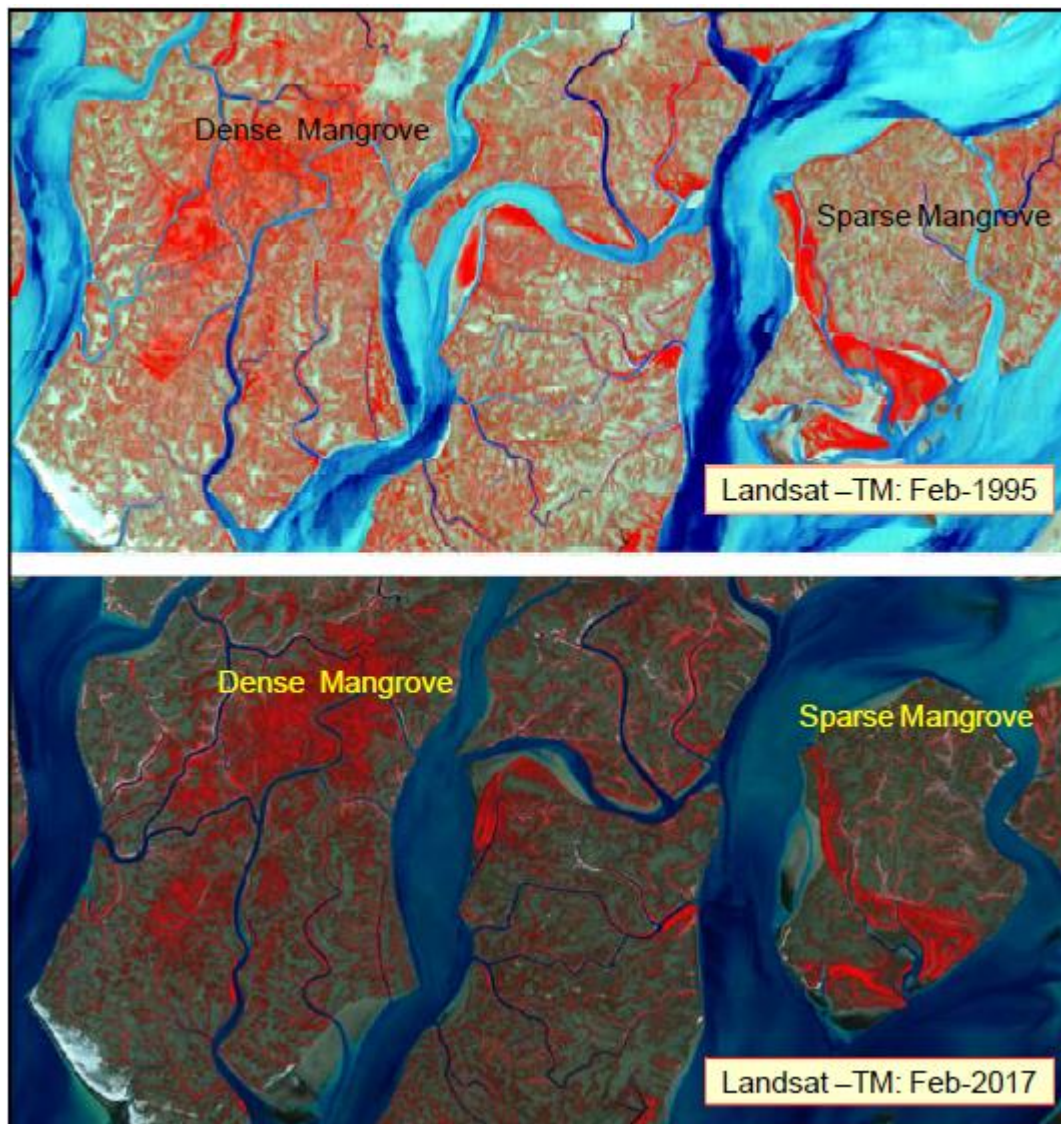

Fig. 4. Landsat TM images of Feb. 1995 and Feb. 2017 covering parts of Lakhpat Taluka

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3.4. Remote Sensing Satellite data analysis

The Landsat TM and Sentinel-2 multi-spectral data covering study area was analyzed using following major steps:
i) Multi-date data preparation and geo-referencing, ii) Administrative boundary superimposing, iii) Extraction of area of interest, iv) Superimposing GPS locations of mangrove sites collected during GT data collection on the registered satellite digital data, v) Identification & delineation of mangrove into different density classes and vi) Generation of Normalized Difference Vegetation Index (NDVI) image.

