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Temporal changes in land cover of mangroves and allied biotopes in Abdasa, Kachchh district, Gujarat, India

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Original Article

Abstract

The present work investigates the temporal land cover changes in mangroves and two other allied biotopes, namely, mudflats and "other vegetation", in the Abdasa taluka of the Northwestern coast of Gujarat, India, through LISS IV satellite imageries with a resolution of 5.8 m. Satellite images from four different years (2007, 2014, 2017, and 2021) procured from the National Remote Sensing Agency, Hyderabad, India, were used for this purpose. Image analysis suggested different levels of geomorphologic change in these three coastal biotopes in the four years of analysis. Mangrove extent increased by a maximum of 17.46 km^2 (50.7%) between 2007 and 2014, although this expansion was only minor between 2014 and 2017, with an increase of 1.59 km^2 (3.06%). Subsequently, between 2017 and 2021, the mangrove extent decreased by 15.01 km^2 (28.06%). Altogether, mangroves in Abdasa had a net increase of 4.04 km^2 from 34.4 to 38.49 km^2 throughout the course of the 14-year assessment between 2007 and 2021, representing an increase in the area of 11.7%. Most of the mangrove increase was on the northwest coast of Abdasa near the village of Golay. Mudflats, on the other hand, experienced a very slight decline of 0.4 km^2 from 2007 to 2014, from 202.4 km^2 to 202 km^2. Subsequently, between 2014 and 2017, they dramatically increased by 69.82 km^2 before experiencing another decline of 165.92 km^2 between 2017 and 2021. As compared to mangroves and mudflats, the third land cover category, "Other Vegetation," underwent only a marginal change in its land cover during these 14 years of study, with a net increase of 1.74 km^2 from 17.6 to 19.34 km^2, accounting for a 9.88% increase in its area. This dynamic shift in the study area's coastal land cover is caused by a complex interaction of physical, chemical, and biological processes. It is suggested that the ongoing plantation effort, the favourable effects of rising sea levels, altered near-shore currents and sediment dynamics were the primary causes of the net growth of the 4.04 km^2 in the Abdasa mangroves during the period of study. This study signifies the importance of investigating changes in the mangrove extent at regular intervals at a local scale, which could contribute to the conservation and protection of this vital ecosystem, especially in the light of climate change-associated sea level rise, coastal erosion, and industrial development.

Keywords: *Areal extent, GIS, Avicennia marina, mudflat, other vegetation*

Introduction

Geographical Information System (GIS) has a vast array of applications in different disciplines, and its practical utility in studying many natural ecosystems is immense. The application of the GIS technique is wide and far-reaching and encompasses almost all scientific disciplines (Franklin, 2001). It is equally useful and important in monitoring and assessing ecosystems such as mangroves that are difficult to access. As an integrative digital methodology, it combines diverse data and techniques into a convenient spatial analysis and mapping framework (Davis and Quinn, 2004). Combining GIS with remote sensing and field data is highly helpful in mapping and monitoring various terrestrial and marine ecosystems, including mangroves (Thakur *et al.,* 2019; Kumar *et al.,* 2021). In recent years, GIS and RS have been increasingly used to investigate mangrove vegetation dynamics to understand the changes in its forest structure, as it is often crucial and forms an essential aspect of vegetation ecology (Dahdouh-Guebas *et al.,* 2000c, 2002). Using GIS and RS approaches, the effects of climate change on mangroves on both a regional and temporal scale could be monitored quite efficiently (Hu *et al.,* 2018; Thakur *et al.,* 2020 a, b; Mondal *et al.,* 2021). Paul *et al.* (2016) conducted an in-depth assessment of remote sensing studies on mangroves and other coastal resources and highlighted the deep understanding

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that GIS and RS techniques facilitated on different terrestrial and coastal ecosystems.

Similarly, Wang *et al.* (2018) conducted the first chronological analysis of mangrove remote sensing studies between 1956 and 2018 and concluded that future research in mangrove remote sensing would be more focused on spatiotemporal changes. Pandey *et al.* (2019) in the Bhitarkanika mangroves in Odisha, India, presented the first demonstration of how both spatial distribution of the species and calculation of the biomass in the mangrove Forest could be simultaneously performed by using satellite imageries. Using stabilized cameras and photogrammetry, Niwa *et al.* (2020) demonstrated for the first time how remote sensing techniques might be used to measure the size and distribution of individual trees in a mangrove forest. Murthy *et al.* (2021) presented the three-decadal development of remote sensing through continuous improvement of Indian satellite technology and data and its application in managing coastal resources, including the mangrove ecosystem.

