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Research Paper

Coastal landforms and land use analysis of southwest coast of Karnataka, India

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Abstract
The rapid growth of population settlement along the coastal areas around the world has placed significant stress on the coastal environment (both core and peripheral) which is very fragile and highly vulnerable due to human activities. The vulnerability of coastal environment is a result of the combination of several factors and sources. In order to keep the coastal areas to be useful for future generations, it is imperative to have immediate action plans for sustainable coastal development and its derivatives need to be encouraged and promoted. The present study is an attempt to understand the landforms and analysis of coastal land use pattern for the period from 2006 to 2016 using IRS time series datasets and GIS environment in the selected coastal areas of Dakshina Kannada and Udupi District. The study identified important coastal landforms along with nature and characteristics of such features. The study revealed significant development in the land use and land cover pattern.

Keywords: *Landforms, remote sensing, geomorphology, NDVI, west coast*

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I. INTRODUCTION

The Canara region of Karnataka comprises three coastal districts namely, Dakshina Kannada,Udupi and Uttar Kannada. Canara region lies between Konkan in the north and Malabar region in the south, while the Arabian Sea in the west and Western Ghats in the east. The length of this region from north to south is about 300km while the width varies from 30 to 110km. The regions are drained by many rivers and important among them are Nethravathi, Gurupura, Pavanje, Shambhavi, Udyavara,Sita, Swarna, Haladi, Chakra and Kollur, Aghanashini, Sharavathi,Gangavalli, Kalinadi and others bringing an enormous quantity of sediment to the Arabian Sea along the west coast.

Beach morphological changes in the region are controlled by the southwest monsoon. The maximum morphological changes occur during early monsoons (June-August). During this period most of the material is transported to the offshore and some alongshore. Most of the material appears to be returned during the fair-weather season. With pristine beaches, coastal cities, idyllic isles, historic monuments, myriad ancient temples, churches, mosques and Jain Basadis, the coastal Karnataka is enchanting. The present study is an attempt to understand the landforms and analysis of coastal land usepattern for the period from 2006 to 2016 using IRS time series datasets and GIS environment in the selected coastal areas of Dakshina Kannada and Udupi District.The study identified important coastal landforms along with nature and characteristics of such features. The study revealed significant development in the land use and land cover pattern.

GEOLOGY OF THE STUDY AREA

The coastal stretch and the adjacent Western Ghats are composed of precambrian (Archean) rocks and the Phanerozoic formations.The Nethravati and Gurupura river basin lies in the southwestern part of the Dharwar Craton which is the coastal stretch of the Western Dharwar Craton. Laterites cover extensive part along the coastal tract as well as foothills of Western Ghats, which occurs as plateaus and cappings over basement rocks. The laterites have been formed during the Tertiary period. Poorly developed Quaternary formations can be seen along the coast of Karnataka and they are represented by boulder-pebble beds deposited on the Paleo-river channels of Nethravati and Gurupur (Subrahmanya et al., 1991).

Beaches and its adjoining land area extending from Someshwar (12°47'10.35"N Latitude and 74°51'12.44"E Longitude) in the south to Maravanthe (13°42'17.59"N Latitude and 74°38'32.76" Longitude) in the north, covering about 110 km has been considered for this study. The study area spreads over two districts viz., Dakshina Kannada and Udupi. The main beaches covered under the study are Someshwar, Ullal, Tannirbavi, Bengre, Panamboor, and, Surathkal (Plate1) in Dakshina Kannada and Kaup, Malpe, St. Mary's Island and Maravanthe (Plate 1) in Udupi district.

II. METHODOLOGY

The study was carried out using remote sensing and GIS technology. The multi-dated satellite images of Indian Remote Sensing Satellites (IRS series) were obtained from National Remote Sensing Service Centre (NRSC) Hyderabad, India, for the years 2006 and 2016. Various thematic maps like geology, geomorphology, LU/LC, Aspect, Raster TIN (Triangulated Irregular Network), Slope, Hill shade, drainage and NDVI (Normalized Difference Vegetation Index) and shoreline change maps were generated based on remotely sensed data products and the derived thematic maps (spatial data) and the non-spatial data was integrated in a GIS environment to understand the coastal landforms, coastal dynamics, and coastal vulnerability in the area under study.

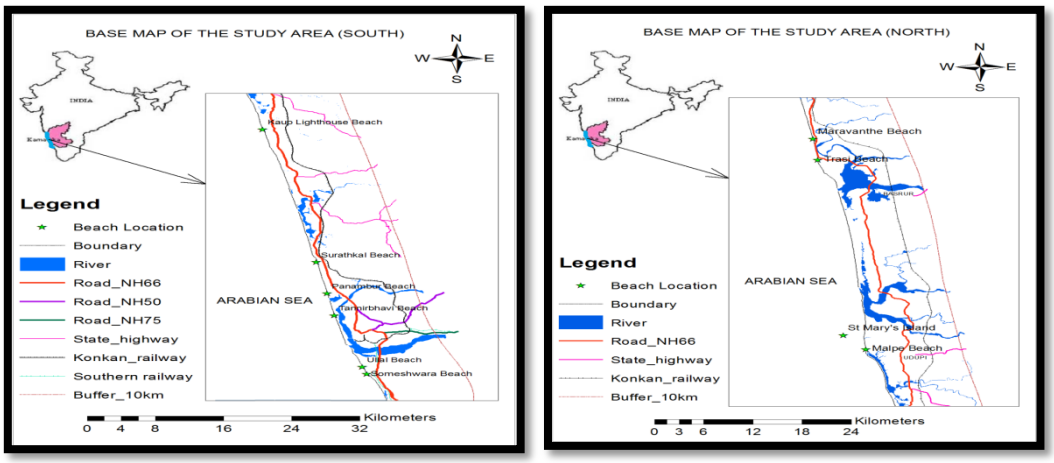

Plate 1 Base Map of the Study Area IPlate 2Base Map of the Study Area II

GEOMORPHOLOGY

The Indian Peninsular gneissic complex (granite, granitic gneiss and migmatitic gneisses) and Bababudan Group (quartzite, chloritic phyllite, metabasites and meta-greywacke) of rocks of Archean age are the dominant rock types in the study area (Radhakrishna and Vaidyanadhan 1994). Basic intrusive like dolerites and gabbros and acidic intrusive like pegmatite and quartz veins and pink porphyritic granites are also found.