3.4.1. Spectral Reflectance of Mangrove Vegetation

The conversion of digital numbers from the image data to useful quantities such as spectral radiance ($L\lambda$), and top-of atmosphere (TOA) reflectance (ρP) will provide a better basis for the comparison of data between images taken from different acquisition dates and/or by different sensors. In this study digital numbers from the image data were to spectral radiance ($L\lambda$), and top-of atmosphere (TOA) reflectance (ρP) using standard formulae available in the literature (Chander et al., 2009).
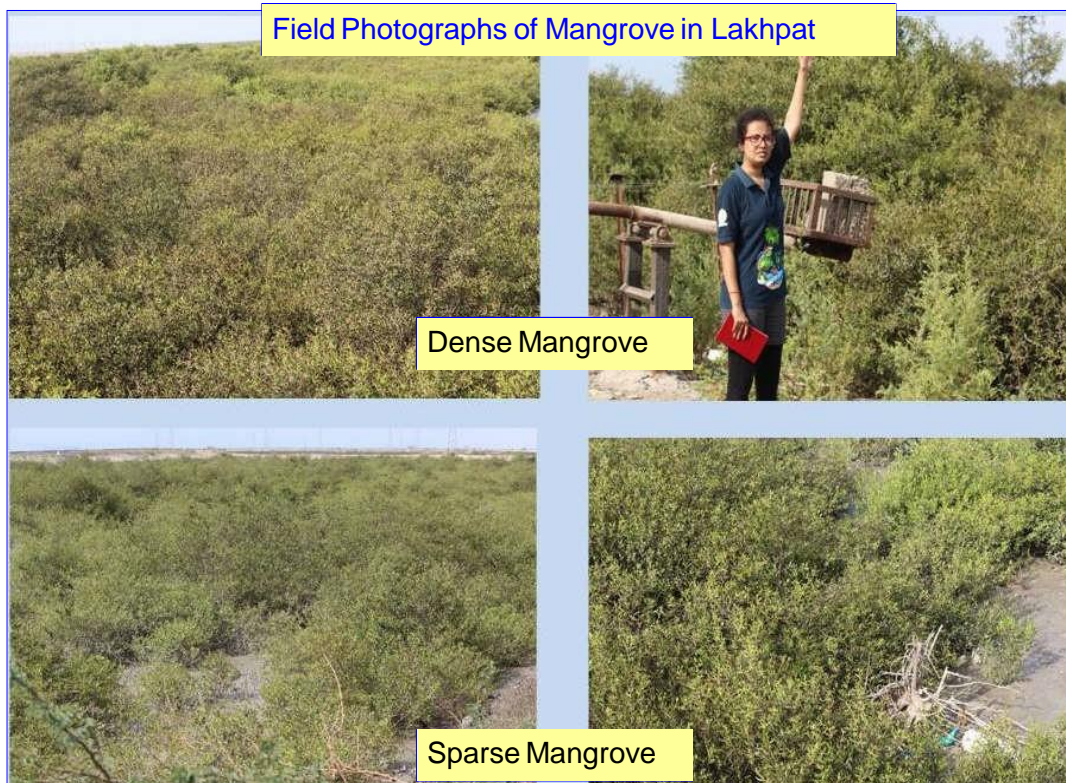