Monitoring of the Gulf of Kachchh mangroves using GIS and RS techniques was earlier carried out by many workers (Shah *et al.*, 2005; Kumar *et al.*, 2012; Mahapatra *et al.*, 2013; Bhavsar *et al.*, 2014; Mahapatra *et al.*, 2015; Upadhyay *et al.*, 2015; Pasha, 2016; Disha *et al.*, 2017; Nayak, 2017; Jayanthi *et al.*, 2018; Vaghela *et al.*, 2018; Khare and Shah, 2019). Studies by Srivastava *et al.* (2015) specifically pointed out climate change induced degradation in the density of Mundra mangroves of Kachchh district. Dharmesh *et al.* (2021) evaluated changes in land use and land cover on the eastern side of the Gulf of Cambay, Gujarat, between 1978 and 2017 using GIS and RS techniques and discovered a diminishing trend in mangrove cover throughout this time. The advancement made in the quantitative evaluation of different physical features of mangroves at the international and national levels was highlighted by Gnanappazham *et al.* (2021) and Maurya *et al.* (2021). All these previous works highlighted the need for regular monitoring of this vital coastal ecosystem in terms of the extent and nature of the change, which will serve as an essential management tool for long-term conservation. Temporal change detection based on GIS is useful from many perspectives since it detects the nature and extent of change along with its spatial pattern (Thakur *et al.*, 2020 a, b). This aspect, however, has started receiving attention in recent years due to its significance in understanding its vegetation ecology (Dahdouh-Guebas *et al.*, 2000c, 2002; Bhattaraia and Giri, 2011). Earlier GIS studies on the mangroves of Gujarat presented only a succinct reference to Kachchh mangroves in terms of floral diversity and zonation (Nayak and Anjali, 2001). Despite a reported increase of 45 km² between 2001 and 2021 (FSI, 2021), discernible changes in Kachchh mangroves due to aggressive industrialization and natural processes like erosion and the resultant alteration in

many of its ecosystem characteristics are quite visible, calling for an investigation in its spatial and temporal changes (SAC, 2014). Increased awareness and renewed conservation efforts in terms of massive plantation activities by different mangrove stakeholders added another dimension to the ongoing areal changes. Against this backdrop, the objective of this study was to quantify the temporal changes in the Abdasa mangroves of Kachchh, as it is one of the largest mangrove formations on the Kachchh coast. This study was further prompted by the large-scale coastal industrialization and the threat posed by accentuated vulnerability of this coastal stretch to natural processes such as erosion, accretion and shoreline shift. Remote Sensing and GIS technique is used as data collection tool in this study to quantify land cover changes of mangroves, mudflats and allied vegetation in four different years, such as 2007, 2014, 2017 and 2021.

Material and methods

Study area

The Abdasa Taluka of Kachchh district is located on the northwest coast of Gujarat in western India between the Latitudes 23°29'33.52''N; 23°29'44.66''N and Longitudes 68°35'4.04''E and 68°34'35.35''E. Ecologically Sensitive Areas (ESAs) in this taluka include mangroves, Bustard wildlife sanctuary and turtle nesting sandy beaches in the south. Mangrove forest is an important ecological entity in this taluka and it is mostly confined to the dissected coast in the north-western part while the southern part is mostly a plain
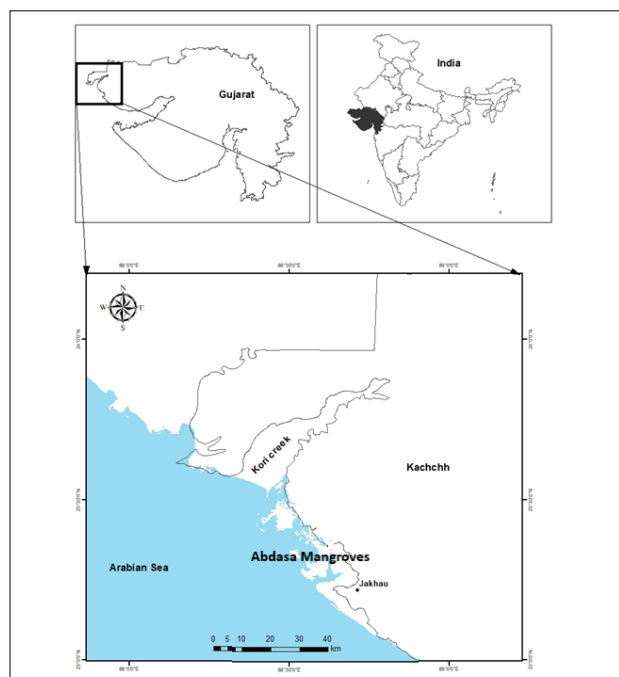

