Journal of the Indian Society of Remote Sensing (November 2021) 49(11):2701–2719
https://doi.org/10.1007/s12524-021-01419-1

RESEARCH ARTICLE

Assessment of Landscape Ecological Connectivity for Sustainable Management of Digha–Shankarpur Coastal Tract, West Bengal, India

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Received: 10 November 2020 / Accepted: 8 August 2021 / Published online: 17 August 2021

Abstract
Landscape ecological study put forwards immense effectiveness for learning ecological connectivity in tropical coastal environments. Landscape ecology provides a well-developed theoretical and equipped structure for concentrating on sophisticated multi-scale questions concerning the influence of spatial outline on the ecological procedure. The present study deals with the climatic and altitudinal gradient which has resulted in a diversity of flora under the micro-geomorphological component of the delicate coastal setting. The native vegetation of coastal areas plays a significant role to stabilize the alluvium surface against wind erosion and provides habitat dissemination for wildlife. Accordingly, vegetation diversity has also been estimated through the randomly selected three transects (A, B and C) with 25 grids. Five types of vegetation communities are identified through the transact method (e.g., grasses, heaths, scrubs, small trees and large trees) and 25 types of micro-landscape units are identified in these transects of Ramnagar-I and Ramnagar-II coastal Administrative Blocks. The coastal vegetation is widely distributed and extended over the beach ridge surface; beach ridge fringed coastal plain; swale topography; inner coastal plain with abandoned creeks and older natural levee bank surfaces. The study divulges the relationships between vegetation and landform units of the coastal chenier plain surface and examined the morphological characteristics of the landscape instability. The interrelationship between habitats and morphological units demonstrates the interconnecting activities with each other in this particular sensitive ecosystem. The micro-morphological unit mainly beach ridge and natural levees has immense significance in connection with the floral species diversity as well as affluence of floral species.

Keywords Landscape ecology · Digital elevation model (DEM) · Plant ecology · Micro-landscape unit · Transect and habitats

Introduction

A landscape ecological approach is the learning of ecological connectivity to appropriate patches and a mixture of balancing resources. The German word 'Landschaftsokologie' means landscape ecology which was first ever transformed by German geographer Carl Troll in 1939 (Troll, 1968). He developed this term and also modeled the numerous spontaneous discernments regarding landscape ecology of his near the beginning work, which consisted of pertaining remotely sensed data explanation to revise the associations of involving environment and vegetation. Landscape ecology has been studied in several ways (Pickett & Cadenasso, 1995; Risser et al., 1984; Turner, 1989; Turner et al., 2001; Urban et al., 1987), but mutual among these explanations it is the precise focus on the significance of spatial heterogeneity for ecological progression. The focal point of landscape ecology causes and consequences of spatial heterogeneity which is separated from how landscape ecology is sometimes defined (Bastian, 2001; Opdam et al., 2001; Zonneveld, 1990). A landscape is an extensive vicinity where a bunch of acting together

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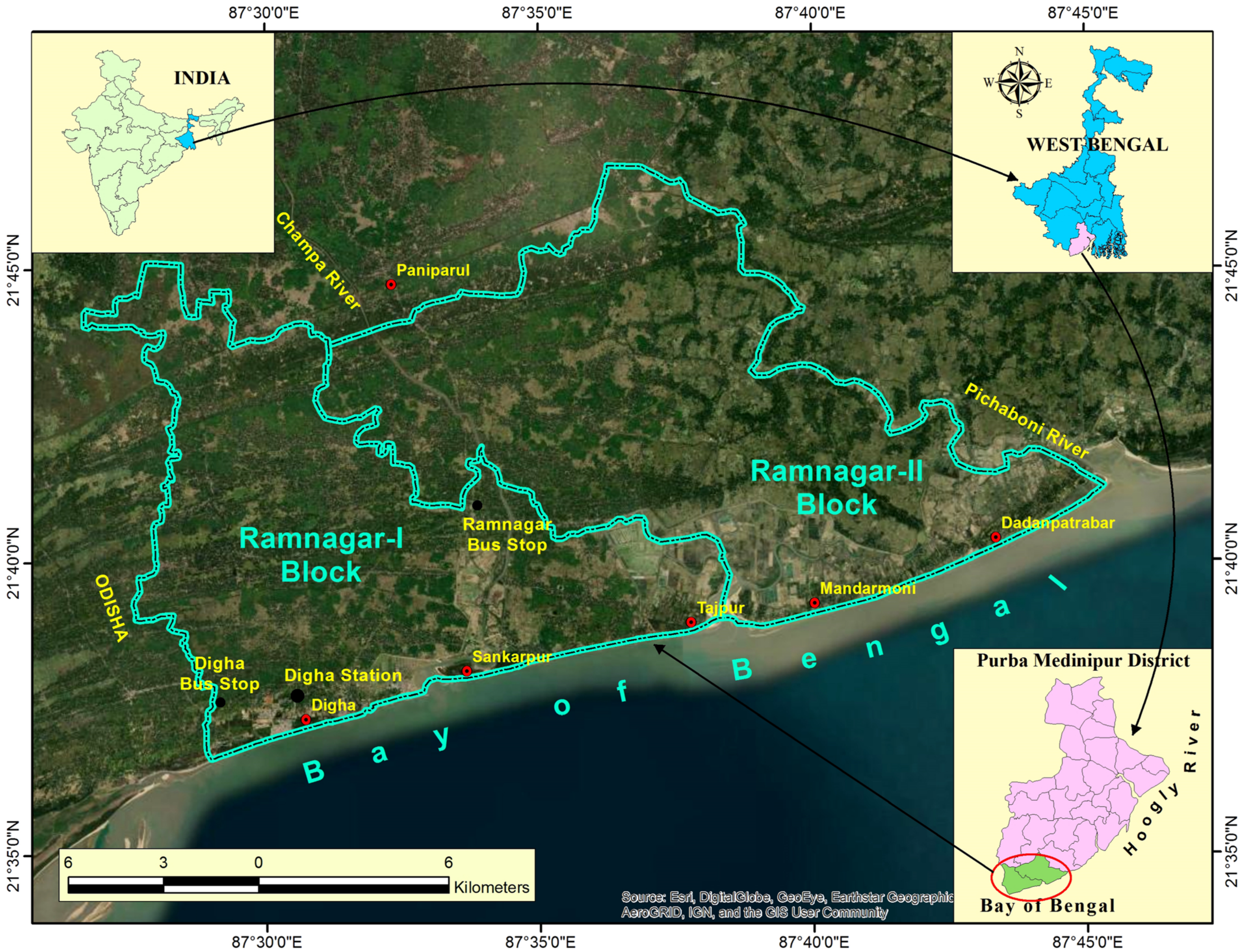

Fig. 1 Location map of the study area

ecosystems is frequently located in a parallel outline. The landscape is produced by two systems that are jointly contained by its edge-specific geomorphological methods and precise disorders of the factor situates. Landscapes are different considerably in aerial extent, and a confined to a small area of a few meters or hundreds of meters transversely is at a finer level of scale than a landscape. In geographical literature, the landscape acts an essential part, with most explanations focusing on the dynamic association connecting two characteristics-natural landforms or physiographic regions and human cultural groups (Grossman, 1977; Hall et al., 1988; Sauer, 1963). For this intention, landscape ecology has been strongly and increasingly more endorsed as an ecologically significant advance for investigative species-environment associations in a wide assortment of structured shallow water and maritime habitat types (Grober-Dunsmore et al., 2009; Irlandi et al., 1995; Robbins & Bell, 1994).

Most significant research in landscape ecology encompasses the reasons and consequences of spatial pattern in landscapes, the special possessions of commotion, ecological flows in landscape mosaics, land use and land cover modification and landscape conservation and sustainable management (Forman, 1995; Turner et al., 2001; Wu & Hobbs, 2002; Turner, 2005; Wu et al., 2007). Landscape ecology is the study of how landscape structure influences the profusion and allocation of organisms with the multiplicity scales of the landscape. So, landscape ecology focuses on three characteristics of the landscape such as structure, function and modification. The structure stands for the spatial associations between the typical ecosystems

Fig. 2 Vegetation survey in each grid along the selected three transects with the GPS tracker

or rudiments whereas function deals with the relations among the spatial features and modification comprise with the modification in the arrangement and purpose of the ecological mosaic over time (Andersen, 2008; Groom et al., 2006; Moody & Woodcock, 1995). In this context, the physiography of the alluvium coast plays a very significant role in coastal morphodynamics in response to outer environmental impacts with a significant change in boundary conditions of the local area. 'Chronological Development of Coastal Landscapes' through landform units in different orders of formations, their surface morphometry, drainage features, hydro-geomorphology and changing tidal prisms has been assessed to explain the nature of shoreline dynamics of the coastal plain topography (Cooke & Doornkamp, 1990; Kamila et al., 2020a, 2021).