Fig. 5. Field Photographs of Dense and Sparse Mangroves in Lakhpat Taluka

The spectral reflectance of mangrove density classes and other land use classes was generated in the Landsat-TM optical spectral bands to understand the spectral behavior of mangrove and other land use classes (Figure-6). The spectral reflectance of dense and sparse mangrove is quite different in all the spectral bands and also different from coastal water and mud-flats. The mangroves have lower reflectance at shortwave infrared band-5 since it is sensitive to water content as compared to near-infrared band-4.
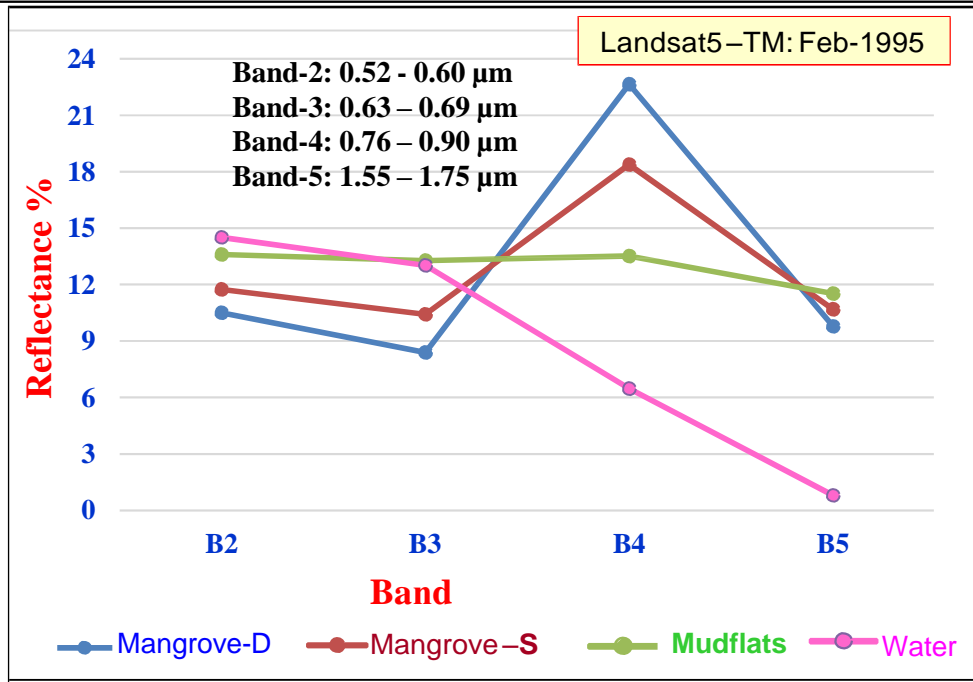
Fig. 6. Spectral Reflectance of Dense and Sparse Mangrove Classes

3.4.2. Mangrove Vegetation Density classification using NDVI Image

Various vegetation indices have been developed for qualitative and quantitative assessment of mangroves using multi-spectral data. The vegetation indices based on the Visible and Near Infra-Red (VNIR) region such as Normalized Difference Vegetation Index (NDVI) (Tucker, 1979) are highly related to biophysical variables such as leaf area index (LAI) and normalized photosynthetically active radiation (NPAR) (Baret & Guyot, 1991). Thus, they are an appropriate basis for assessing ecosystem functioning when vegetation is active.

Indexes such as the Normalized Difference Water Index (NDWI), based on shortwave infrared (SWIR) bands are more sensitive to moisture in soil and vegetation than VNIR indexes (Fensholt & Sandholt, 2003; Gao, 1996; Ghulam et. al., 2008). NDVI method was used to evaluate the forest density cover of mangroves (Yuvaraj et al., 2014). The coastal mangrove vegetation density in the study area was identified based on the ground truth data and they were classified into dense and sparse mangrove classes based on NDVI values obtained from NDVI image. The NDVI is computed as follows:

Normalized Difference Vegetation Index = (NIR-R)/(NIR+R)

Where,
NIR = reflectance in the near-infrared band
R = reflectance in the red band

3.5. Thematic Layers of various factors considered for Mangrove Health Assessment

A study was carried out for characterizing the health status of the Indian mangrove on the basis of multiyear, multi season, remote sensing data. Normalized Difference Vegetation Index (NDVI) from SPOT-VGT coinciding with the stress period (March - May) for one decade (1999 - 2008) was subjected to maximum value compositing (MVC). From this analysis a four-category health index status based on threshold values was developed. Results showed that around 38 % and 27 % of total mangrove in India belonged to very-healthy and healthy categories, respectively. In general, the health index was lower in western coast mangroves compared to east coast. The health index was highest for the island mangrove systems (Andaman and Nicobar), and lowest along the Gujarat coast (Chellamani et al, 2014).

Monitoring the changes in mangrove cover and density due to various factors affecting its health and its modeling using Remote Sensing and GIS is very important and necessary for carrying out mangrove regeneration and developmental activities for sustainable mangrove development along the coast. In this study, health assessment of mangroves in Lakhpat taluka was attempted using Multi Criteria Decision Making (MCDM) approach. Factors affecting health of Mangroves considered in this study are: i) Distance of mangroves from human settlement, ii) mangrove cover/density analysed based on Normalized Difference Vegetation Index (NDVI), iii) Distance of mangrove from Industries and Ports, iv) Erosion / accretion demarcated using Landsat TM data of 1995 and 2017 and v) availability of Sea water flow during the high tide for good mangrove growth.

3.5.1. Distance of mangroves from human Settlements

The major anthropogenic factors in case of South and Southeast Asia are: development of coastal agricultural land and shrimp farming ponds in intertidal areas are considered as the major factors behind mangrove degradation. of these, conversion of mangrove forest for agriculture is typically prominent in countries like India, Bangladesh, Myanmar, Thailand, and Indonesia (DasGupta and Shaw, 2013).