Fig. 1. Abdasa Mangroves in Kachchh district, Gujarat

sandy coast (Fig. 1). With 798.74 km^2, Kachchh mangroves comprising Abdasa mangroves as the single largest mangrove formation on the west coast of India; they are tide-dominated over wash fringe type as per the classification of Ewel *et al.* (1998). The mangrove stand of Abdasa is a typical arid zone mangrove formation featuring characteristics such as a lack of floral diversity and zonation and poor vegetation morphometrics. The area has a hot and dry summer climate and a cold winter with a rainy monsoon season in between. Throughout the year, except for the monsoon, the climate is hot and dry. Meteorologically, the year can be divided into three distinct seasons, namely, winter (November to February), summer (March to July) and pre-monsoon (August to October). Four decadal average rainfall is a meagre 390 mm, which occurs during the southwest monsoon (July-August). The temperature rises rapidly after March and the month of June is the hottest month, with a maximum temperature of 46-47 ^{o}C. The months of January and February are the coolest months of the year, with mean daily minimum temperatures as low as 5-8 ^{o}C. Due to low rainfall and run-off, the coastal soil is deficient in nutrients, harbouring only hardy halophytic plants such as *A. marina, Suaeda nudiflora* and *Salicornia branchiata.*

The 108 km long coastal length of Abdasa has geomorphic features with muddy and heavily fractured northern coasts and sandy southern coasts. The northern coast is characterized by numerous small mangrove-occupied Islets and mudflats, while the southern coast from Pinkleshwar is sandy and uniform without any creek systems. The northern shoreline has many small, medium and major creek systems, which are highly ramified. Important creeks are Kharo and Sinthodi, which, with their rich mangrove formations, support a good fishery livelihood. Closeness to the international border of the coastline has made it highly sensitive, with the least human population of 48 persons/ km^2.

Temporal changes in the six land covers, namely, mangroves, mudflats, allied vegetation, saline soil, water and salt pan during 2007, 2014, 2017 and 2021, were gleaned in the present study. LISS IV Satellite imagery of pre-monsoon season procured from the National Remote Sensing Centre (NRSC), Hyderabad, was used for this purpose. Of the six land cover classes, mangroves, mudflats and allied vegetation were analyzed during these years as they are closely interconnected and dependent habitats. The procured imagery has a resolution of 5.8 m with UTM projection with spheroid and datum named WGS 84 in UTM zone 42 north, which meets the requirement of estimating the areal extent of mangroves, mudflats and 'Other Vegetation' categories of Abdasa taluka and its current status. The supervised classification method is applied to delineate the mangroves and other natural resources. The details of the satellite imagery used are,. Satellite: IRS Resourcesat-2A;

years 2007, 2014, 2017 and 2021, Date 26 April; Sensor: LISS 4; Bands: 3; Pixel Resolution: 5.8 m.

Pre-processing of satellite data, including geometric correction, atmospheric correction and, radiometric correction and clipping of the area, was carried out. The rectification was done to correct distorted images to create a more faithful representation of the original scene. It typically involves the initial processing of raw image data to correct for geometric distortions. Geometric corrections were carried out to address errors in the relative positions of pixels. These errors are induced by sensor viewing geometry or terrain variations. The geometric correction was done based on Ground Control Points (GCPs), and the image was re-sampled using the nearest neighbourhood interpolation method. Spectral values assigned to specific information classes are determined by pixels located within these areas of the image. Pixels located within these areas are the training samples used to guide the classification algorithm to assign specific spectral values to appropriate information classes. Surveys were conducted in the mangroves of Abdasa taluka to collect training samples for different land use and land cover using Garmin GPS. With the help of training samples, a classification map was generated based on the Maximum Likelihood Supervised Classification (MLC) model using ERDAS (Version 9.3) Software. Based on MLC, mudflat and water were classified.