Coastal vegetation provides a barrier against coastal hazards such as landfall, storm surges and tidal inundation during cyclonic events. They also act as a source of sand to refill the beach during the phase of erosion. So the protection of coastal vegetation is important for the long-term protection of beachfront properties. It is not sufficient to describe the patterns of species turnover at an ecotone; one must think about the underlying causes of that turnover,

Table 1 Field survey data sheet regarding plant ecology of transect A (near Old Digha) November 2018

Grid no	Plant ecology					% of vegetation per grid	Areas of vegetation (m^2)	Elevation (m)	Field moisture
	Grass (%)	Heath (%)	Scrub (%)	Small trees (%)	Large trees (%)				
A 1			5	9	15	28.87	72,173.29	5.01–8.17	Medium
A 2			10	15	60	85.03	212,574	7.56–10.93	Medium
A 3	8		15	20	45	87.93	219,820	7.04–9.33	Medium
A 4	6		20	30	35	91.46	228,647	6.08–9.96	Medium
A 5	4		7	15	20	46.46	116,161	4.01–7.95	Low
A 6	1	1	1	2	2	6.63	16,586	5.60–6.99	Low
A 7	4		5	10	15	34.03	85,077.78	3.38–6.58	Low
A 8	4		5	15	20	44.35	110,886	3.00–7.95	Medium
A 9	5		10	40	15	69.86	174,689	4.07–6.98	Medium
A 10	4		8	20	10	41.64	104,087	4.00–5.96	Low
A 11	2		10	15	20	47.37	118,420	4.73–7.80	Medium
A 12	2		7	10	15	34.30	85,740.29	5.09–12.47	Low
A 13	3		10	15	20	48.14	120,345	9.29–12.99	Low
A 14	4		10	20	45	79.31	198,264	8.16–10.99	Medium
A 15	3		7	25	40	74.74	186,860	8.01–10.94	Medium
A 16	7	4	15	20	45	90.67	226,672	5.64–9.98	Medium
A 17	4	3	5	8	15	34.66	86,646.78	4.00–7.96	Low
A 18	0.5		1	1.5	1	4.02	10,055	5.04–6.68	Low
A 19	8		10	20	15	52.51	131,287	4.03–5.62	Medium
A 20	1		3	5	8	17.16	42,901.19	5.37–5.99	Low
A 21	3	3	4	10	20	39.74	99,338.78	4.00–5.80	Low
A 22	4	2	5	15	5	31.04	77,603	3.86–5.92	Low
A 23	5	4	5	10	20	44.43	111,091	5.38–7.85	High
A 24	6		10	15	25	56.26	140,652	2.01–9.97	High
A 25	5		8	10	20	42.92	107,341	4.00–6.98	High

Each grid is considered 500 m × 500 m = 2,50,000 m^2 (0.25 km^2)

how species are responding to the environment and the relative distributions of these species along the gradient. The study heated discussion at this time that the significance of a landscape ecology approach is tremendously heterogeneous arrangements that differentiate the coastal habitat dynamism which will help the understanding and interconnections between movement behavior and the spatial patterning of the landscape (Hobbs, 1990; Bastian et al., 2006; Crooks & Sanjayan, 2006). In due course, this should direct to more ecologically important decision-making in resource management. This is such progress that has been commencing for a dissection of the West Bengal coastline. The map geared up for the West Bengal coast underneath this study can be dilapidated by the districts and blocks administration drawn in the disaster lessening and executive plan.

Materials and Methods

Developments in landscape ecology illustrate the important relationships between spatial patterns and ecological processes. In this present study, these developments incorporate quantitative methods that link spatial patterns and ecological processes at broad spatial and temporal scales. Coastal morphometric attributes (1 km by 1 km grid cells are used for the identification of relief elements based on DEM) and high-resolution interpolated digital elevation model (DEM) have been prepared to draw the (50-cm

Table 2 Field survey data sheet regarding plant ecology of transect B (near Tajpur) November 2018

Grid Nos	Plant ecology					% of vegetation per grid	Areas of vegetation (m^2)	Elevation (m)	Field moisture
	Grass (%)	Heath (%)	Scrub (%)	Small trees (%)	Large trees (%)				
B 1	10		10	15	20	54.63	136,573	4.24–7.62	Medium
B 2	4		10	25	35	74.25	185,640	6.14–10.11	Medium
B 3	5		5	20	35	65.56	163,911	4.78–10.64	Medium
B 4	3		5	15	20	42.97	107,427	6.66–13.70	Low
B 5	0.5		0.5	0.5	1.5	3.57	8915.84	2.80–10.26	Low
B 6	2		8	10	25	44.98	112,462	3.86–7.35	Low
B 7	6	4	8	10	20	47.93	119,825	4.40–6.48	Medium
B 8	1	1	2	3	5	12.01	30,037.60	3.95–5.86	Low
B 9	1	1	3	4	5	14.20	35,522	4.66–6.08	Low
B 10	2		8	10	20	39.60	99,004.5	4.32–7.60	Low
B 11	6	3	10	25	55	99.31	248,272	4.68–10.02	Medium
B 12	3	3	8	15	25	53.92	134,807	3.86–10.60	Medium
B 13	5		8	10	20	42.97	107,430	4.15–10.58	Medium
B 14	4		5	30	35	73.64	184,091	3.20–11.06	High
B 15	3		10	45	15	73.39	183,475	1.00–13.21	High
B 16	4		8	50	15	76.96	192,411	6.80–14.59	High
B 17	4		10	25	30	69.17	172,936	2.68–11.82	High
B 18	2		2	5	4	13.03	32,578.80	1.98–5.70	Low
B 19	3		5	5	10	23.12	57,811.10	2.98–4.92	Low
B 20	1		2	3	15	21.00	52,510.69	2.40–6.24	Low
B 21	0.5		1	1	1.5	3.91	9774.58	2.78–6.15	Low
B 22	0.5		0.5	1	0.5	2.30	5740.45	3.35–5.00	Low
B 23	2		3	8	4	16.51	41,270.50	3.53–6.48	Low
B 24	6		10	30	20	66.01	165,034	3.42–6.96	High

Each grid is considered 500 m × 500 m = 2,50,000 m^2 (0.25 km^2)

interval) contour line through the replication of image calculation procedure for the recognition of micro-geomorphological components, characterization of the landscape units and coastal evolution process of the studied area (Kamila et al., 2020a). Surface soil moisture has been estimated through the temperature vegetation dryness index (TVDI) method (Kamila et al., 2020b) to identify the soil moisture concentration of the study area (Fig. 4) and Spectral Angle Mapper (SAM) is used to classify the plant ecology diversity of the study area.

However, the biological processes have been estimated through phyto-geomorphological mapping. Finally, some secondary data (climatic data, tide data, census data, hazards data, etc.) are also collected and analyzed through some statistical methods to understand the coastal processes and the pressure of coastal resources. This linkage of time, space and environmental change can assist managers in applying plans to solve environmental problems. Through this work, the increased attention in recent years on spatial dynamics has highlighted the need for new quantitative methods that can analyze the patterns, determine the importance of spatially explicit processes and develop reliable models.

Multivariate analysis techniques are frequently used to examine the landscape level and vegetation patterns throughout this present work. The present study incorporated the cluster analysis method for classifying plant communities of the coastal belt. The study analyzes gradients across space and time between ecosystems of the coastal dune to determine relationships between distribution patterns of animals in their environment. Looking at where animals live and how vegetation shifts over time

Table 3 Field survey data sheet regarding plant ecology of transect C (near Jaldah Mohana) November 2018

Grid no	Plant ecology					% of vegetation per grid	Areas of vegetation (m^2)	Elevation (m)	Field moisture
	Grass (%)	Heath (%)	Scrub (%)	Small trees (%)	Large trees (%)				
C 1						NA		3.66–7.29	
C 2						NA		3.00–5.34	
C 3	3		5	10	8	25.51	63,888.89	2.98–4.94	Low
C 4	4		10	35	50	99.00	245,327	4.66–6.12	Medium
C 5	2		15	30	15	62.39	155,974	5.12–5.96	Medium
C 6	3	1	10	55	20	88.72	221,796	5.39–8.04	Medium
C 7	5		15	15	20	54.77	136,915	2.92–8.32	Medium
C 8	2	1	3	5	8	18.40	46,000.80	3.67–6.68	Low
C 9	2		7	10	15	34.20	85,503.80	4.17–5.52	Low
C 10	7		8	10	10	34.60	86,492.78	4.60–6.42	Low
C 11	4		6	20	10	39.51	98,773.39	3.02–5.94	Low
C 12			0.5	2	0.5	2.63	6574.38	2.90–5.24	Low
C 13	0.5		0.5	1.5	0.5	3.42	8544.90	3.82–7.08	Low
C 14			2	5	3	9.55	23,865.1	3.75–7.40	Low
C 15	4		8	10	15	37.21	93,015.39	2.48–6.54	Low
C 16	2		2	5	10	19.42	48,559.80	2.23–4.78	Low
C 17	0.5		0.5	3	1	5.45	13,620.80	2.90–4.92	Low
C 18	1		1	10	2	14.09	35,211	4.00–5.00	High
C 19	0.5		0.5	2.5	0.5	4.30	10,743.80	4.18–5.54	Medium
C 20	5		8	10	20	41.91	104,748	4.62–7.01	High
C 21	3		3	8	10	23.62	59,037.89	5.41–6.88	Medium
C 22			0.25	0.5	0.25	1.27	3156.80	5.28–7.05	High
C 23	1		1	4	1	6.94	17,348.30	3.95–6.88	High
C 24							NA	3.92–5.10	High
C 25							NA	3.17–5.18	Medium
C 26							NA	3.25–5.00	Medium
C 27	1		1	2	1	4.80	11,998.90	2.31–5.03	High
C 28	2		3	8	1	14.30	35,762.30	1.39–5.52	High
C 29	8		10	10	3	30.59	76,487.89	1.21–3.41	High

Each grid is considered 500 m × 500 m = 2,50,000 m^2 (0.25 km^2)

may provide insight into changes in coastal processes as well as climatic changes over time across the landscape as a whole.

Geographical Settings of the Study Area

The coast is an exclusive environment where land, sea and atmosphere interrelate and interact constantly influencing a narrow piece of spatial zone distinct from the coastal zone. In other words, coastal zones are the vicinities having persuaded of both marine and terrestrial processes (Fig. 1).