Dependency of local communities on mangroves has been traditional; however in recent times during the post globalisation era mangroves are facing serious threats due to over harvesting of coastal resources due to the rapid growth of population, migration into the coast and industrialization (Britta and Duke, 2005). The impact of human settlements on mangrove health in this study was analyzed by creating layers of distances from coastal mangroves. Settlements near to the mangroves were identified and digitized using Sentinel-2 (10m spatial resolution) multi-spectral Image. Buffer analysis was carried out and buffers of various distances of settlements from mangroves boundary were created. The buffers of 0 to 10 km, 10 to 20 km and 20 to 35 km were generated surrounding settlements in GIS environment. Buffers show distance of mangrove from settlement areas and thereby potential area of mangrove that may be impacted. Mangroves nearer to the settlement are prone to be impacted more than the mangroves far from the settlement. The Buffers of various distances of mangroves from habitation generated and superimposed on Sentinel-2 image covering coastal areas are shown in Figure-7.
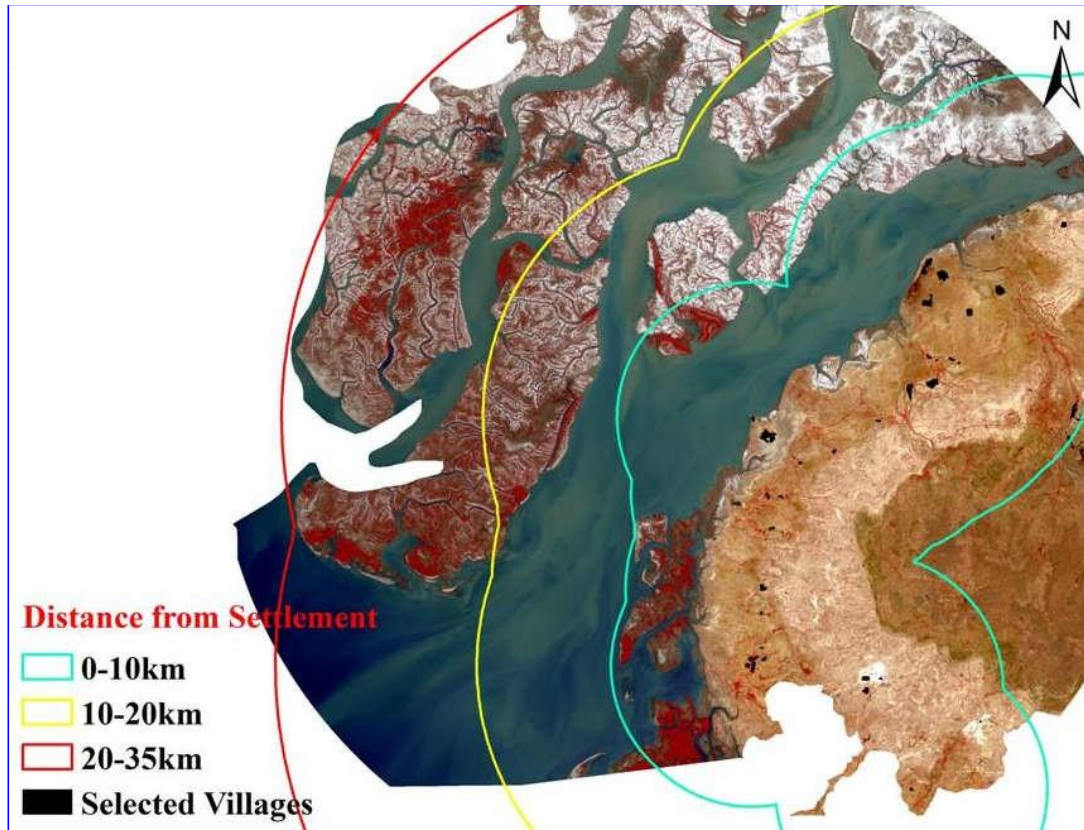
Fig. 7. Buffers of various distances of mangroves from habitation superimposed on Sentinel-2 image covering coastal areas

3.5.2. Distance of mangroves from Industries and Ports

The impact of development of industries and ports in the Lakhpat taluka on mangrove health in this study was analyzed by creating layers of distances from coastal mangroves. The ports and industries in this region were identified using Sentinel-2 (10m spatial resolution) multi-spectral Image. Buffers of various distances for example, 0 to 10 km, 10 to 20 km and 20 to 35 km were generated surrounding ports and industries in GIS environment.

