Heliyon 6 (2020) e04685

Contents lists available at ScienceDirect

Heliyon

journal homepage: www.cell.com/heliyon

Research article

Structural characteristics of mangrove forest in different coastal habitats of Gulf of Khambhat arid region of Gujarat, west coast of India

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ARTICLE INFO

Keywords:
Mangroves forest
Coastal habitat
Community structure
Species diversity
Environmental assessment
Environmental health
Environmental management
Environmental risk assessment
Plant biology
Ecology
Environmental science

ABSTRACT

Tropical mangroves are most productive and highly sensitive to environmental change and act as good bio-indicators of the environmental quality and health of any coastal ecosystem. The present study initiated to know the current ecological status of mangrove species at four selected study sites namely Bhavnagar (Ghogha coast), Bharuch (Dahej coast), Surat (Dumas beach) and Navsari (Purna estuaries), Gulf of Khambhat, Gujarat, India. Observation for a period of one year from January 2014 to December 2014. Mangroves were evaluated for their community structures at each site by standard quadrant method and different diversity indices were used for characterize the species diversity in a mangrove community. The mangrove forest habitat supports the occurrence of a total 16 species (6 mangrove species and 10 associated plant species), 15 species occurred at Navsari, whereas 7, 6 and 10 species occurred at Bhavnagar, Bharuch and Surat respectively. Out of six mangrove species, *Avicennia marina* was found to be most dominant and abundant mangroves occurring among all the four study locations. The most abundant and dominant mangrove associates were *Suaeda maritima* and *Sesuvium portulacastrum*. Simpson's diversity index was varied at a range of zero to 0.6538, showing the presence of less mangrove diversity. Navsari site presented higher diversity with Shannon and Wiener Species Diversity Index of 1.179 in comparison to other sites. The present study revealed that the species abundance, density and diversity of flora associates depend upon species density and diversity of mangroves. Therefore, mangrove forest habitats need to be protected and regular assess.

1. Introduction

Mangrove are salt tolerant evergreen forest ecosystem found mainly in the tropical and subtropical inter-tidal regions of the world between approximately 32° N and 38° S latitude and total mangrove cover has been estimated to be approximately 15.6 million hectares globally (FAO, 2010). Mangroves are ecologically important components of the coastal ecosystems that are under severe threat globally from a range of causes (Hai et al., 2020) and they provide potential contributions in ecological services (Kumari et al., 2020), provides habitat for many terrestrial and marine species (Nagelkerken et al., 2008), various food resources, shelter and site for fertilization for variety of aquatic fauna resulting into rich biodiversity. These are important to mankind not only as valuable food, but also largely contribute to the maintenance of marine food chain and livelihood. Mangroves help in maintaining the marine ecosystem structure and function through trophic relationship. Mangroves distribution and abundance in intertidal areas could be considered as a direct indicator of the habitat health of the coastal ecosystem and they are highly sensitive to environmental change. In terms of floristic diversity total 46 true mangrove species belonging to 14 families and 22 genera are found in Indian mangrove habitats (Ragavan et al., 2016). Around 3 % of the earth total mangrove vegetation are stands in India (FSI, 2019). The ecophysiological studies of mangrove plants that are adapted to various extreme environmental conditions like salinity, high temperatures, low oxygen and contaminated environments are prerequisite to tackle the current problems facing mankind like food security, pollution and the endangered habitats. Mangrove wetlands are characterized by such qualities as a humid climate, saline environment, waterlogged soil or muddy soil. Mangrove plants grow in waterlogged soils and capable of tolerating salinity ranging from 2% to 90% (Selvam and Karunagaran, 2004). Mangroves are varied in size from shrubs to tall trees. The mean height of mangrove plant are 5–25 m (MacNae, 1968), but mainly depends on the age and regional locations of stands (Snedaker, 1978). Maritime climate on the coastal biosphere has a direct effect on the vegetation and is influenced by tides, wave action, salt spray, saline water and the nature of substratum. The Gulf of Khambhat is the major