The mangroves and 'Other Vegetation' in the study area were analyzed using the normalized difference vegetation index (NDVI) (Kriegler *et al.,* 1969). Vegetation was analyzed by NDVI values using the following equation 1 because they represent a normalized ratio of reflected visual and near-infrared energy.

(1) NDVI = (NIR − RED)/ (NIR + RED)

NDVI values were examined to separate vegetative areas from barren areas. As a result, it was concluded that vegetative areas can be separated from non-vegetative areas by using a threshold value of NDVI 0.3 for this study area. Based on NDVI values, mangroves, mudflats and other vegetation were classified. Land Cover, as observed in the imagery of 2007, 2014, 2017 and 2021, was classified into six classes: mangroves, mudflats, Other Vegetation, saline soil, saltpan and water. This imagery classification was supported by ground truthing through fieldwork, as it is essential to check and collect most of the ground information required for mapping.

A reconnaissance field survey was undertaken to get acquainted with the general land cover pattern of the area. Different patches of mangrove area characteristics were recorded. The variation and tonal patterns observed in the ground-truthing were

recorded on the existing images. Ground truthing patterns and characters recorded in the image were verified in the mangrove areas, creeks, mudflats, and other vegetation. Various features identified in the ground-truthing were correlated with the image element, and GPS observations were obtained for multiple land covers by superimposing on the satellite images.

Results

Special Characteristics

Ground truthing indicated that the mangrove stand of Abdasa taluka is a single species in nature, composed invariably of *Avicennia marina* (Forsk.) Vierth. var. *acutissima,* which is known for its environmental sturdiness to withstand prolonged drought, lack of riverine inflow, high water salinity and ambient temperature. The aridity of the coast and hinterland generally has a significant defining impact on the biota's diversity, growth, and spread in the whole region. As a major flora of Abdasa, the ability of *A. marina* to tolerate a hypersaline milieu is well-proven (Naidoo *et al.,* 2011). Mangroves of Abdasa and the adjacent Lakhpat talukas form a contiguous patch due to their geographical proximity. Unlike other mangrove stands on the Indian west coast, exploitation of mangrove forests for forest produce such as honey, firewood, building material and others, except fodder, is unknown in these mangroves. Mangroves of Abdasa are low-energy environments and face natural hazards such as sea level rise, erosion and accretion (ICMAM, 2004), with a significant part of the coastline facing high vulnerability risk (SAC, 2014). Due to the single-species nature of the stand, zonation, a unique feature of the mangrove forest, is absent. However, the morphometric gradient in vegetation structure due to differential tidal inundation is visible. The majority of the mangroves are open-type and moderately dense, while dense forests are absent as per the classification of FSI (2021). An estimated density of mature trees in 1963 and 3800 trees/ha with an average value of 3070 trees/ha is estimated (Unny *et al.,* 2022). Overall tree height ranged between 1 to 6.7 m, though, in most trees (42.8%), tree height was between 1.8 and 2.5 m. Aridity, poor rainfall, wide fluctuation of ambient temperature and lack of terrestrial run-off are some of the major governing characteristics of these mangroves (Unny *et al.,* 2022). Mangrove stands mostly occur as distinct individual patches segregated by sandy beaches, creek systems, and mudflats, apparently due to different geomorphic settings and oceanographic features of the coastline. In most of the stands, frontline mangroves abetting the waterfront are dense with better vegetation structure in density, height and canopy cover, and the forest thins down towards the landward interior due to differential tidal flushing. Until recently, mangrove formation in this taluka was least disturbed due to a very low population density of 48 persons/km^2.