Buffers show distance of mangrove from ports and industries and thereby potential area of

mangrove that may be impacted. Mangroves nearer to the ports and industries are prone to be impacted more than the mangroves far from the ports and industries. The buffers of various distances of mangroves from ports and industries generated and superimposed on Sentinel-2 image covering coastal areas in Lakhpat are given in Figure-8.

3.5.3. Distance of mangroves from Water Line

The extent of water line along the coastal area was delineated using Sentinel-2 multi-spectral image in GIS environment.
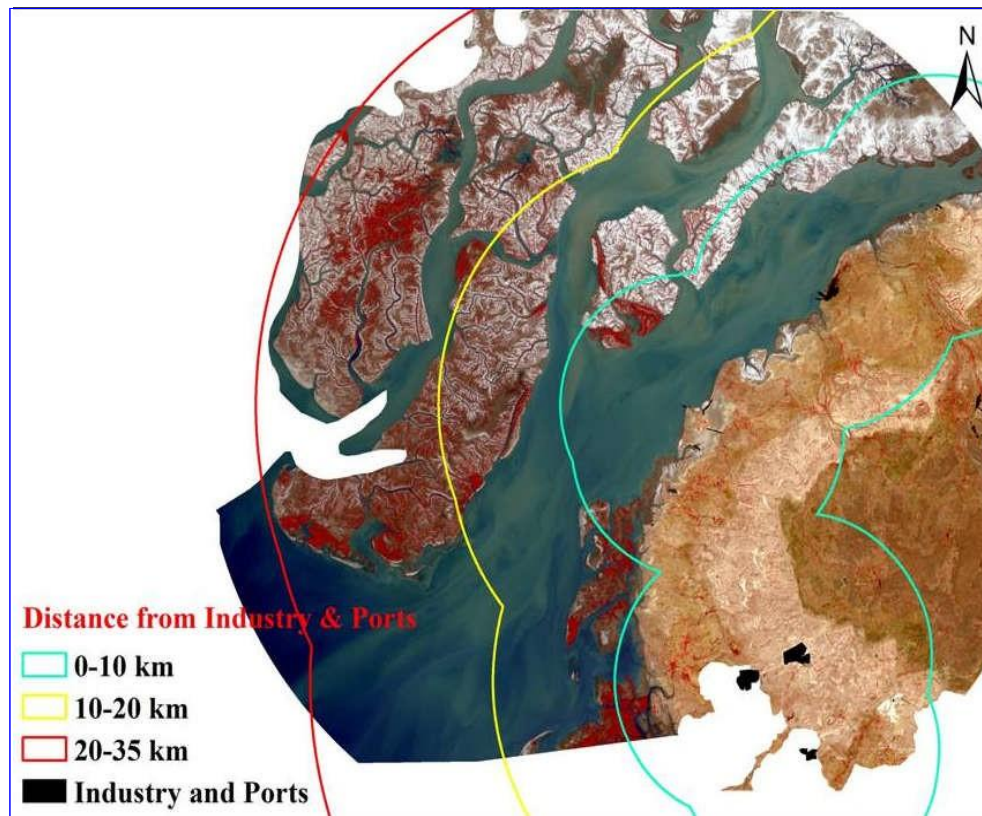
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Fig. 8. Buffers of various distances of mangroves from port and industries superimposed on Sentinel-2 image covering coastal areas

In the island areas there is almost no impact of tidal waves therefore, there is very small area where erosion / accretion can be seen in these areas. Buffers of various distances for example, 0 to 10 km, 10 to 20 km and 20 to 35 km were generated from the water line delineated using Sentinel-2 multi-spectral image in GIS environment. Buffers of various distances for example, 0 to 10 km, 10 to 20 km and 20 to 35 km were generated from the water line delineated using Sentinel-2 multi-spectral image in GIS environment. Buffers show distance of mangrove from water line which may have impact on health of mangroves in the coastal areas. The buffers of various distances of mangroves from water line were generated and superimposed on Sentinel-2 image covering coastal areas in Lakhpat are given in Figure-9.