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https://doi.org/10.1016/j.heliyon.2020.e04685
Received 25 March 2020; Received in revised form 16 May 2020; Accepted 7 August 2020
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mangrove ecosystem of the west coast. *Avicennia marina* is the extensively growing and dominated true mangrove distributed throughout the Gujarat coast (Bahuguna et al., 2013). Gulf of Khambhat is home to *Avicennia marina*; it is generally known as gray mangrove or white mangroves, the community of these tree species is in many forests of Indian coastal edges. Studies on the ecology, distribution, diversity of mangrove species and mangrove associates have been carried out in many coastal areas in India such as Andhra Pradesh (Madhusudhana Rao et al., 2015), Andaman and Nicobar Islands (Kiruba-Sankar et al., 2018; Sreelekshmi et al., 2020a), Goa (Pawar, 2012), Gujarat (Bhatt and Shah, 2009; Ragavan et al., 2016), Karnataka (Kumar and Kumara, 2012), Kerala (Vidyasagaran and Madhusoodanan, 2014), Maharashtra (Kantharajan et al., 2018), Odisha (Jena et al., 2013; Mohanta et al., 2020), Pondicherry (Balach et al., 2009), Tamil Nadu (Arunprasath and Gomathinayagam, 2014), West Bengal (Brahma and Mukherjee, 2016; Sreelekshmi et al., 2020b). The present survey has been made to procure a list of mangrove and mangrove associates in gulf of khambhat region. The current study aimed to investigate and enumeration of the available mangrove plant resources and obtaining a broad representation of the existing floristic variations in different coastal area of gulf of khambhat, Gujarat, India, based on field observations.

2. Material and methods

2.1. Study area

The study was carried out at the Gulf of Khambhat region of Gujarat, India, which is located between latitude of 20° 30′ and 22° 20′ N and between longitude 71° 30′ and 73° 10′ E. The four sampling sites (Figure 1) namely Bhavnagar, Ghogha coast (21°40′ N, 72°17′ E); Bharuch, Dahej coast (21°71′ N, 72°52′ E); Surat, Dumas beach (21°4′N, 72°42′ E); Navsari, Purna estuaries (20°55′N, 72°47′ E) were selected based on the availability of mangroves on the inter-tidal area of Gulf of Khambhat region of Gujarat, India.

2.2. Sampling and data collection

Fixed area plot measurement i.e. quadrate techniques was applied for the study of mangrove vegetation characteristics based on the standard methodology (Cintron and Novelli, 1984; DOD, 1998). The selection of areas for the study was considered by the representativeness, accessibility and importance of the mangroves. Only mangrove plants were selected for the quadrate study. In each site, the mangrove vegetation was analyzed by means of ten quadrates were established randomly along the coastline in order to determine plant diversity and species composition of the stand. The size of the quadrates was fixed at 3 m × 3 m. The species of mangrove located outside the quadrats were included as a part of species inventory. Enumeration of mangrove, species name, species individuals, tree height and the DBH (diameter at 1.3 m above the ground) were recorded which are used to determine the ecological status of mangrove vegetation. The field data were collected at low tide in different sessions during January 2014 to December 2014.

2.3. Species identification

The mangrove vegetation in all the sites under study, scanned by repeated visits in different seasons of the years. The specimens of mangrove plant and associated flora collected from all sites were critically identified to species level with the help of standard books and manuals of mangroves (Banerjee et al., 1989; Naskar, 2004; Pandey and Pandey, 2010), standard field guide to mangroves (Lovelock, 1993), standard literatures (Blasco, 1975; George, 2005; Kathiresan, 2000) and also consulting the flora of madras presidency (Gamble, 1915-1936) for analyzing taxonomically and later verified in the laboratory. And moreover, the herbarium specimen was also verified by the scientists at Gujarat Ecological and Research (GEER) Foundation.