This rising coastal plain is made up of sand and mud deposited by fluvial and Aeolian process which is also a mid-eastern division of Kanthi Coastal Plain, covers an area of about 294.39 km^2 stretching between 21°37′54.88“N to 21°46′39.78”N latitude and 87°26′40.90“E to 87°37′36.64”E longitude. The study area is the most delicate, dynamic and prolific ecosystem and is fairly often under anxiety from both anthropogenic

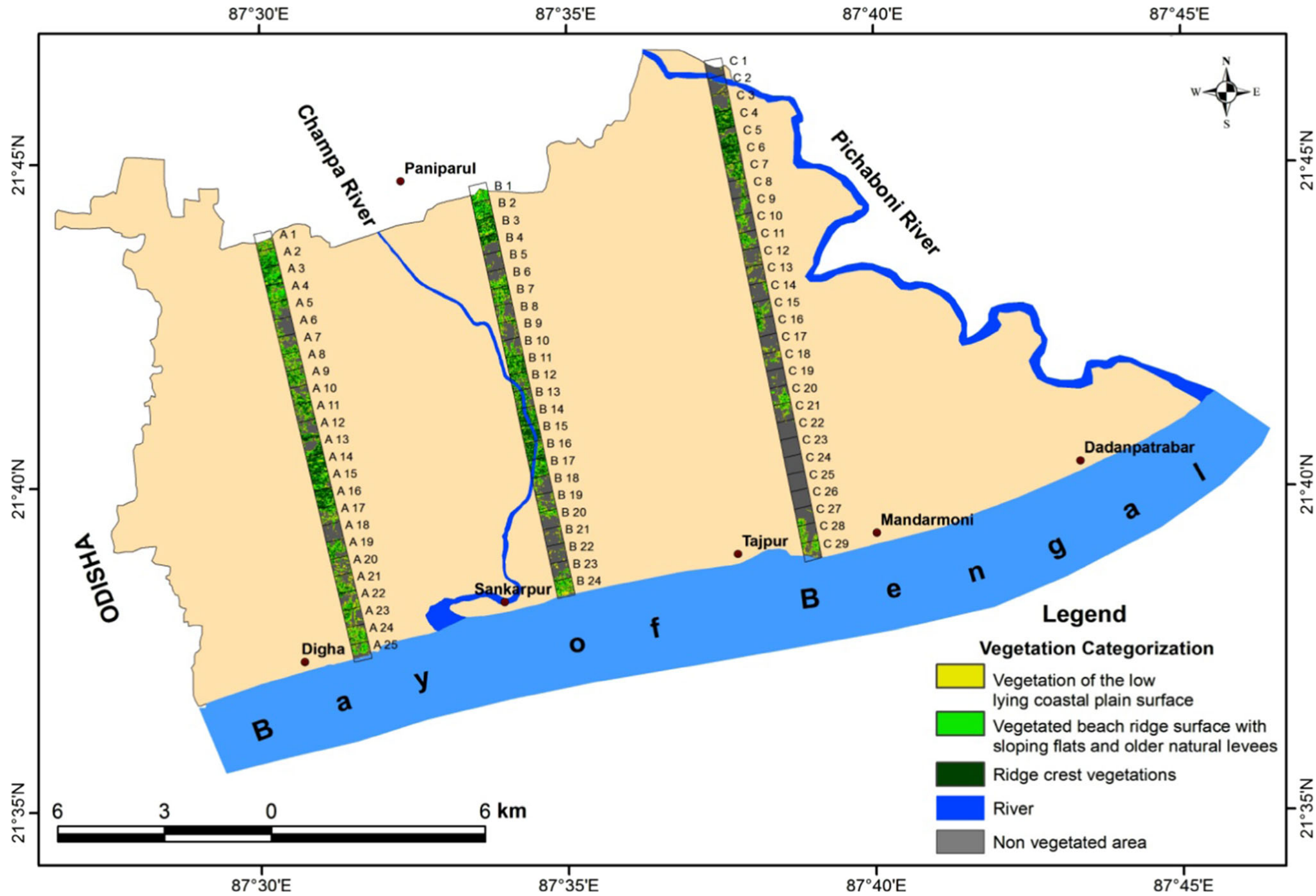

Fig. 3 Grid-wise spatial distribution of species communities along transects of A, B and C

conducts and the natural course also. It supports a great quantity of floral and faunal biodiversity. This coastal zone is capable of an incredibly extensive variety of habitats such as mangroves, seagrasses, sand dunes, vegetated stungle, mudflats, salt marshes, estuaries and lagoons which are considered by diverse biotic and abiotic processes.

Results and Discussion

Coastal habitats are extremely fragile and specialized to this particular environment which is most vulnerable to human activities, and therefore, vegetation ecology studies are preferred to predict responses of landscape monitoring. This study has been carried out on plant species distribution of Ramnagar-I and Ramnagar-II coastal Administrative Blocks. For the study of species diversity analysis, the transect method has been marked out in three instant sites such as near Jaldah Mohana, Tajpur tract and New Digha belt where the compact vegetation diversity is detected. This survey work mainly identifies 106 species of plant species on 75 grids.

Grid-Wise Distribution of Coastal Vegetation

An extensive field survey has been conducted to identify the diversity of species and plant ecology which have present in each grid. During the field survey, a GPS tracker is enabled for tracking the route of the study area for touching every grid of individual transects (Fig. 2). Simultaneously the relation has also been recorded during the field survey among the percentages of the occupied plants, altitudinal variation and field moisture condition to formulate the further species monitoring strategies (Tables 1, 2, 3). The present study deals with the sample survey method including 75 grids (each grid considered in 500 m × 500 m) of three transects. Every transect has 25 grids and every single transect is extended from the south to north direction of the study area (Figs. 3, 4).

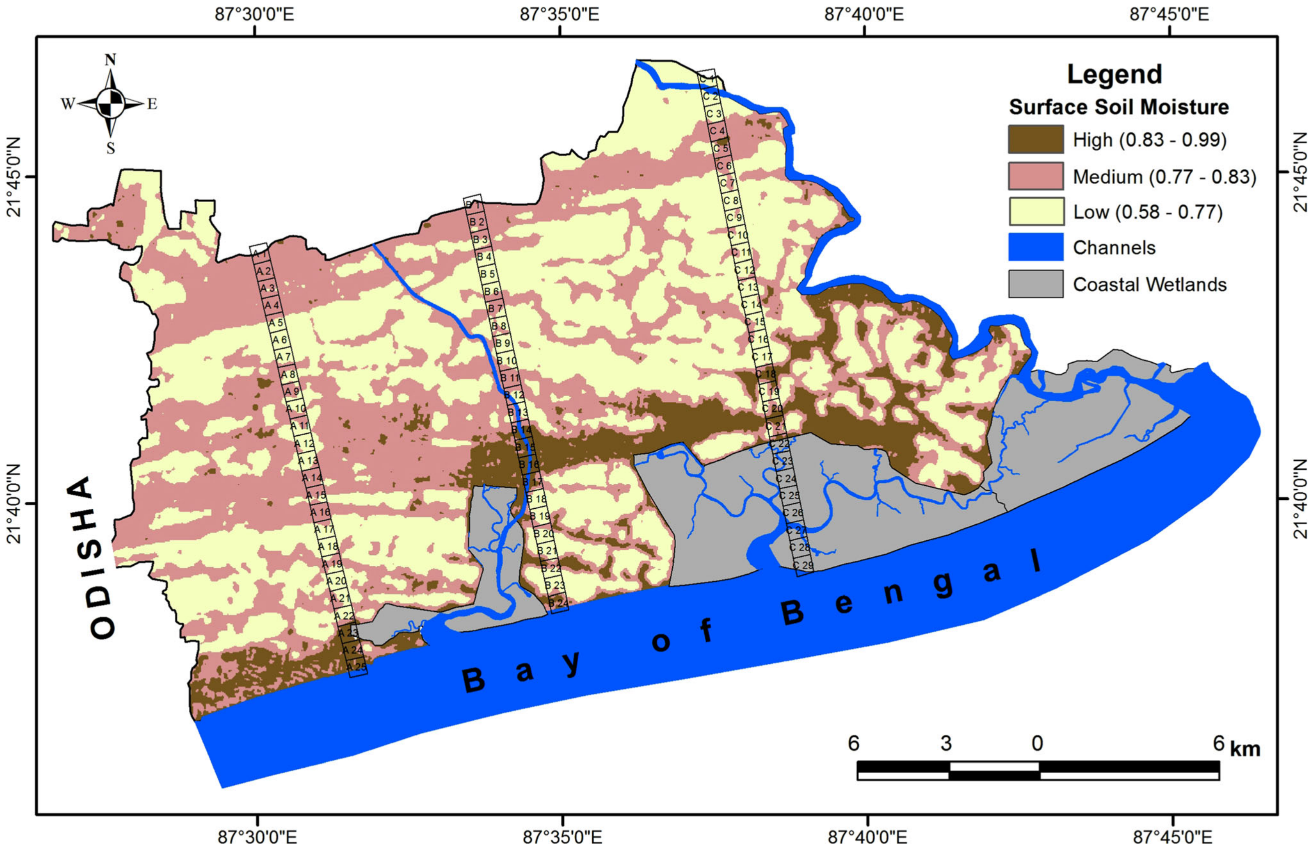

Fig. 4 Surface soil moisture condition of the study area (including every grid)