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3.5.4. Impact of Erosion / accretion on Mangrove Health

The shoreline changes induced by erosion and accretion are natural processes that take place over a range of time scales. The mangrove vegetation along the shorelines protects them from erosion by stabilizing sediments with their tangled root systems. Mangrove roots collect sediments and slow the water flow to protect the coastline and prevent the erosion. Mangrove can only grow in areas away from direct waves mangroves protect shorelines from erosion by stabilizing sediments with their tangled root systems. Mangrove forests cover the intertidal area created by coastal accretion as a result of the interaction between river and sea (Vo et al., 2013). However, various natural and

man-made factors can induce the erosion along the coast which can have impact on the mangrove growth and health over the period of time. In this study, erosion and accretion in the coastal areas over the period of 22 years was demarcated using Landsat TM data of February-1995 and February-2017. Both the images were of the low Tide level having minimal tidal variation, and the shorelines for both images was digitized in GIS environment and erosion and accretion areas were mapped. Erosion and accretion occurs along the shore line in the tide dominated areas where mangroves are affected. The tide dominated erosion considered unhealthy whereas accretion along the shore line is considered healthy for mangrove growth. The erosion / accretion map of the coastal areas of Lakhpat taluka is given in Figure-10.
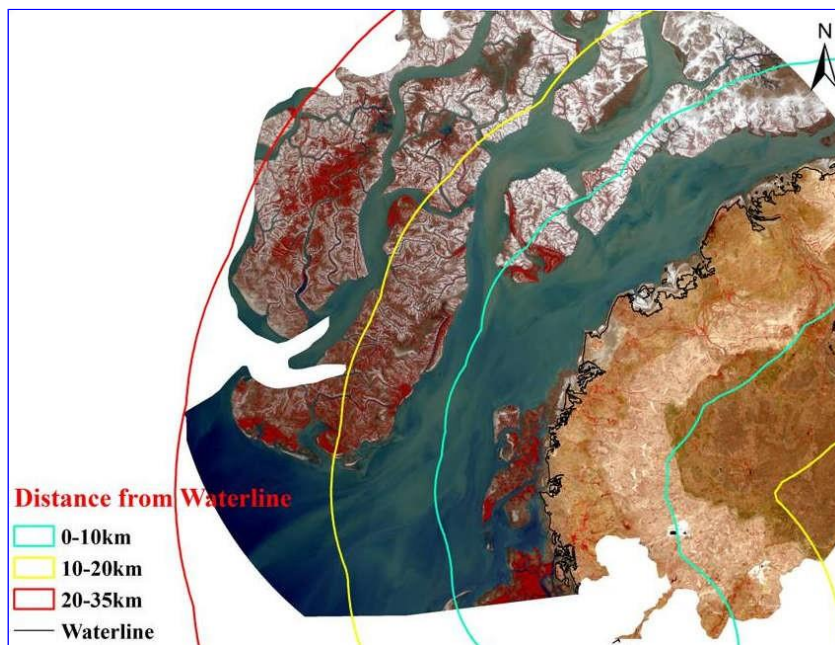

Fig. 9. Buffers of various distances of mangroves from water line superimposed on Sentinel-2 image covering coastal areas
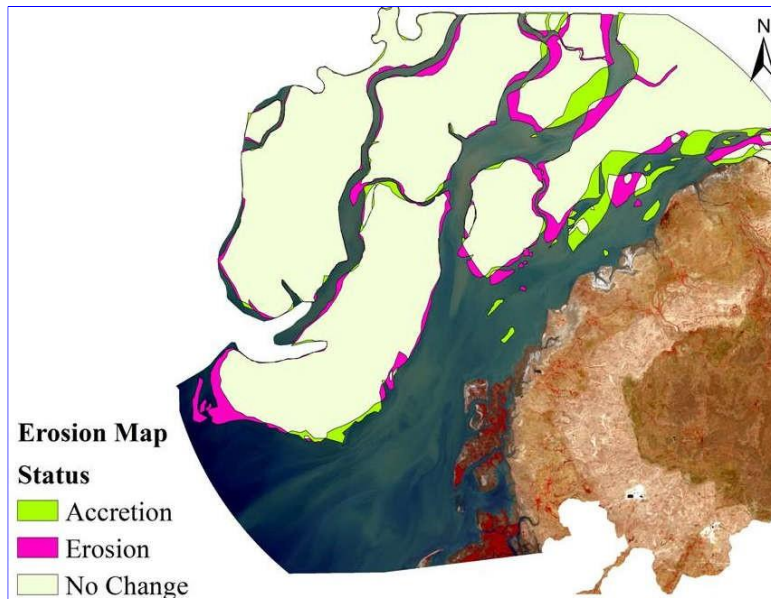
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Fig. 10. Erosion / Accretion map of the coastal areas of Lakhpat taluka

3.5.5. Mangrove cover / density Classification based on NDVI

The NDVI image of study area was used to generate mangrove density layers for mangrove health assessment.