2.4. Quantitative analysis

During field study collected quadrat data was analyzed for measuring the quantitative structure of the mangroves in the terms of frequency, density and abundance. Mangrove density was reported as the number of mangrove tree within one hectare plot. In order to understand the population structure and distribution pattern of mangroves in these study sites the collected data was used to derive some ecological variables. The ecological variables such as species diversity, density, basal area and frequency were calculated using standard formulas (Nautiyal et al., 2015). Three different diversity indices were used namely species richness (SR), species evenness (J) and species heterogeneity (H') for characterize the species diversity in a mangrove community with standard methods as outlined in measuring biological diversity (Magurran, 2004). We calculated species richness using Menhinick Index, species evenness was calculated using Pielou's index and Shannon's equitability indices. Whereas, species heterogeneity or species diversity was measured using

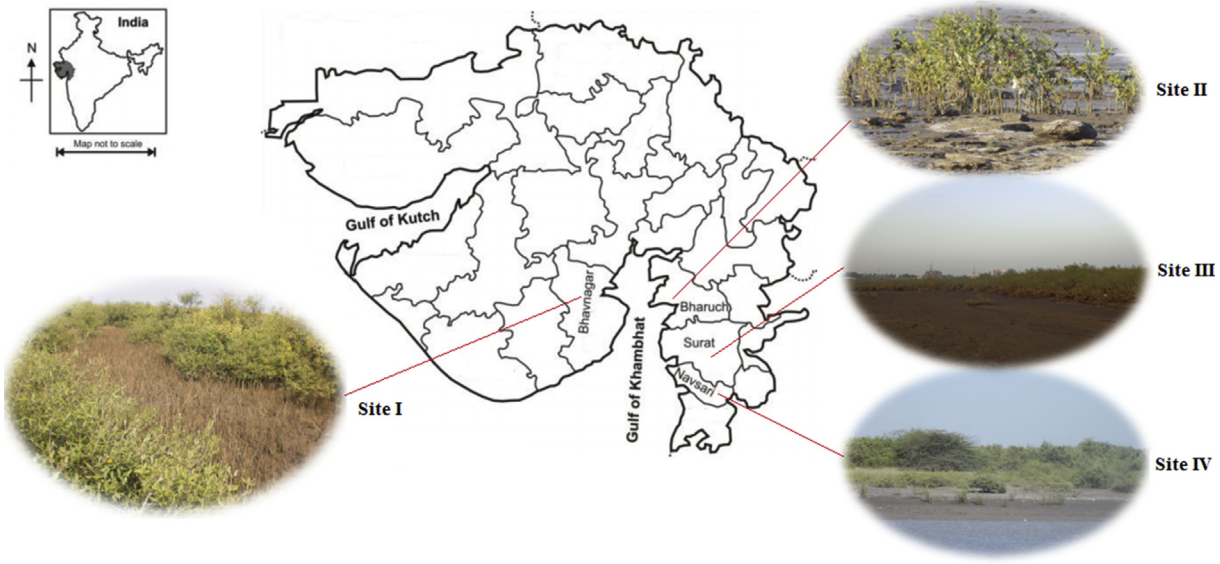

Figure 1. Map showing the study sites and habitat of mangrove vegetation in the Gulf of Khambhat, Gujarat, India.

Simpson's index and Shannon-Wiener index. All these indices, commonly used in ecological community studies were calculated using Paleontological Statistics (PAST) software (Hammer et al., 2001).

2.5. Statistical analysis

Cluster analysis was performed to find out the similarity index among all the sampling points of mangrove sites, based on their quadrat data (presence/absence transform data) using Bray–Curtis cluster analysis by Biodiversity Professional statistical analysis software. Cluster analysis classifies the total community composition at the four mangrove sites. A Dendrogram is usually used for briefing the categorized clustering.

3. Results and discussion

3.1. Species composition

A total of six true mangrove species belonging to three families and five genera, ten mangrove associates from eight families were recorded from the four intertidal area of Gulf of Khambhat region, Gujarat, India (Table 1 & Figure 2). Five mangrove species (*A. marina, A. ilicifolius, B. cylindrica, C. tagal and Sonneratia apetala*) were found in Navsari (Purna estuaries), three mangrove species (*A. marina, A. Officinalis and Sonneratia apetala*) were recorded in Surat (Dumas beach), two (*A. marina, and A. Officinalis*) from Bharuch (Dahej coast) and only one mangrove tree species (*A. marina*) were recorded from the Bhavnagar (Ghogha coast).