Temporal changes

Mangroves on the Abdasa coast are mainly distributed in small islets of mudflats, which are intersected by numerous minor creek systems enabling tidal inundation. The areal extent of mangroves in Abdasa taluka showed modest positive changes over the four years of the study: 2007, 2014, 2017, and 2021. In all these four years, a progressive and fluctuating increase in mangrove extent could be discerned (Fig. 2a to 2d; Table 1). During 2007, mangroves' areal extent was 34.4 km^2, which increased to 51.9 km^2, registering a rise of 17.46 km^2 during 2014 and accounting for a 50.7% addition. Mangroves west of Golay village in the northern part of the taluka showed the highest increase, whereas mangroves in the coastal region of Akri and Gosa villages showed only marginal growth (Fig. 2a and 2b). Between 2014 to 2017, mangrove extent again registered a marginally positive rise of 1.59 km^2, from 51.9 to 53.5 km^2, accounting for 3.06% growth (Fig. 2b and 2c). While other mangrove patches remained largely unchanged, this marginal increase was primarily in the mangrove formations west of the settlement of Kosa. Unlike previous years, in the subsequent period between 2017 and 2021, mangrove extent registered a decline to the tune of 15.01 km^2, from 53.5 to 38.49 $km^{2,}$ accounting for a 28.06% reduction (Fig. 2c and 2d). This reduction was mostly confined to the mangrove patches west of Golay village. Altogether, in 14 years between 2007 and 2021, a marginal increase of 4.04 km^2 from 34.4 to 38.49 km^2, accounting for an 11.7% increase in areal extent, could be discerned. The majority of these changes are contiguous to the already existing patches, mostly in the mangrove formations in and around Golay village and, to some extent, west of Kosa village further south (Fig. 2a to 2c). Analysis of images indicated that mangroves along the Abdasa coast were expanding between 2007 and 2021. Most of this mangrove increment was confined to the mudflats of the western coastal stretch of Golay village in the northernmost part of the taluka.

Mudflats near mangroves are an important allied and contiguous biotope, as mudflat habitat frequently transforms into mangroves when conditions are favourable. The extent of mudflat in the Abdasa coastal belt underwent marginal changes akin to mangroves during four different years of analysis between 2007 and 2021. Mudflats were 202.4 km^2 in 2007 and remained nearly identical with an extent of 202 km^2 in 2014, representing only a negligible reduction of 0.4 km^2, accounting for a 0.18% decline in extent (Table 1). During this period, mangroves, a closely allied habitat, underwent an increase of 50.7%. However, between 2014 and 2017, mudflats recorded an increase of 69.82 km^2 from 202 to 271.82 km^2, representing 34.56% positive growth. Mangroves during this period recorded a marginal increase of 3.06%. In the subsequent period of analysis from 2017 to 2021, mudflats registered a significant decline to the
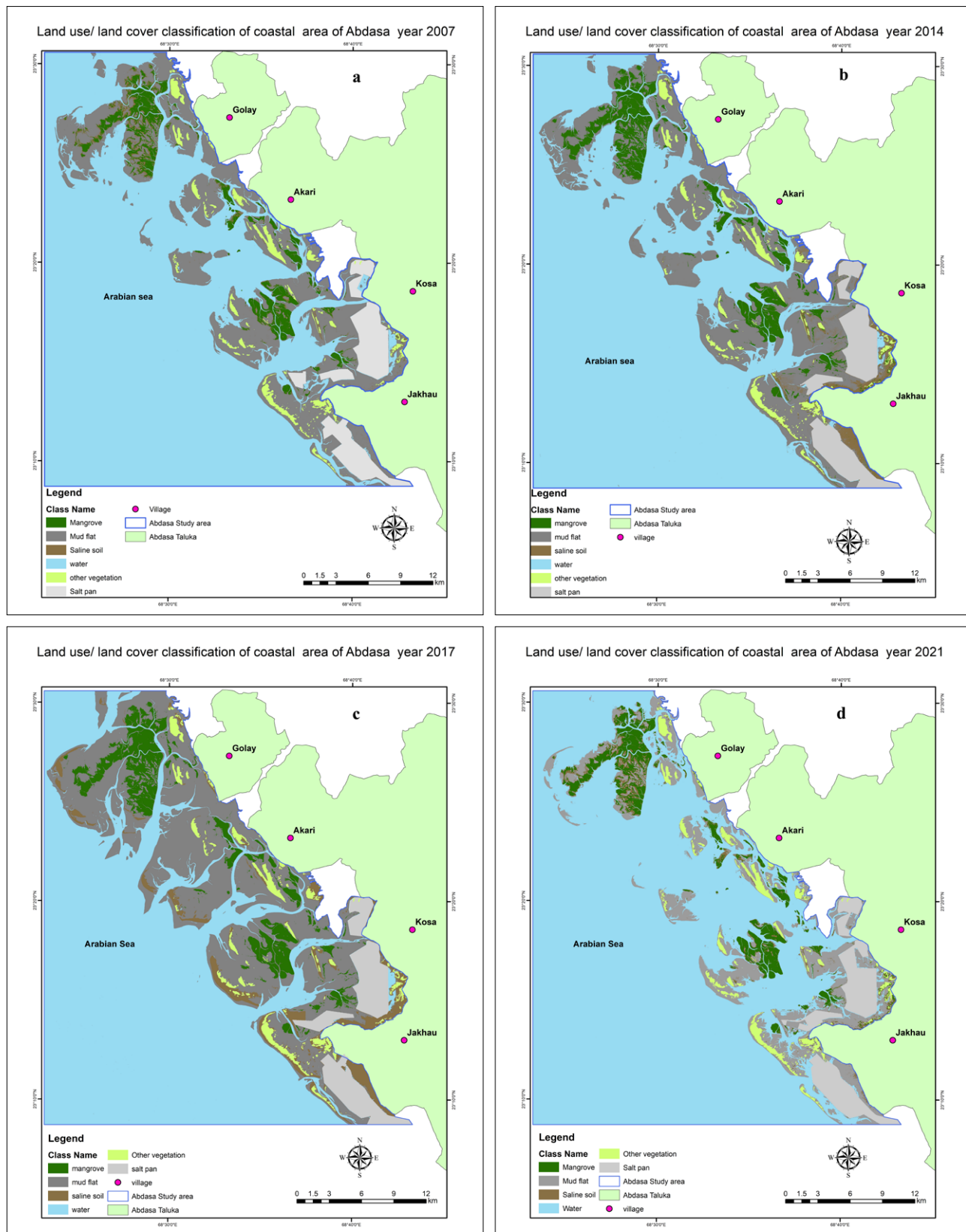
Fig. 2. Land Use/Land Cover Classification of Abdasa Mangroves and Biotopes in a). 2007, b) 2014, c) 2017 and d) 2021