The Histogram statistics of NDVI image were generated to define range for dense, moderate and sparse mangrove classes. Mangrove density classes of dense, moderate and sparse in coastal areas are given in Figure-11.
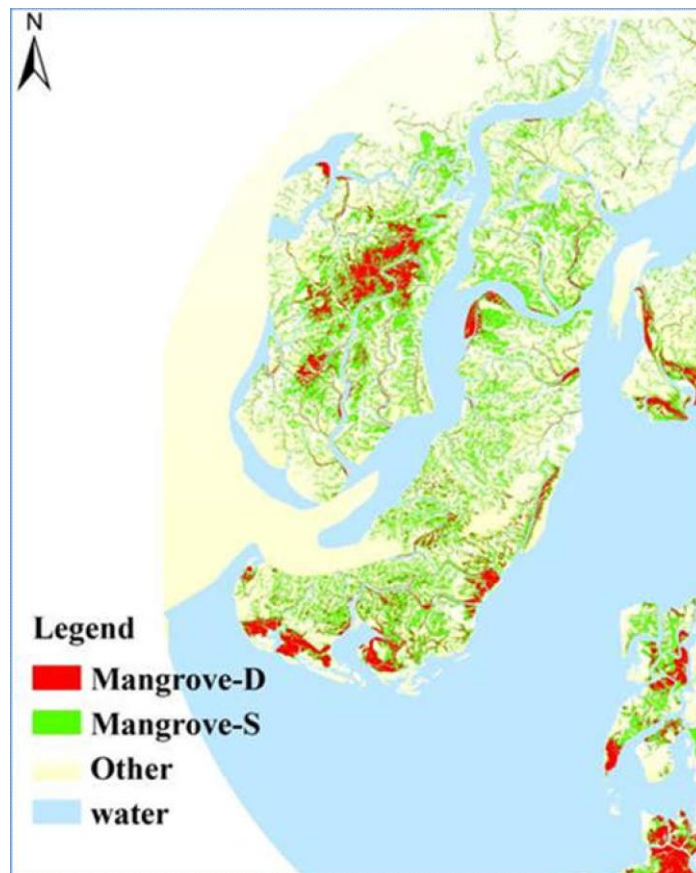

Fig. 11. Mangrove density classes generated based on NDVI values

4. Results and Discussion

In this study, multi-temporal Landsat TM data covering Lakhpat taluka (block) of February-1995, February-2017and Sentinel-2 multi-spectral data (spatial resolution 10-m) of April-2017 was analysed. The mangrove vegetation around the coastal areas was identified and classified into dense and sparse density classes based on NDV thresholding approach. The health assessment of mangroves in Lakhpat taluka was attempted using Multi Criteria Decision Making (MCDM) approach including various parameters like mangrove density based on Normalized Difference Vegetation Index (NDVI), Distance of mangroves from human settlement, Distance of mangrove from Industries and Ports which have direct impact of growth and health of mangroves, Erosion/ Accretion over the period of last 22 years and availability of Saline water flow during the high tide for good mangrove growth. The buffers layers of various distances for example, 0 to 10 km, 10 to 20 km and 20 to 35 km were generated from the existing mangroves using Sentinel-2 multi-spectral image in GIS environment.

4.1. Assignment of ` criteria ratings and weights

The weighted summation method is one of the most commonly applied MCDM techniques. Canham (1990) used the weighted summation method to evaluate some hypothetical forest management plans. Qureshi and Harrison (2001) used weighted summation as one of the evaluation methods to compare riparian revegetation options. Hajkowicz et al. (2002) used the weighted summation technique to evaluate eleven management options for Lower Murray Reclaimed Irrigation Areas (LMRIA) in South Australia. Yakowitz and Weltz (1998) addressed the problem of qualitative hierarchical weights and presented an analytical method to calculate the minimum and maximum value scores of the alternatives. The method is applied after commensurate attribute values have been determined for each alternative. It does not require specifying explicit weights for attributes. The decision tool is particularly useful for examining alternatives by multiple decision-makers. Sheppard (2005) developed an MCDM framework t o

sustainable forest management (SFM) in Canada which provided specific guidelines for applying and testing participatory MCDM decision support techniques with stakeholder inputs. The framework evaluates alternative forest management plans and shows that the complexity in incorporating sustainability criteria can be adequately handled using MCDM.