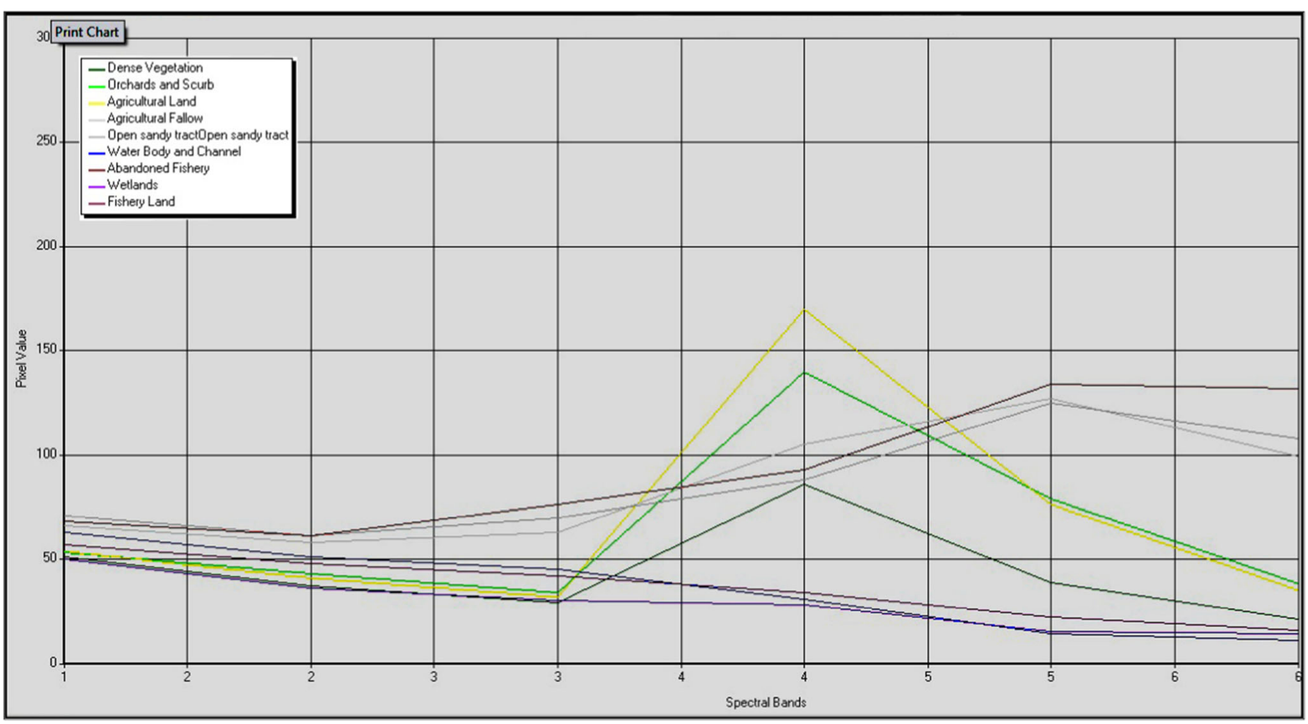

Fig. 5 Spectral signature profile of distinct land use/land cover features

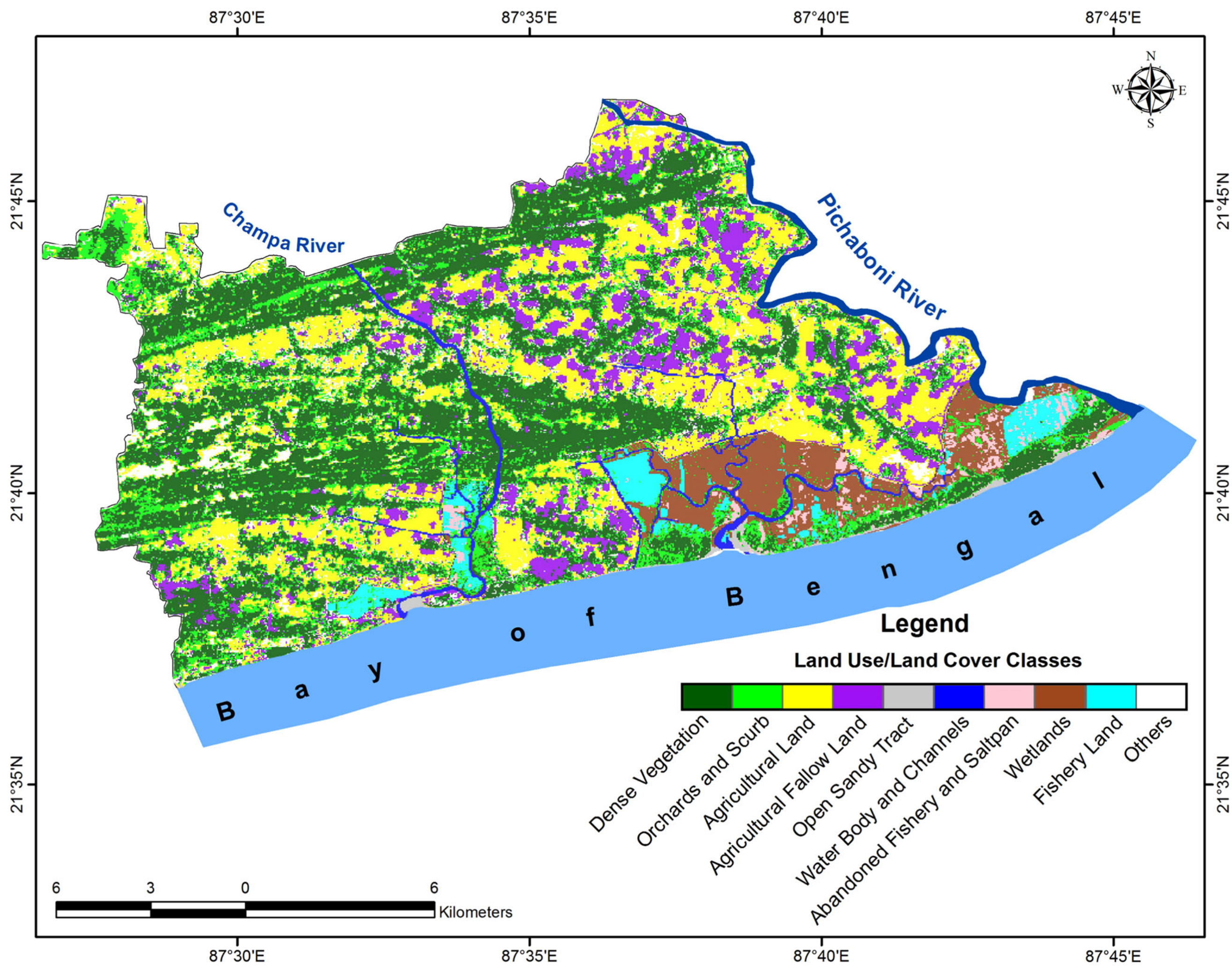

Fig. 6 Land use/land cover classification of entire study area

The Spectral Angle Mapper (SAM) supervised classification method is a modest and logical technique for mapping the land use land cover features through the image spectra validation. It is a physically based spectral categorization that uses an *n*-D angle to equivalent pixels to indication spectra. The algorithm establishes the spectral resemblance between two spectra by calculating the angle connecting the spectra and treating them as vectors in a space with dimensionality equivalent to the number of bands. In this procedure, End-member spectra utilized by SAM can come from American Standard Code for Information Interchange (ASCII) files or spectral libraries, or research can pull out them directly from remotely sensed data (as Region of Interest (ROI) average spectra). SAM evaluates the angle between the end-member spectrum vector and each pixel vector in *n*-D space lesser. It is a very effective grouping technique for the region to classify the plant ecology because it suppresses persuade of shading effects to emphasize the target reflectance distinctiveness. So the spatial distribution and patterns of the identified floral species of each grid are delineated based on the SAM classification and ground truth verification for the spatial zonation of the vegetation into three transects. After that, the occupied areas of the floral species are being calculated for assessing the zonal approach of the species in every grid from Sentinel -2 Multi-Spectral Instrument (MSI) satellite imagery. The SAM was able to provide reasonable classification results (Figs. 5, 6) so the entire study area is classified in ten (10) types of LU/LC categorization in 2018 (e.g., dense vegetation; orchards and scrub; agricultural

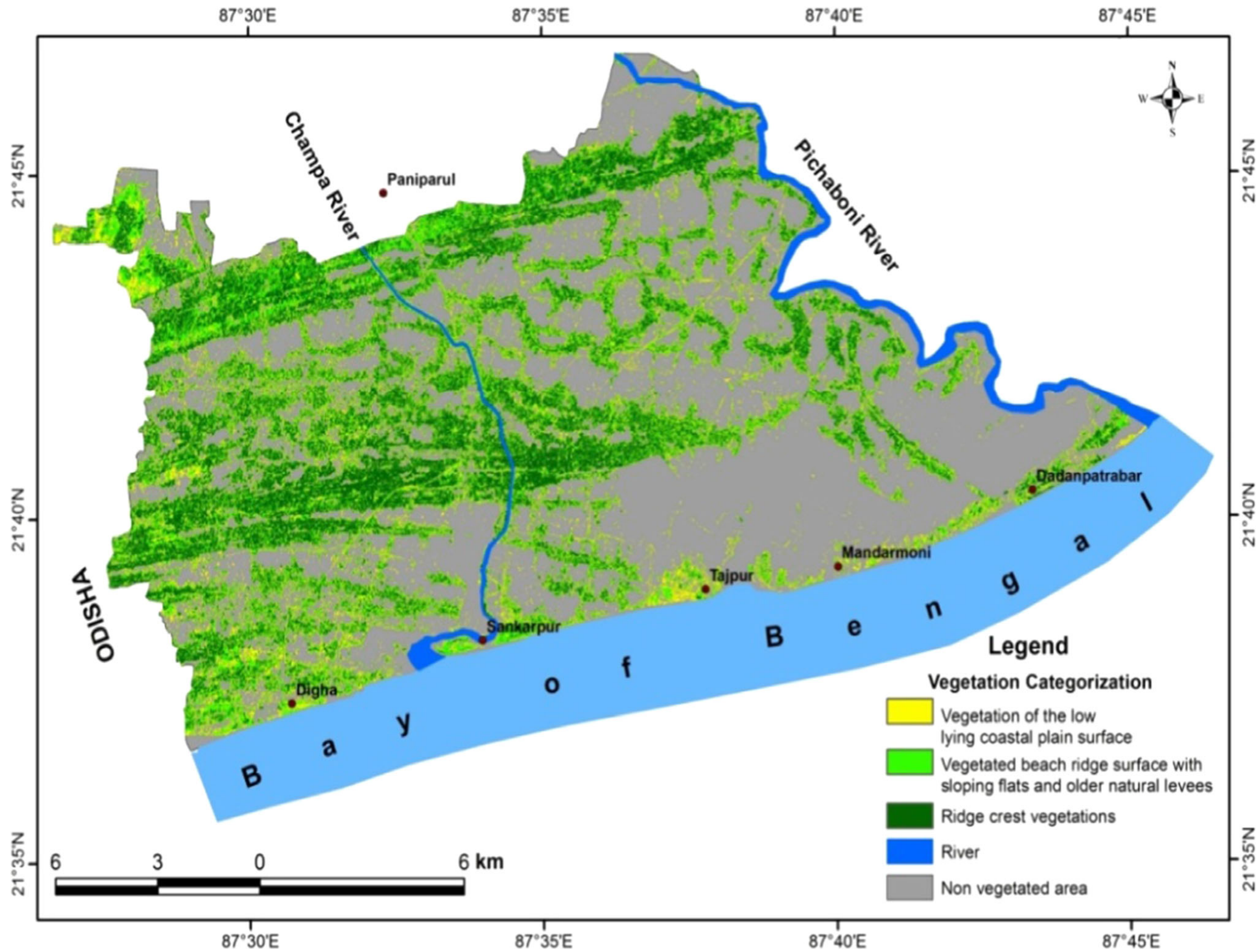

Fig. 7 Overall scenario of vegetation types with different topographic units

land; agricultural fallow land; open sandy tract; waterbody and channels; abandoned fishery and saltpan; wetlands; fishery land and others land).