Table 1. Land cover changes in the Abdasa mangroves and allied habitats between 2007 and 2021

Land Cover	2007	2014	2017	2021	2007 to 2021 % Increase
Mangroves	34.40	51.9 (50.7%)	53.50 (3.1%)	38.49 (-28.1%)	11.74%
Mudflat	202.40	202 (-0.2%)	271.8 (34.5%)	105.89 (-61%)	-47.68%
other vegetation	17.60	18.4 (4.8%)	18.1 (-1.5%)	19.34 (6.4%)	9.90%
Saline soil	12.30	16.1 (31.1%)	35.3 (119.4%)	14.62 (-58.6%)	19.06%
Salt pan	42.10	43.5 (3.3%)	46.3 (6.5%)	40.93 (-11.7%)	-2.85%
Water	669.80	646.6 (-3.5%)	553.4 (-14.4%)	759.29 (37.2%)	13.37%

tune of 165.92 km², from 271.82 to 105.89, which represented -61.04%. The extent of mangroves likewise experienced a drop of 28.06% in this period. In total, between 2007 and 2021, mudflats registered a major decline of 96.47 km², representing -47.6%. Unlike mangroves, changes in the extent of mudflats were widespread throughout the coastal stretch of the taluka as gleaned from Fig. 2a to 2d.

The land cover, 'Other Vegetation', was 17.6 km² during 2007, which registered a marginal increase of 0.8 sq. m during 2014 to 18.44 km², which accounts for a 4.79% increase. This growth is pervasive throughout the mudflats and is restricted to the mangrove formations' edges. Between 2014 and 2021, this land cover class remained almost unchanged, with 18.2 km² recording only a meagre reduction of -0.2 km², representing a -1.46% decline. However, in 2021, the extent of the 'Other Vegetation' category marginally increased by 1.1 km² from 18.2 to 19.3 km², representing a 6.4% positive growth. Between 2007 and 2021, the 'Other Vegetation' category registered a net increase of 1.74 km², accounting for 9.88% in their areal extent between 2007 and 2021. Comparing mangroves and mudflats, the land cover category, 'Other Vegetation,' underwent only marginal changes, as shown in Fig. 2a to 2d.