A. marina was the only species recorded in all stations studied whereas, the sporadic occurrence of *A. officinalis* were observed at both Surat and Bharuch mangrove forest sites, limited number of *Ceriops tagal* present only in Navsari, Purna estuaries river sides and did not occur in the study plots.

Many different types of mangrove species present within the world (approx. 90 species) but the *Avicennia marina* is a cosmopolitan species which can grow in several coastal habitats and first reported by Blasco (1975). The predominant species of mangrove in the study area was *Avicennia marina*. A total fifteen species of mangroves are found in Gujarat, although eleven mangrove species are rare. However, over 90% of the mangrove forests are represented by a single species i.e. *Avicenna marina* (Pandey and Pandey, 2013). Bhatt and Shah (2009) has reported 7 mangrove species viz. *Avicennia marina, Bruguiera cylindrica, Ceriops tagal, Rhizophora mucronata, Sonneratia apetala, Acanthus ilicifolius* and *Aegiceras corniculatum* from the Purna Estuary, South Gujarat, India and 9 species of mangrove associates and 6 species of salt marsh were also reported in our study. Table -1 indicate that Navsari (Purna estuaries) site is highly diverse and Bharuch (Dahej coast) the least. Bhavnagar has the highest mangrove tree density among others. During field survey, observed the health of mangrove forest, they are decent growth in the months of monsoon and dropped to the minimum in the months of summer. Of the mangrove associated species (Table 1) *Prosopis juliflora, Sesuvium portulacastrum, Suaeda maritima* was the most common species and widely distributed, being recorded from each sites. The total community composition analysis (Figure 3) confirm that site II and site III are most similar to one other (0.75 similarity means that 75% of the total number of species observed between both sites), whereas site I clearly separated from other pairs at much lower level of similarity (<60%).

In size, mangroves range from bushy stands of dwarf mangroves or scrubby type with stunted growth found in Gujarat, to 30 m or taller stands found within the Sunderbans. The Gulf of Khambhat region, Gujarat mangroves are of low height having less diameter at breast height (DBH) or basal area and a limited number of mangrove species (Table 2) compared to other mangroves of the world. The mangrove forest of Gulf of Katchh region, Gujarat have a similar range of mean height and basal area as in the forest of the present study (Thivakaran et al., 2003; Sawale and Thivakaran, 2013). Recent study (Devi and Pathak, 2016) on mangroves species in Gulf of Khambhat, Gujarat also supported to this study.

3.2. Mangrove diversity assessment

For the mangrove community study, three different diversity indices were used namely species richness (SR), species evenness (J) and species heterogeneity (H') and varied between the four study sites (Table 3). Species richness is obtained from counting the number of plant species in a given ecosystem, region or particular area. In this study, Menhinick Index was used to examine the species richness in the study area. Values for Menhinick index were 1.03, 0.07, 0.16 and 0.21 at the study sites I, II, III and IV respectively. According to Menhinick index, sites IV (0.21) was the richest area with mangrove species in the gulf of khambhat as compared to other sites.

Table 1. Occurrence of true mangrove Species and mangrove associated species in study sites.

Mangrove				Sites*			
Species		Family	Life Form	Site I	Site II	Site III	Site IV
Avicennia marina	True mangroves	Acanthaceae	T	+	+	+	+
Avicennia Officinalis		Acanthaceae	T	-	+	+	-
Acanthus illicifolius		Acanthaceae	S	-	-	-	+
Bruguiera cylindrica		Rhizophoraceae	T	-	-	-	+
Ceriops tagal		Rhizophoraceae	T	-	-	-	+
Sonneratia apetala		Lythraceae	T	-	-	+	+
Ipomoea pescaprae	Mangrove associates	Convolvulaceae	C	-	-	+	+
Porteresia coarctata		Poaceae	H	+	-	-	+
Prosopis juliflora		Fabaceae	S	+	+	+	+
Opuntia elatior		Cactaceae	S	+	-	-	+
Sesuvium portulacastrum		Aizoaceae	H	+	+	+	+
Ipomoea biloba		Convolvulaceae	C	-	-	+	+
Suaeda maritima		Amaranthaceae	H	+	+	+	+
Aloe vera		Xanthorrhoeaceae	S	+	-	-	+
Salvadora persica L.		Salvadoraceae	S	-	+	+	+
Urochondra setulosa		Poaceae	H	-	-	+	+

+ = presence; - = absence.