Grid-wise vegetation is categorized into three transects such as vegetation of the low-lying coastal plain surface (30 km^2), vegetated beach ridge surface with sloping flats and older natural levees (48 km^2) and ridge crest vegetations (53 km^2) through the SAM technique. Such a minute categorization of the floral species is alienated through the spectral response of different groups of species in each grid (Fig. 7).

Identification of Micro-landscape Units

The present study also deals with very high-resolution DEM for the understanding of the micro-landscape units of the entire region of the study area. The DEM is classified based on elevation (m) in six (6) units such as modern tidal flood plain (0–3 m); estuarine flood plain and paleo tidal basin and interdune valley flats (3 m–6 m); beach ridge and natural levees (6–9 m); dune flat and dune terraces (9–12 m); moderately high dune ridge ranges from 12 to 15 m and isolated dune ridge (15–18 m) to understand the coastal morphological setup. The study can easily identify very precise micro-topographic units from the high-resolution interpolated DEM. So the present study is comprised of high-resolution interpolated DEM to understand the

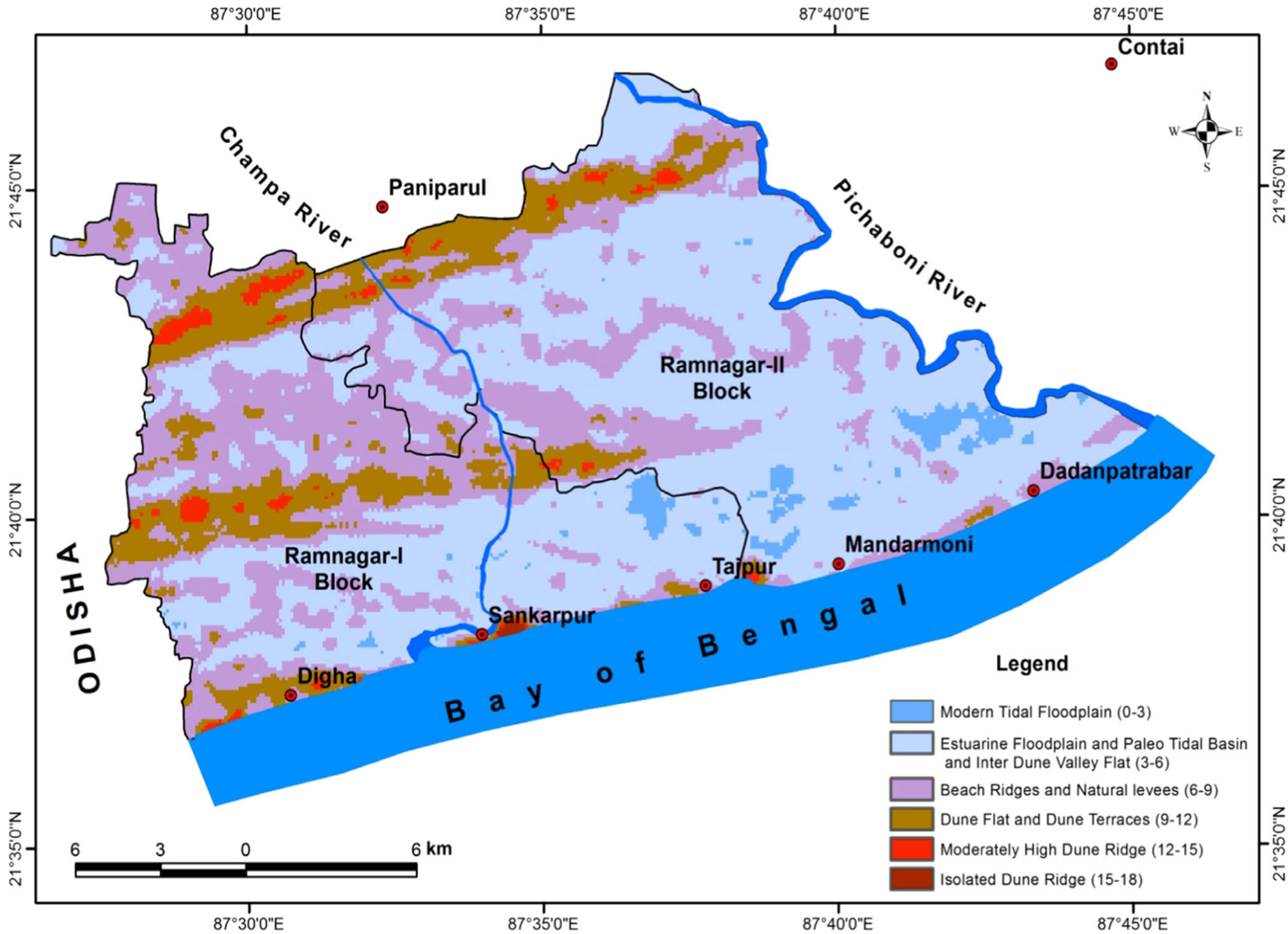

Fig. 8 Topographic micro-zonation of coastal landforms

diverse altitudinal variation in each grid of three transects. The variation of elevation fluctuates in transect A, B and C sequentially 2.01 m to 12.99 m, 1.98 m to 14.59 m and 1.19 m to 8.32 m (Figs. 8, 9).

Relation Between Micro-topography and Floral Species

After the consideration of elevation in every transect, the longitudinal profile has been drawn from the seaward side to the landward side to assess the grid-wise micro-terrain units. Every grid represents different types of landscape units.

This cross profile shows the macro- and micro-zonation of the topography and also the diversity of the plant community under the different topographic variables (Figs. 10, 11, 12). The diversity of vegetation is distributed in the different characters of the terrain in each grid. On the other hand, the nature of the topography controls the variability of the plant species community of the region.

Spatial Variability of Plant Community

Grid-wise species categorizations are plotted in a linear way against each other to showing the comparative changeability of the plant community of AB, BC, AC and ABC transect. The species communities are familiarly close to the Grid-1 to Grid-14 of AB transects, Grid-15 to Grid-24 of BC transects and there is a far similarity of species found in AC transects. So the comparative linear pattern of the species category of ABC transects reflects the presence of a heterogeneous group of a plant community dominated by the topographic attributes of the landscape units. The maximum diversity of vegetations are occupied

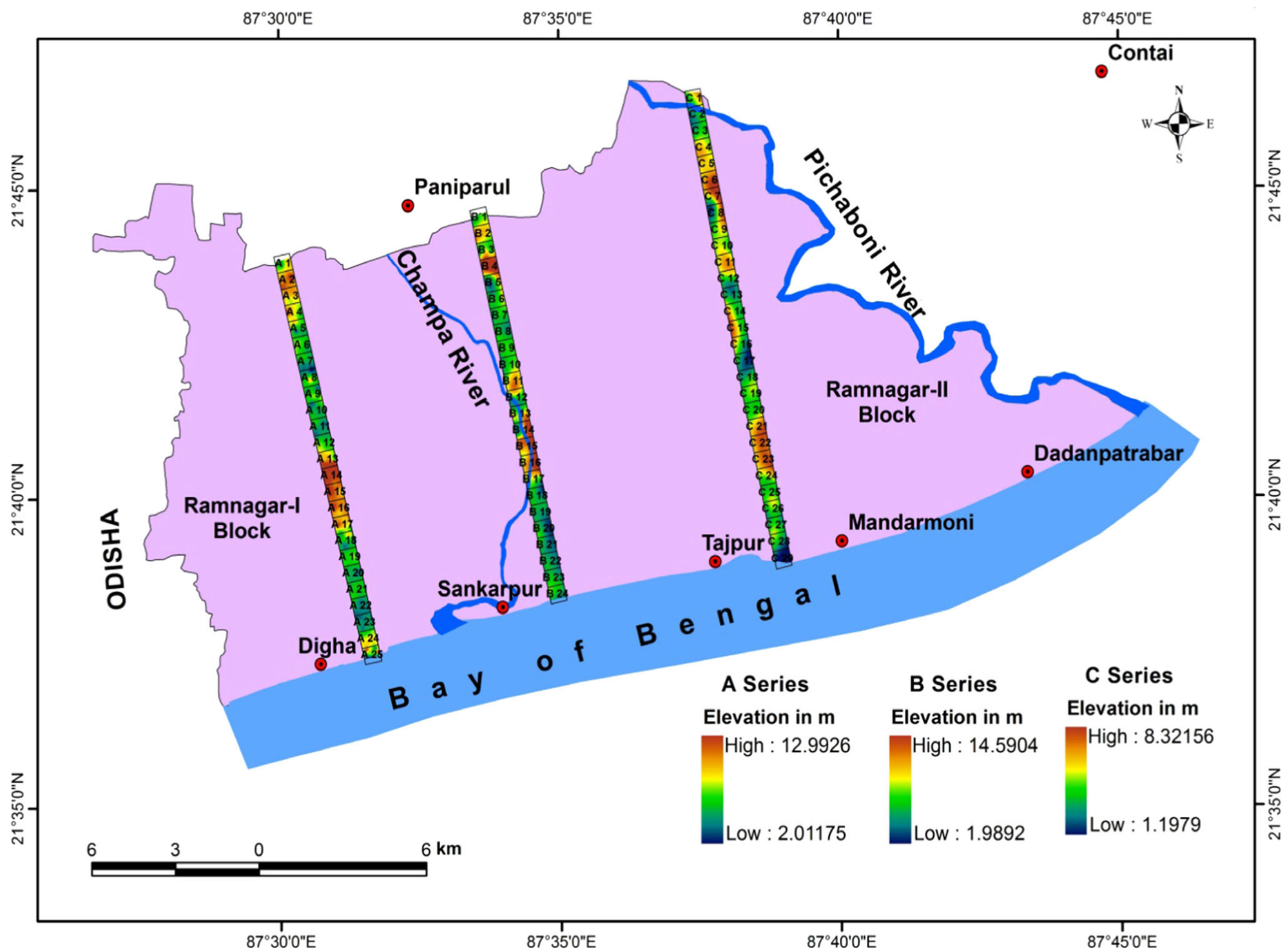

Fig. 9 Grid-wise altitudinal variation of transect A, B and C

by the beach ridge surface; beach ridge fringed coastal plain surface; inner coastal plain surface with narrow beach ridge segment; beach ridge separated by swale valley; inner coastal plain surface with older levee bank; inner coastal plain with abandoned creeks; inner coastal plain with beach ridge remnant surface in the transect of A, B and C (Table 4).