All the three studied biotopes, namely, mangroves, mudflats, and 'Other Vegetation' registered positive and negative changes in their extents during the study period of 2007 to 2021; mangroves

and 'Other Vegetation' category increased marginally, while mudflats, as an allied biotope, registered a drastic reduction to the tune of -47.6% (Fig. 3). The other land cover categories, namely saline soil, salt pans, and water, did not show any consistent trends of decline or increase in the four different years of study.

Discussion

The mangrove environment is dynamic and undergoes morphological changes as a result of physical processes that involve tidal currents and associated sediment transport mediated by biological agents (van Maanen *et al.*, 2015). Numerous physical and chemical processes control and define the structure, extent, density, variety, and other ecological and biological characteristics of mangroves (van Maanen *et al.*, 2015). Only a few studies were holistically done in the past to understand the physical-chemical-biological interlinkage that shapes the evolution of this ecosystem and the morphological setting that hosts it (van Maanen *et al.*, 2015). Wolanski *et al.* (1992a) reviewed the physical processes acting on the mangrove ecosystem in the tropics and highlighted the dynamic nature of mangrove extent in tune with many governing oceanographic processes. In this context, the recorded changes in the extent of Abdasa mangroves are to be viewed.

The mangroves of Abdasa and the adjacent Lakhpat talukas are the major mangrove formations of the Kachchh district, which constitute 67.97% and 16% of Gujarat and India's mangroves, respectively. Kachchh mangroves have consistently increased over the last five decades, as evidenced by regular remote sensing studies (FSI, 2021), except for a decline between 1990 and 2000, which was likely caused by the 1999 devastating cyclone that crossed the Kachchh coastline at Kori Creek, close to Abdasa, inflicting heavy damage on the mangroves of this region (Guide, 2001; Ohte *et al.*, 2021). In the Gulf of Kachchh, the period from 2008 to 2011 had the highest rate of mangrove expansion in a time frame of four decades (Pasha *et al.*, 2016). Their study identified coastal stretches with 33 positive and 11 negative trends in mangrove cover in the whole of the Gulf of Kachchh, including the present study area. Mangrove cover in the Kachchh
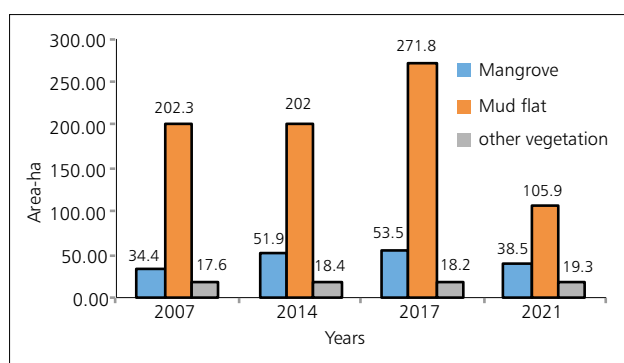

Fig. 3. Temporal changes in the areal extent of mangroves and allied biotopes of Abdasa in 2007, 2014, 2017 and 2021

coastal stretch was 706 km^2 in 2001, which rose to an extent of 798.74 km^2 in 2021 (FSI, 2021). The scientific approaches to restoration and rehabilitation, the use of local resources, the participation of both the public and private sectors in mangrove plantation, and effective monitoring and post-plantation care are attributed to the consistent growth of mangrove extent in Kachchh and Gujarat (Shah and Ramesh, 2022). Contrarily, coastal industrial development has impacted the mangrove ecosystem in this coastal stretch. Tax holidays declared following the 2001 earthquake paved the way for the proliferation of numerous coastal industries, which, in addition to fragmenting mangrove habitats, have altered the physical and chemical characteristics of mangrove creeks (ICMAM, 2004). Industries such as thermal power stations, ports and jetties, cement industries, Special Economic Zones, salt works, and mines are located either nearby or amidst mangrove formations of the Abdasa coast, posing serious fragmentation and degradation threats to this coastal ecosystem. It was found that the mangrove health of nearby Lakhpat taluka in terms of vigour and growth is negatively impacted by industries within 10 km of them (Vaghela *et al.,* 2018). Additionally, traditional resource utilization by way of grazing and fodder collection in Kachchh mangroves was also rampant (Singh, 2000). Despite these significant anthropogenic and natural disturbances, Abdasa mangroves showed a net increase of 4.04 km^2 from 34.4 in 2007 to 38.49 km^2 in 2021, accounting for an 11.7% rise in areal extent.