* **Site I** Bhavnagar (Ghogha coast)**; Site II** Bharuch (Dahej coast)**; Site III** Surat (Dumas beach)**; site IV** Navsari (Purna estuaries)**. S-** Shrub, **T-** Tree, **H-** Herb, **C-** Climber.

Figure 2. (A) *Acanthus illicifolius* (B) *Avicennia marina* (matured tree) (C) *Avicennia marina* (young seedling) (D) *Avicennia Officinalis* (E) *Bruguiera cylindrica* with propagules (F) *Ceriops tagal* (G) *Sonneratia apetala* (H) *Ipomoea biloba* (I) *Suaeda maritima* (J) *Sesuvium portulacastrum* (K) *Urochondra setulosa* and (L) *Salvadora persica.*

Mangrove plant community that Navsari, Purna estuaries (site IV) shows to be the most diverse location with the greatest species diversity, Species richness, abundance and evenness in comparison to other sites. Surat, Dumas beach (Site III) lies next to it and Bhavnagar, Ghogha coast (site I) and Bharuch, Dahej coast (site II) is lowest. The special structure of mangrove community revealed less diversity at Bhavnagar and Bharuch study site which could be due to the plantation of selected species.

Pielou's index of species evenness indicates the degree of structuring of community and constrained between 0 and 1. The evenness value 0 indicates that the area species-poor communities (presence of a single species). A value near 0 means that a single species may be dominant with the other very rare and a value close to 1 indicates low variation of species abundances within communities i.e. all species occur in relatively similar proportion.

In the present study Shannon diversity index (H′) for mangrove species was recorded highest in Navsari, Purna estuaries (1.179) followed by Surat (0.194) whereas Bhavnagar and Bharuch study site shows zero index value (Table 3). Generally, Shannon's index falls within in the range of 1.5–3.5 considered for a well-diversified area and if it is zero there's no diversity (Margalef, 1972). Diversity values in the study area suggest that the mangrove ecosystem may be under stress due to natural and/or anthropogenic factors. In the same way, diversity index values less than 1.0 for micro invertebrate fauna in estuarine waters system of mangrove ecosystem indicating heavy pollution and the macrofaunal community is under stress (Wilhm and Dorris, 1966; Kumar and Khan, 2013; Pawar, 2015).

Diversity indices provide more information about community composition. For species heterogeneity assessment, Simpson's index and Shannon-Wiener index used in this study. All the diversity indices showed that Navsari, Purna estuaries was the most mangrove diverse area and followed by Surat, Bharuch and Bhavnagar study site. Poor diversity of mangrove and associated biological features with low abundance and dominance of *Avicennia marina* indicate highly stressed environment (Kulkarni et al., 2010).

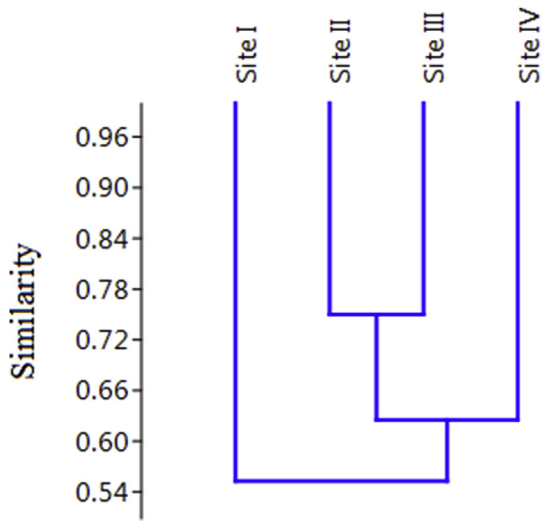

Figure 3. Dendrogram of total community composition at the four sites calculated using group average linking of Bray-Curtis similarities (calculated from +/- transform data).