Because soil moisture concentration is very substantial in the dune furrows, dune valleys, sloping flats of the coastal sand dunes and ancient beach ridges. On the other hand, due to tidal inundations, the wetlands of the coastal belt support the potential zones for the growth and extension of floral habitats. Nutrient recycling and sediment recycling are gradually increased in the micro-zones due to the extensive growth of plant communities under tropical hot and humid environments. Finally, the spatial distributions of different plant diversity zones are integrated with the micro-topographic units of the coastal landscape (Fig. 13).

Interrelationship Between Habitats and Morphological Units

Coastal landforms, any of the relief distinctiveness present along any seashore are the consequence of a combination of processes, sediments and the geology of the coast itself. The maritime province of the world is made up of extensive diversity of landforms obvious in a continuum of dimensions and shapes ranging from soothingly sloping beaches to high cliffs yet coastal landforms are best well-thought-out in two broad categories: erosional and depositional. The general outlook of any coast may be

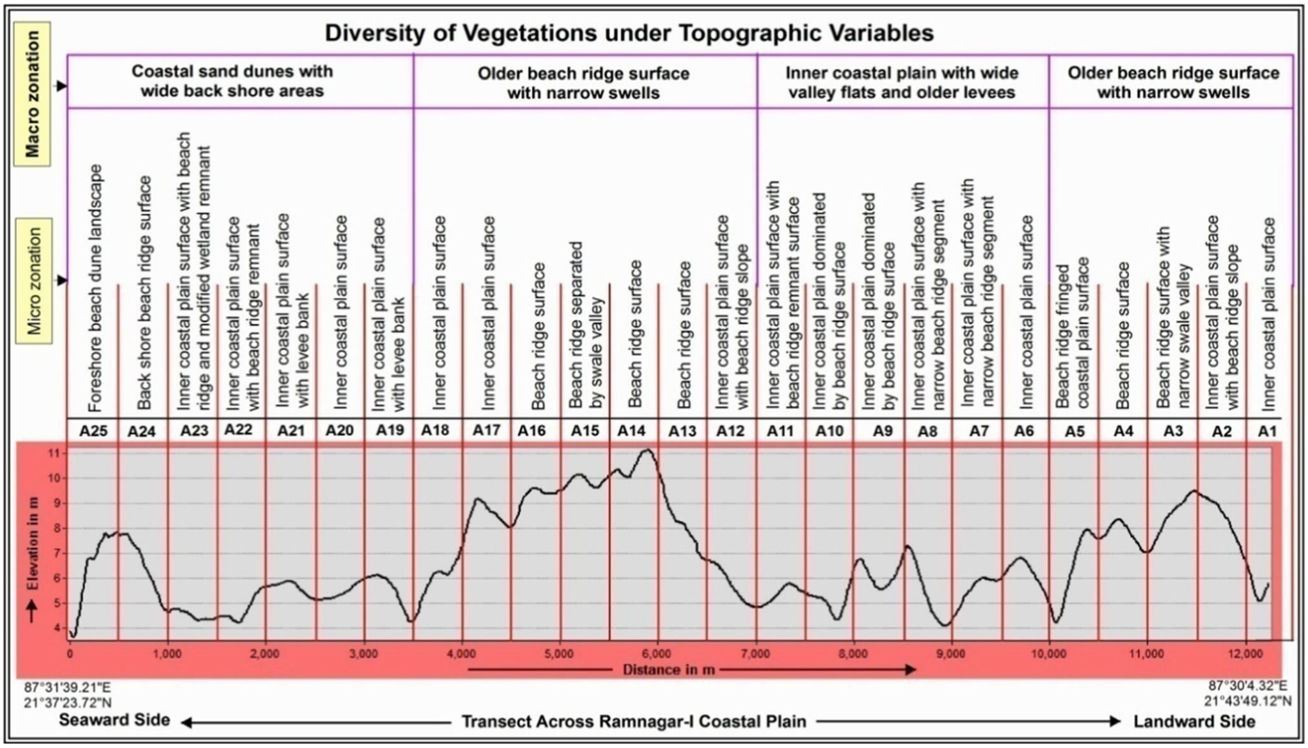

Fig. 10 Diversity of vegetation under topographic variables of 'A' transect

illustrated in stipulations of one or the other of these categories. It should be renowned that each of the categories has various types of processes and special kinds of biological possessions which are always functioning for built up the coastal surroundings. The present study area is also incorporated several kinds of habitation units like large trees, small trees, scrubland, heathland and grassland based on the spatial diversity, richness and evenness of species that are highly interconnecting and interact with each other. Accordingly, this individual's ecosystem build-ups the vast coastal ecosystem (Table 5).

From Table 6, it is very clear that small tree habitation is much more frequent than other habitation of floral species whereas the heathland habitation is occupied a very small sort of land. Other habitation zones lie in between the land cover of these two classes. Plant ecology has also been categorized into different classes like grass, heath, scrub, small tree and large tree in a primary level for the monitoring of biodiversity status of the studied region (Fig. 14).

The present study also highlighted that small tree habitation with 33.79% area occupancy is the sum of the different micro-geomorphological units. 33.79% of land occupancy is 0.04% from isolated dune ridge (15–18 m), 1.01% from moderately high dune ridge (12–15 m), 7.87% from dune flat and dune terraces (09–12 m), 20.46% from beach ridge and natural levees (06–09 m), 4.43% from the estuarine flood plain and paleo tidal basin and interdune valley flat (03–06 m) and 0.02% from Modern tidal flood plain (00–03 m). So it is very clear that beach ridge and natural levees area is highly covered with small tree habitation with 20.46%. On the other hand, every habitation zones are also occupied the beach ridge and natural levees portion with a large amount of land percentage than other micro-morphological units. Thus the micro-morphological unit mainly beach ridge and natural levees has immense significance in connection with the floral species diversity as well as affluence of floral species (Fig. 15).

The present study area is also incorporated several kinds of habitation units like large trees, small trees, scrubland, heathland and grassland based on the spatial diversity, richness and evenness of species that are highly interconnecting and interact with each other. Land cover pattern is directly correlated to coastal management strategies. The local people of the present low-lying deltaic coast are recurrently altering the land cover pattern by their necessities without discerning the initiation risk related to land

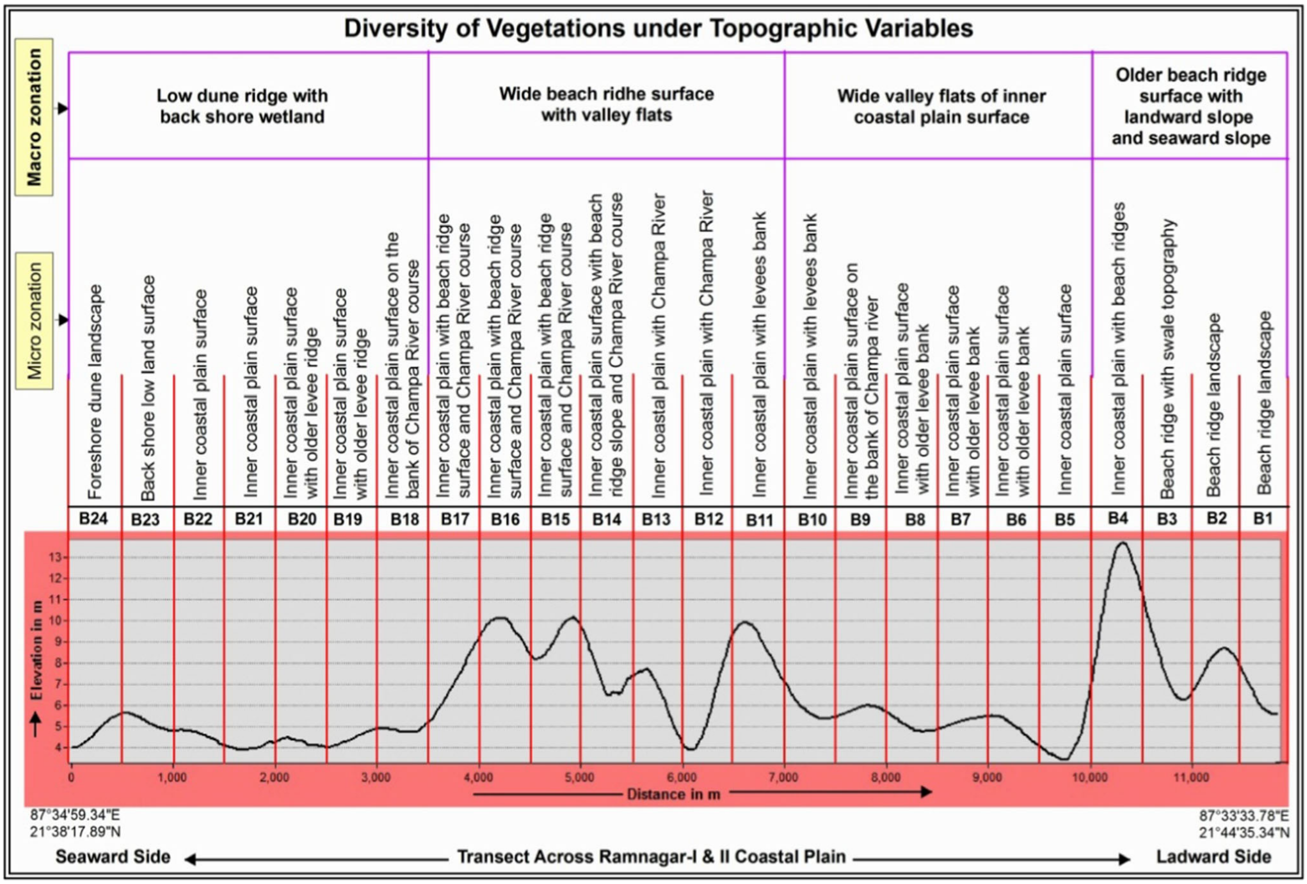

Fig. 11 Diversity of vegetation under topographic variables of 'B' transect

use practices. Now a day the wetland and marshy land are distorted into the industrial fish farming sectors and shrimp farming plots. In this context, the coastal dwellers should follow the scientific land use practice, and at the same time, they should also be aware of the advent risks produced by the unscientific land use pattern.