Of late, the Kachchh coast has witnessed massive mangrove plantations by different government agencies and coastal industries to the tune of 5,000 ha. This government and industry-initiated plantation activity was matched by strong conservation and protection measures. Traditional resource use, rampant earlier, was curtailed as core mangrove areas were brought under strong physical protection by the forest department. While these measures contributed to the consistent increase in mangrove extent in Kachchh, multiple and interrelated oceanographic factors such as climate change-induced sea level rise, altered near-shore current patterns, and changes in sediment dynamics appear to have played a significant role in stimulating this increase. Despite a sea level rise of 3.3 mm/yr, mangrove extent in Iron increased from 1986 to 1997, and a decline in net area was witnessed between 1998 and 2017, though rainfall was abundant during this period (Mafi-Gholami *et al.,* 2020). Though the Kachchh coast is stated to be highly vulnerable to climate change in terms of sea level rise (Mahapatra *et al.,* 2015), raising sea level to the tune of 2-3 mm/year for the Kachchh coast, coupled with changing littoral current patterns, could be a major factor for this consistent raise evidenced in the present study. Paleobotanical studies of mangrove communities elsewhere revealed that mangroves opportunistically colonise suitable conditions during more rapid sea level rise in terrigenous, lagoon and low island settings (Ellison, 2015; 2020) similar to that of Kachchh. The persistence of mangroves over many

geological disasters indicates their ability to cope with moderately high rates of relative sea level rise (Woodroffe *et al.,* 2015). Most of the increase in mangrove extent of Abdasa during the period of study (2007-2021) occurred in the coastal stretch of Golay village, where copious space on the landward side is available in the form of mudflats and saline lands, enabling mangrove transgression towards the landward side. Landward transgression is possible if the landward margin is free from hindrances such as man-made and natural structures, not impeding the mangrove spread (Friess *et al.,* 2019). Thus, the consistent increase in mangrove extent at a regional scale in Abdasa and Kachchh, as well as in Gujarat at a larger scale, could be explained in this context because many of the mangrove formations have mudflats nearby as an allied biotope. They are the largest coastal habitat in Gujarat at 22603.65 km^2 (Geevan and Dixit, 2012). In addition, mangroves possess the ability to cope with rising sea levels and increased inundation through sediment accretion and land elevation, which enable them to spread landward and colonise new areas (Kirwan and Megonigal, 2013). In addition, macro-tidal conditions with a large sediment supply, such as that of Kachchh, in the face of rising sea levels largely promote accretion and platform formation, reducing mangrove vulnerability while enabling landward transgression of mangroves as shown by Xie *et al.* (2022) in their modelling studies. Conforming to this, most of the extension in the present study was towards the landward side and contiguous to the existing mangrove formation. Therefore, it appears that sea level-induced accretion and related changes might be the facilitating agents for this increase in mangrove extent, along with other allied biotopes in Abdasa and at a larger scale in the whole Kachchh coastal stretch. Saintilan *et al.* (2020) suggested that the expansion of mangrove forests as an aftermath of vertical accretion seems to have a limit and accretion, and the consequent mangrove expansion ceases at a relative SLR of 6.1 mm/year. Additionally, it was predicted that the effects of sea level rise would differ spatially, having either beneficial or negative impacts (Ward *et al.,* 2016). This variation is likely to be based on microlevel topography, prevailing littoral current, precipitation, and human-centred changes in altering topography, such as coastal development. Macro-tidal conditions along the Kachchh coast, with a large sediment supply, further promote accretion and reduce the mangrove vulnerability to slow and medium sea level rise, as confirmed by Xie *et al.* (2022). In addition, regular and periodic changes in the prevailing littoral current patterns, induced by anthropogenic or natural causes, altered the sediment dynamics of this coastal stretch, which in turn bring about periodic gain or loss in the extent of mangroves and other related coastal habitats.

It is concluded that in response to both natural and anthropogenic impacts, the Abdasa taluka's mangrove extent and associated biotopes underwent moderate changes between 2007 and

2021. Mangroves appear to be directly impacted by coastal industrial development around them, either through degradation or loss. To conserve their ecosystem services and functions, it is imperative to identify these zones of change using remote sensing methods and prioritize places for restoration.

Acknowledgements

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