3.3. Effect of ecological factors on the growth and diversity of mangroves

The species composition, growth and structure of the mangrove forest varies as a function of geophysical, geographical, geological, hydrographic, biogeographical, climatic, edaphic factors and the other environmental conditions. Particular mangrove species are highly depends on climate conditions and the coastal geography. The Gulf of Khambhat region belongs to a semi-arid zone, having a hot bio-climate, very strong average annual thermal amplitude of about 12 °C and an annual rainfall of 900 mm and a dry period of 8 months (Selvam, 2003). In past four decades (1966–2004) a large area of Gulf of khambhat facing serious threat due to landforms and shoreline changes (Gupta, 2014). The tidal range at the Gulf of Khambhat is the largest along the Indian coastline resulting in strong water currents can be up to 3.3 m/s and moreover the erosion/accretion along the coastline due to semi-diurnal tidal effects (Kumar and Kumar 2010). Intertidal soil salinity ranged from 20 to 126 dS/m, soil pH 8.6–10.0 with high sodium adsorption ratio (SAR) and exchangeable sodium percentage (ESP) ranged from 21.48-31.78 and 32.02–43.67% respectively (Keshri et al., 2015). These types of saline alkaline intertidal soils are considered biologically extreme.

The mean annual rainfall at study sites Bhavnagar, Bharuch, Surat and Navsari during year of 1985–2014 is 570, 705, 1355 and 1772 mm respectively (Data from Indian Meteorological Department). Mangrove growth and its spatial distributions are likely to be affected by the change in rainfall patterns (Gilman et al., 2008). The Relationship between number of mangrove species and mean annual rainfall (Figure 4), where mangrove species richness is more in Navsari area with high annual rainfall {1800 mm). Height and DBH of the mangroves found to be maximum with high average annual rainfall at the study sites. A study revealed that, area where mean annual rainfall is less than 1500mm, mangroves are much shorter height around 1–6 m (Duke et al., 1998). Our study also found the similar type of relationship. Higher rainfall and runoff can decrease salinity, reduced exposure to sulphates and increased sediments and nutrients provide in coastal areas, which might cause will increase in diversity, growth rates and productivity in mangrove forests. Whereas, lower rainfall would lead to increased salinity will cause decrease productivity, growth, diversity and seedling survival, so altering competition between mangrove species (Eslami-Andargoli et al., 2009). The mangroves and their associated species in the intertidal area of the

Table 2. Structural characteristics of mangroves of Gulf of Khambhat.

Botanical name (family)	Site	Height (m)	DBH (cm)	Density (Plant/ha)	Relative density (%)	Frequency (%)	Relative frequency	Dominance	Abundance
Avicennia marina (Acanthaceae)	I	0.36–2.0	2–6.1	97222	100	100	100	1	87.5
	II	0.86–1.4	‘2.8	20555	100	100	100	1	18.5
	III	0.66–2.4	1.8–5.2	15222	95.14	100	71.43	0.9514	13.7
	IV	0.4–3.4	2.6–5.6	15777	39.23	100	27.03	0.3923	14.2
Sonneratia apetala (Lythraceae)	I	-	-	0	0	0	0	0	0
	II	-	-	0	0	0	0	0	0
	III	1.7–2.1	3.6–9.3	777	4.86	40	28.57	0.0486	1.75
	IV	0.89–2.2	7.5–10.4	3444	8.56	90	24.32	0.0856	3.44
Bruguiera cylindrica (Rhizophoraceae)	I	-	-	0	0	0	0	0	0
	II	-	-	0	0	0	0	0	0
	III	-	-	0	0	0	0	0	0
	IV	0.9–2.0	2.7–6.1	4222	10.50	80	21.62	0.1050	4.75
Acanthus illicifolius (Acanthaceae)	I	-	-	0	0	0	0	0	0
	II	-	-	0	0	0	0	0	0
	III	-	-	0	0	0	0	0	0
	IV	0.47–0.71	-	16777	41.71	100	27.03	0.4171	15.1

Table 3. Comparison of diversity indices for mangrove community at different study sites.