Conclusion

A systematic landscape ecological consideration and landscape pattern evolution investigation may provide a significant orientation for setting up an ecological risk early warning system, dropping an ecological risk prospect and endorsing a coastal landscape pattern optimization. The study reflects that there is a strong relationship between vegetation and the nature of coastal alluviums with marine and tidal influences. The backwaters, tidal flood plains and tidal channel/creeks are noted for the deposition of finer alluviums at the period of seasonal floodings and regular tidal floods in the coastal belt. Progressively, they become very significant sediment sinks, temporary flood reservoirs, physical buffer and important bio-shield against the advancing sea in the low-lying coastal tract. They have also very significant chemical function and biological functions in arresting pollutants, filtering water or moistures and ideal nursery grounds for fishes and resting ground for other animals (particularly avifauna). The present coastal belt is highly vulnerable to repeated cyclone attacks, occurrences of tidal waves, swell waves and significant shoreline recession activities. The above functions of the extensive wetlands can absorb the energy of advancing sea waves during storms. The coastal sand dunes and ancient beach ridges also act as the physical barriers and recharged rainwater reservoirs which can support the specific habitats for the coastal belt. Finally, these sensitive areas should be well preserved and should be promoted for the extension of

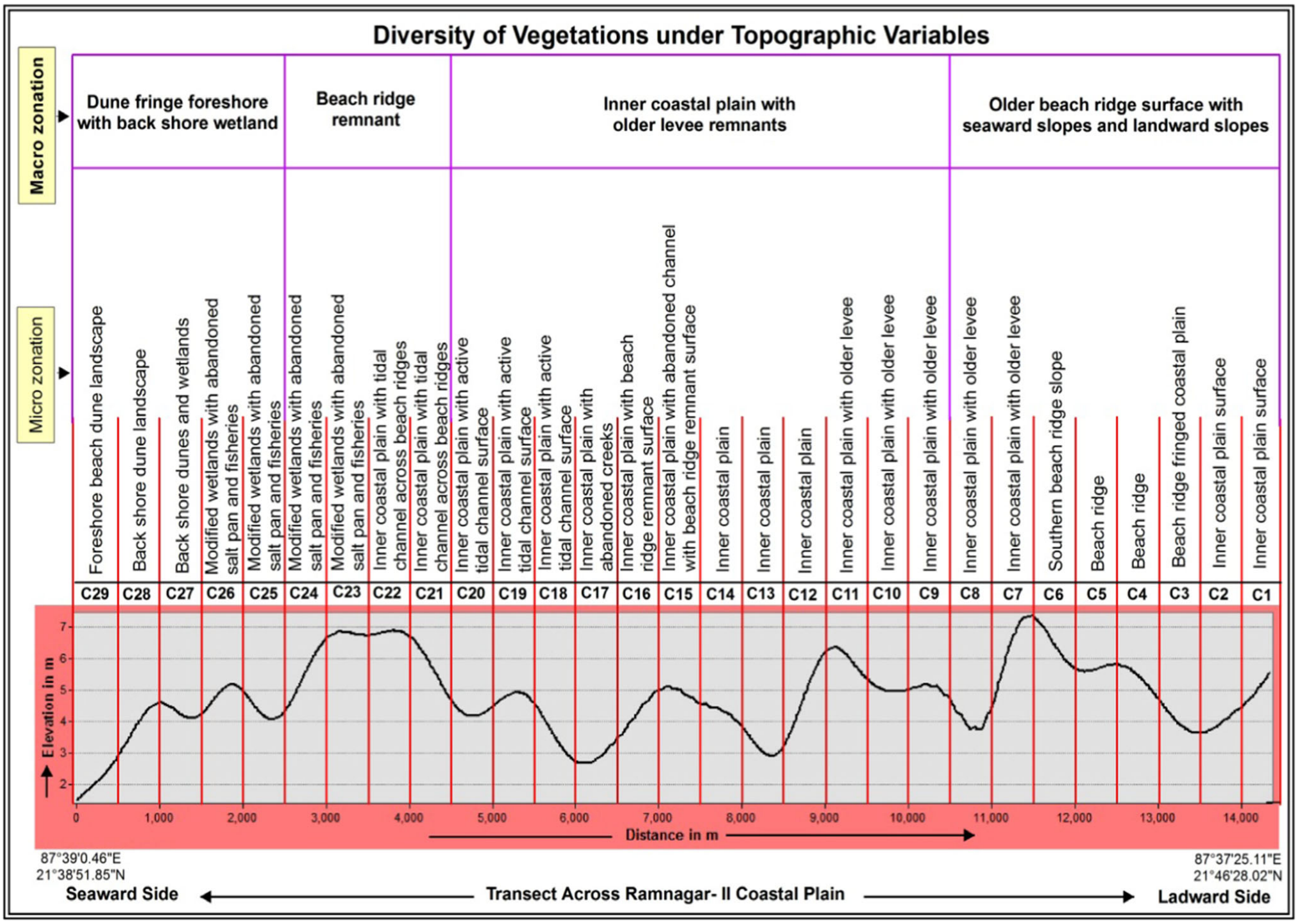

Fig. 12 Diversity of vegetation under topographic variables of 'C' transect

Table 4 Spatial distribution of vegetation diversity along the different landscape units

Grid no.	Landscape unit	Vegetation types
A 5	Beach ridge fringed coastal plain surface	32
A 6	Inner coastal plain surface	32
A 7	Inner coastal plain surface with narrow beach ridge segment	33
A 13	Beach ridge surface	31
A 15	Beach ridge separated by swale valley	40
A 16	Beach ridge surface	36
A 23	Inner coastal plain surface with beach ridge and modified wetland remnant	33
B 7	Inner coastal plain surface with older levee bank	36
B 8	Inner coastal plain surface with older levee bank	43
B 9	Inner coastal plain surface on the bank of Champa river	44
B 15	Inner coastal plain with beach ridge surface and Champa River course	35
C 3	Beach ridge fringed coastal plain	23
C 4	Beach ridge	22
C 16	Inner coastal plain with beach ridge remnant surface	19
C 17	Inner coastal plain with abandoned creeks	21
C 20	Inner coastal plain with active tidal channel surface	21
C 21	Inner coastal plain with tidal channel across beach ridges	21

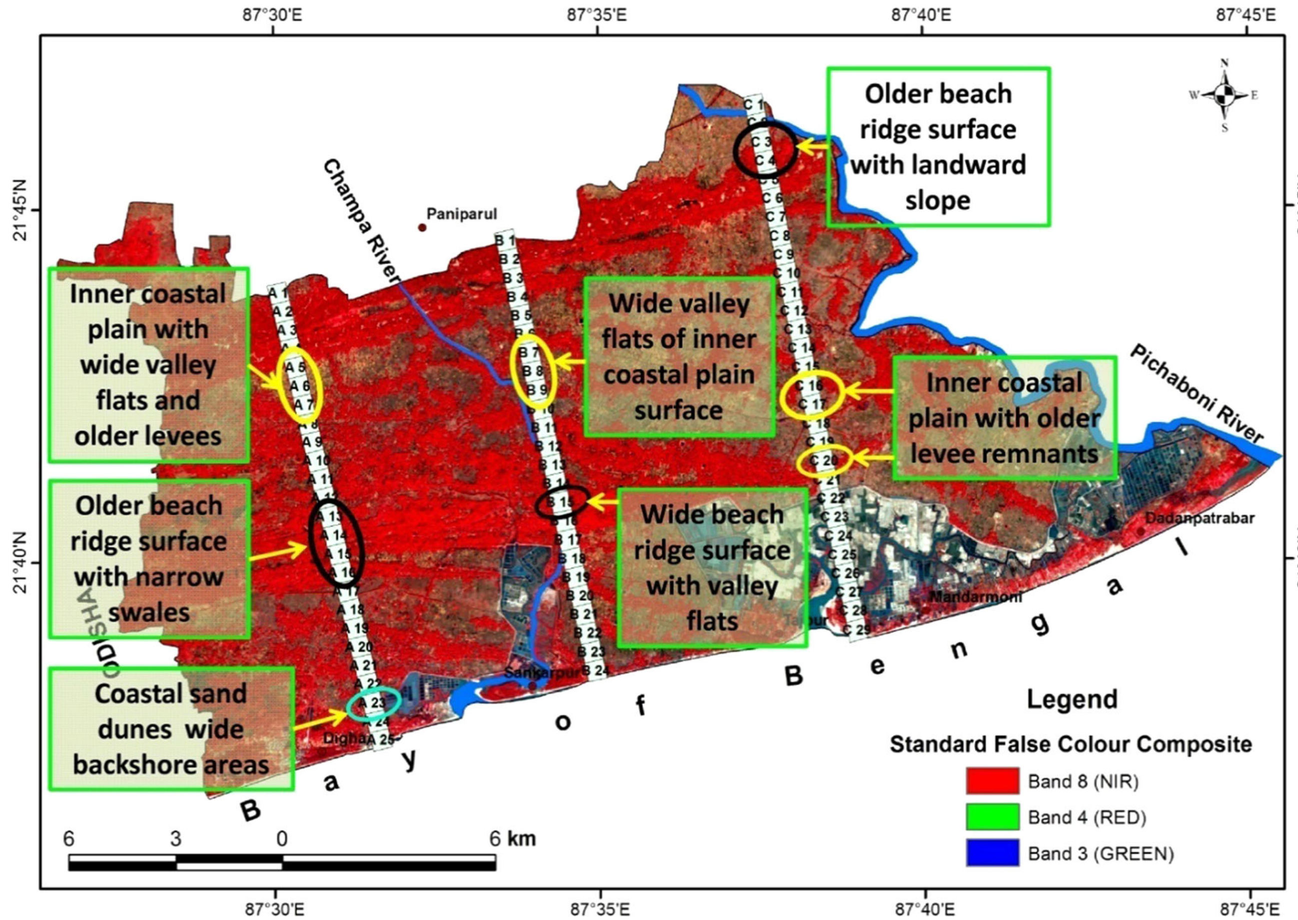

Fig. 13 Relationships of vegetation characteristics with diverse geomorphic features