4.2. Assignment of weights for Indicators of Mangrove Health

In MCDM approach the important parameters are ranked based on their impact on the health of mangroves in coastal areas. According to this approach, we have identified above five important parameters which have significant impact on health monitoring of mangroves. The identified parameters were ranked based on individual parameters importance for health assessment of mangroves. The selected 5-raster layers namely i) Mangrove Density, ii) Human Pressure, iii) erosion / accretion, iv) Availability of saline water and v) Industries and Ports are ranked for mangrove health assessment on a scale of 1 to 3. These parameters were further sub-divided into different categories, for example mangrove density was divided into two categories namely dense and sparse based on NDVI thresholding technique. The erosion parameter was divided into three categories based on erosion / accretion over the period of from 1995 to 2017. The human pressure, availability of saline water and ports and industries were divided into two or three categories based on their distance from mangroves. These rankings are based on its impact on mangrove health from worst to best. Ranking distance of mangroves from habitation and industry and ports for human pressure, is relatively easy. Here we have to decide whether short or long distances have impact on mangrove health, accordingly assign the ranks from 1 to 3. The total sum of the weightages of all the factors was considered as 100 and the weights are assigned based on the importance of that particular parameter on health of mangroves. If all the parameters have equal importance, one can assign same weight to each parameter. However, in this study each parameter has different impact on health assessment of mangroves; different weights in terms of per cent have been assigned to various parameters as given in Table-2 and the distribution of weightages of five parameters graphically represented in Figure 12.

Table 2. Details of Rank and Weights Assigned to various parameters

Indicators	Category	Rank	Weight (%)	Sub- category
Mangrove Density (NDVI)	Dense	3	40	120
	Sparse	2		80
Human Pressure	0–10 km	1	20	20
	10–20 km	2		40
	20–35 km	3		60
Erosion	No Change	3	10	30
	Accretion	2		20
	Erosion	1		10
Availability of Saline Water	0–10 km	3	20	60
	10–20 km	2		40
	20–35 km	1		20
Industry and Ports	0–10 km	1	10	10
	10–20 km	2		20
	20–35 km	3		30

4.3. Mangrove Health Assessment

The health assessment of mangroves in Lakhpat taluka is carried out using Multi Criteria Decision Making (MCDM) approach using various thematic layers that includes distance of mangroves from settlement, distance from Industries and Ports, distance from Waterline, NDVI of dense and sparse mangrove and erosion / accretion. MCDM approach has classified mangroves in four different categories namely, mangroves in good health, mangroves in moderate health, mangroves that are prone to degradation and unhealthy mangroves (Figure-13).
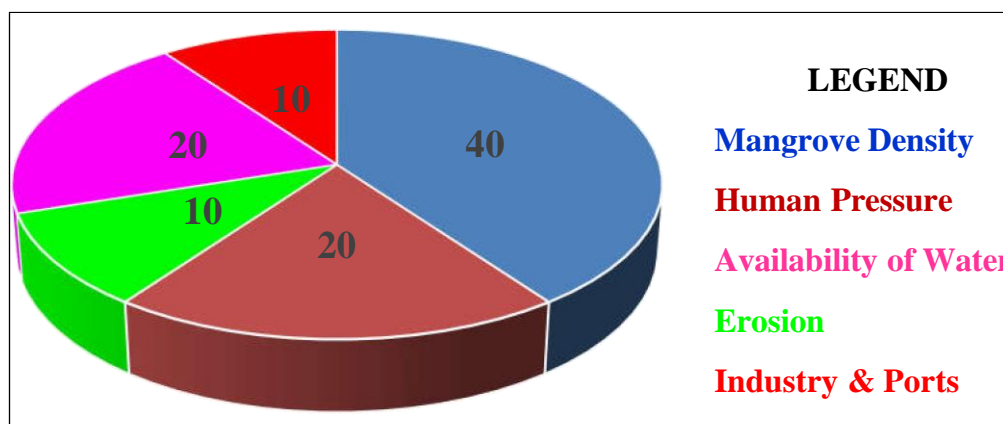

Fig. 12. Graphical representation of Various Health Parameters considered for mangrove health assessment

5. Conclusions

In this study, MCDM approach was adopted to prioritize the different factors affecting Mangrove health. The results indicate that the NDVI which is single parameter indicating the mangrove stand vigour, growth condition and resulting health of mangroves in the area. This factor has been given highest weightage as compared to other parameters. The significant results of this study are as follows:

❖ The major anthropogenic factors like human Pressure and presence of Industries and Ports have negative impact on the mangrove health. Therefore, it was observed that presence of human settlements and Industries and Ports with the buffer region of 0 to 10 km distances from mangroves are unhealthy or prone to degradation in this region.

❖ There are smaller islands in this region with large number of creeks bringing in saline water to the mangrove areas which indicates that availability of saline water to the mangroves is not the limiting factor for good growth of mangroves in these areas.

❖ The results of health assessment are very useful for sustainable planning and management of mangroves in the coastal areas of Lakhpat Taluka.

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