Diversity indices	Site I	Site II	Site III	Site IV
(i) Species richness (S)				
Menhinick's index	0.0338	0.0735	0.1667	0.2102
(ii) Species evenness				
Shannon's equitability or evenness (E_H)	0.00	0.00	0.6411	0.9577
Pielou's index of species evenness (J)	0.00	0.00	0.2805	0.8504
(iii) Species heterogeneity				
Shannon-Wiener index (H′)	0.00	0.00	0.1944	1.179
Simpson's Index of Diversity (1 – D)	0.00	0.00	0.0925	0.6538

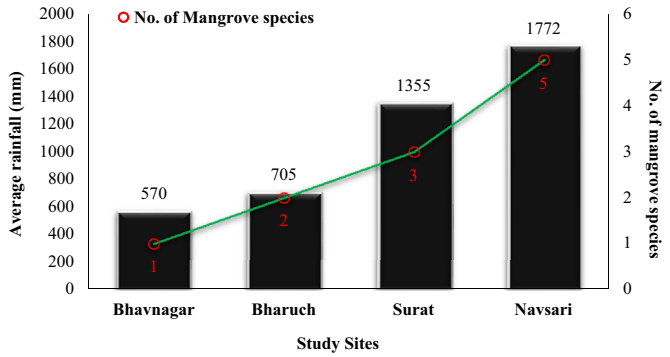

Figure 4. Relationship between number of mangrove species and mean annual rainfall in the study sites.

gulf of khambhat region are affected ecologically by both biotic and abiotic factors. The coastal soil characteristics of the study site may be one of the most important reason for its standing mangrove species diversity. High soil salinity limits water uptake in mangroves and causes decreased photosynthesis, tree density and height. Therefore, the region to exhibit high salinity of water and soil environment leading to stunted or scrubby growth of mangroves indicates disturbed or stressed environment. This study observed that overgrazing by cattle, extensive cutting for fuel/fodder and shrimp farms extension by cutting mangroves are the main biotic factors that affect the diversity of mangroves in this area. Among the abiotic factors, heavy discharge during the rainy season brings high sediment and erosion along the coastline due to tidal effects.

4. Conclusions

The mangrove diversity, dominance and adaptability highly depends on the ecological and environmental condition of the area. Six species of mangroves and ten species of mangrove associate were recorded from the sites under study in Gulf of Khambhat region of Gujarat, India. It is clear from diversity indices of mangrove plant community that Navsari, Purna estuaries (site IV) shows greatest species diversity, Species richness, abundance and evenness in comparison to other sites. Surat, Dumas beach (site III) lies next to it and Bhavnagar, Ghogha coast (site I) and Bharuch, Dahej coast (site II) is the least. The floral community of mangrove habitats is not uniform floristically or structurally because of the various environmental factors that influence on the individual mangrove species differently. Less mangrove diversity in intertidal areas or coastal areas indicating heavy pollution and the flora and faunal community is under stress due to natural and/or anthropogenic factors. The mangrove *A. marina* is the dominant species in the intertidal area of all study sites. Mangroves are the best bioindicator of environmental pollution and health of the coastal ecosystem. However they are being threatened by anthropogenic activities like deforestation, soil and water pollution. They need to be conserved and protected for the conservation of genetically divers group of terrestrial and aquatic organisms. In addition, it is suggested that more study should be conducted in this area in the future. The understanding of the structural characteristics of mangrove vegetation is very useful for the future mangrove management and conservation strategies. Development and maintenance of mangrove belt in and around the intertidal area of gulf of Khambhat were also suggested, and moreover the continued ecological assessment of mangrove is recommended.

Declarations

Author contribution statement

Jitendra Kumar Singh: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Funding statement

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Competing interest statement

The authors declare no conflict of interest.

Additional information

No additional information is available for this paper.

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