Table 5 Calculation of areas in diverse morphological units and plant ecology

Sl.no.	Plant ecology	Areas of plant ecology (km^2)	Percentage of area (%)	Morphological units	Area of morphological units (km^2)	Percentage of area (%)
1	Large tree	37.86	12.86	Isolated dune ridge (15–18 m)	0.31	0.11
2	Small tree	49.48	16.81	Moderately high dune ridge (12–15 m)	4.61	1.57
3	Scrub land	41.55	14.11	Dune flat and dune terraces (9–12 m)	37.96	12.89
4	Heath land	4.23	1.44	Beach ridge and natural levees (6–9 m)	90.83	30.85
5	Grass land	13.12	4.46	Estuarine flood plain and Paleo tidal basin and interdune valley flat (3–6 m)	154.23	52.39
6	No plants	148.15	50.32	Modern tidal flood plain (0–3 m)	6.45	2.19
Total		294.39	100.00		294.39	100.00

Table 6 Percentage of area occupied by the plant ecology in different morphological units

Sl. no.	Morphological units	Occupied area of plant ecology (total area 146.24 km^2)				
		Grass land area in percentage (%)	Heath land area in percentage (%)	Scrub land area in percentage (%)	Small tree area in percentage (%)	Large tree area in percentage (%)
1	Isolated dune ridge (15–18 m)			0.03	0.04	0.14
2	Moderately high dune ridge (12–15 m)	0.13	0.07	0.19	1.01	1.75
3	Dune flat and dune terraces (09–12 m)	2.13	0.57	5.32	7.87	7.96
4	Beach ridge and natural levees (06–09 m)	2.02	1.07	16.99	20.46	10.73
5	Estuarine flood plain and Paleo tidal basin and interdune valley flat (03–06 m)	3.04	1.04	5.86	4.43	5.29
6	Modern tidal flood plain (00–03 m)	1.66	0.14	0.01	0.02	0
	Total area in percentage (%)	8.97	2.89	28.58	33.79	25.84

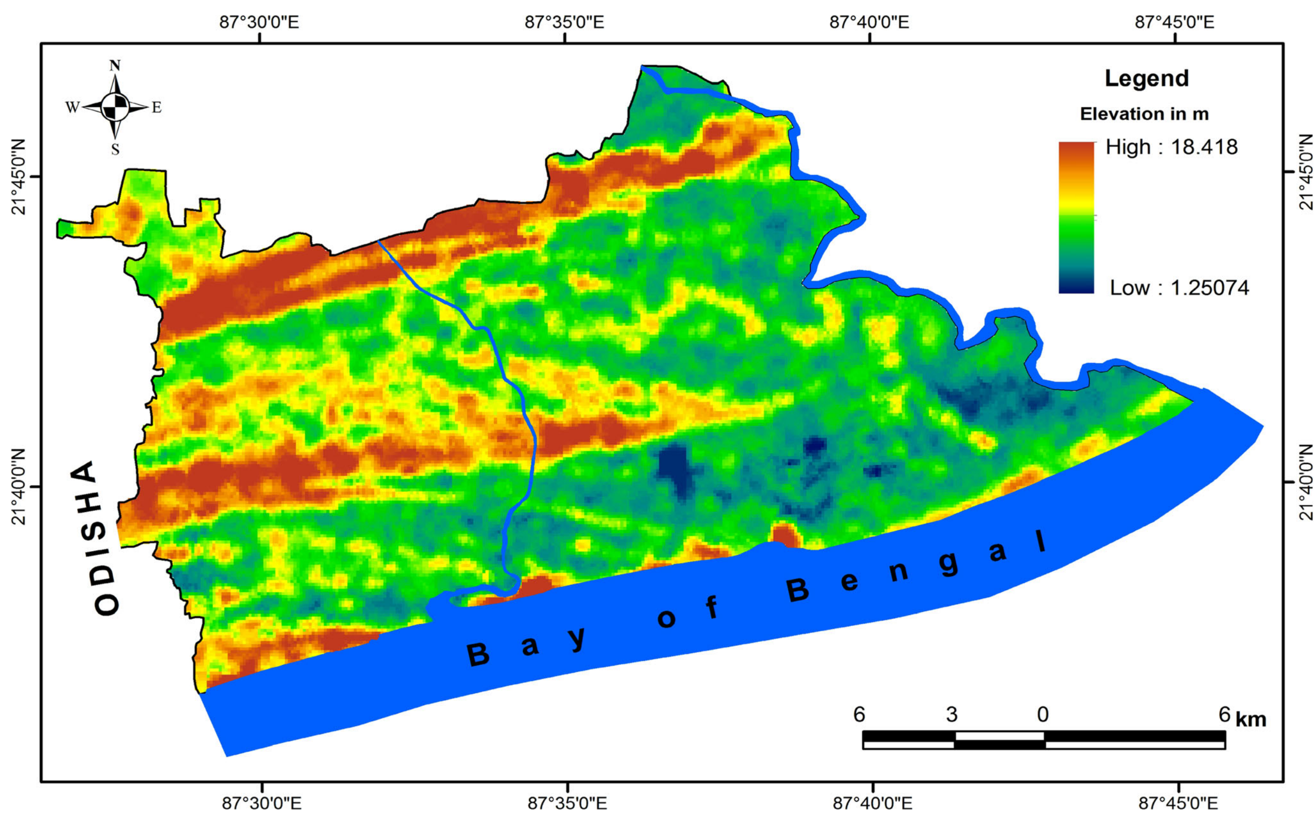

Fig. 14 Topographical variation of different plant ecology

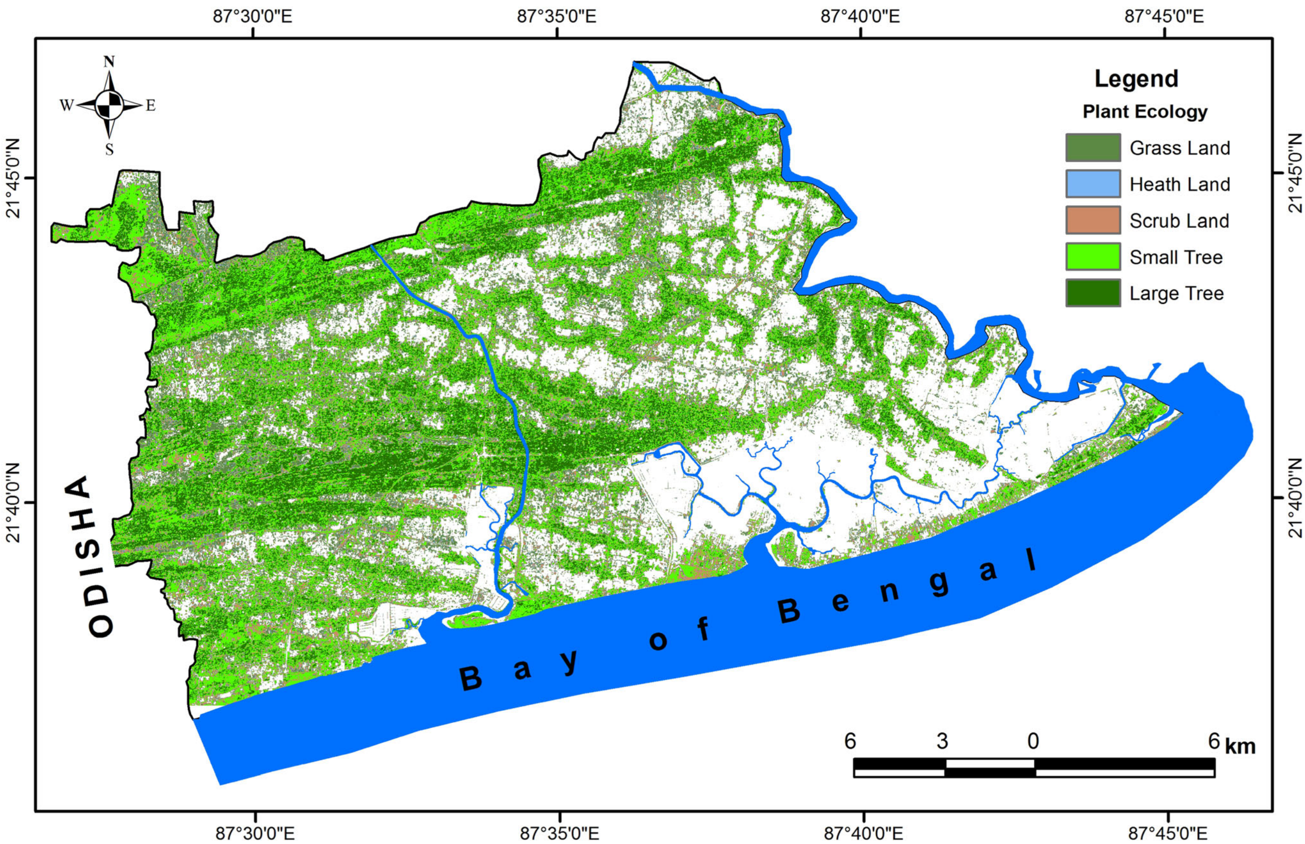

Fig. 15 Plant ecology diversity of the study area

their physical and ecological functions along with the dynamic shoreline behavior at present.

Declarations

Conflict of interest We confirm that this manuscript has not been published elsewhere and is not under consideration by other journals. All authors have approved the manuscript and agree with submission to the 'Journal of the Indian Society of Remote Sensing' Journal. We have read and have abided by the statement of ethical standards for manuscripts submitted to the 'Journal of the Indian Society of Remote Sensing.' The authors have no conflict of interest.

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