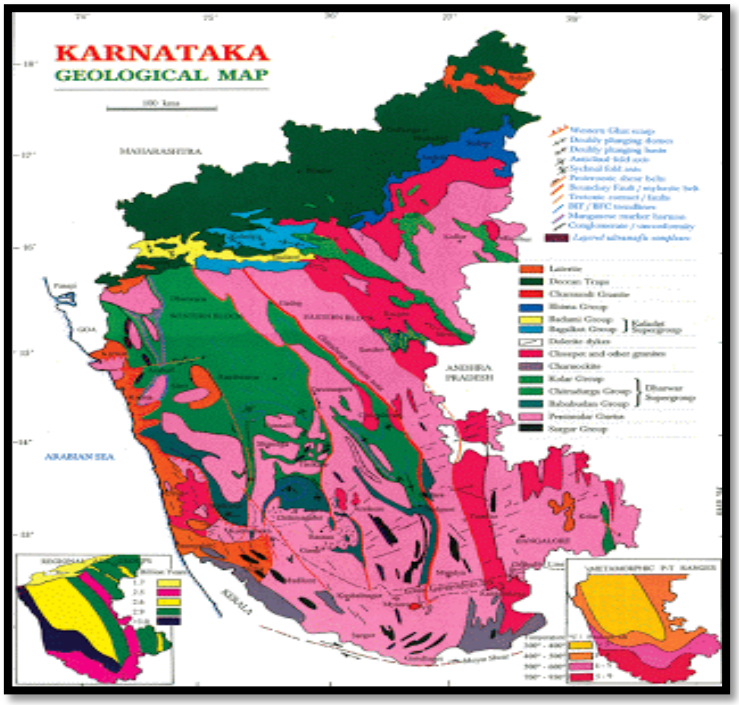

Plate 3 Geological map of Karnataka

Coastal sand is found parallel to the coastline and amphibolites along the river banks. The recent alluvium and colluvial deposits occur along the riverbanks and seacoast. The exposures of crystalline rocks are found as isolated hills along the shore and in the offshore. Black clayey marine sediments with a thickness of 0.30 to >1.00 m occur as lenses along the coast (Deepika et al., 2014) Lateritic-capped pediplains are an important physiographic feature of the study area.

The geological formation of Udupi district is almost like the remaining part for Karnataka, except for few laterites and coastal sedimentary deposits. Major portion of Udupi district is covered with gneisses and laterites. Ancient supracrustal of Sargur type and granulites are also found in some parts of the district.Proterozoic dykes are scattered all over the district. The lateritic plateaus, acid volcanics and alluvium along beaches and rivers are the important Phanerozoic formations found in the district. There has been a good number of systematic works on geology, geomorphology pertaining to different parts of Karnataka carried out by early researchers.

St.Mary's Island – a Geological Monument

The St. Mary's Islands is located 6 km NNW of the port of Malpe in Udupi district, Karnataka and about 670 km south of Mumbai coast is a national geological monument. This monumentone of its kind in India has great potential for developing geo-tourism. Geo-tourism is defined as tourism that sustains or enhances the distinctive geographical character of a place- its environment, heritage, aesthetics, culture, and well-being of its residents (www.national geographic.com). According to Subramanya (2009) basalt of the St. Mary's islands was formed by subaerial sub volcanic activity because at that time (about 88ma), Madagascar was attached to India and the rifting of Madagascar took place around 88 million years agoSubramanya (2009). The islands comprise fully of Ignatius rocks. They have acid composition that consist of dacites, rhyodacites, rhyollites and granophyres and carry basic patches(Subba Rao, 1993).

Geomorphologically Dakshina Kannada district can be divided broadly into three well-defined physiographic units viz. i) Coastal plain ii) Upland pediplain area and iii) Eastern hilly area forming part of the Western Ghats.

The Coastal plain (Plate 3) is a narrow, thickly populated and intensely cultivated area adjoining the coast. There is a considerable extent of barren land along the coast, partly because it is sandy, rocky, and marshy. The area near the sea is covered with coconut plantations. The coastal plain has varying width from less than a kilometre to as much as 10km in the south especially in the Mangalore sector. Their altitude is normally confined within 20 m above the present level; the maximum is about 60m around Mangalore town. The coastal plain is studded with a variety of landforms such as beaches, tidal creeks, lagoons, spits, sand dunes andoffshore islands. Their surfaces are mainly covered by coastal sediments and lateritic soil. There are a few clusters of tiny

islands off the West coast. Notable among them is St. Mary's group of Islands, 4 km off the coast near Malpe. The coastal plain towards west gives rise to Kanara pediplain which rises to the height of 100 m above MSL and merges with the well dissected mesa and butte landforms covered by laterite, and inselbergs of granitoids at an elevation of 100 to 300 m above MSL. This part is well drained and show dendritic pattern by the westerly flowing short course rivers that are active and creating headward erosion.

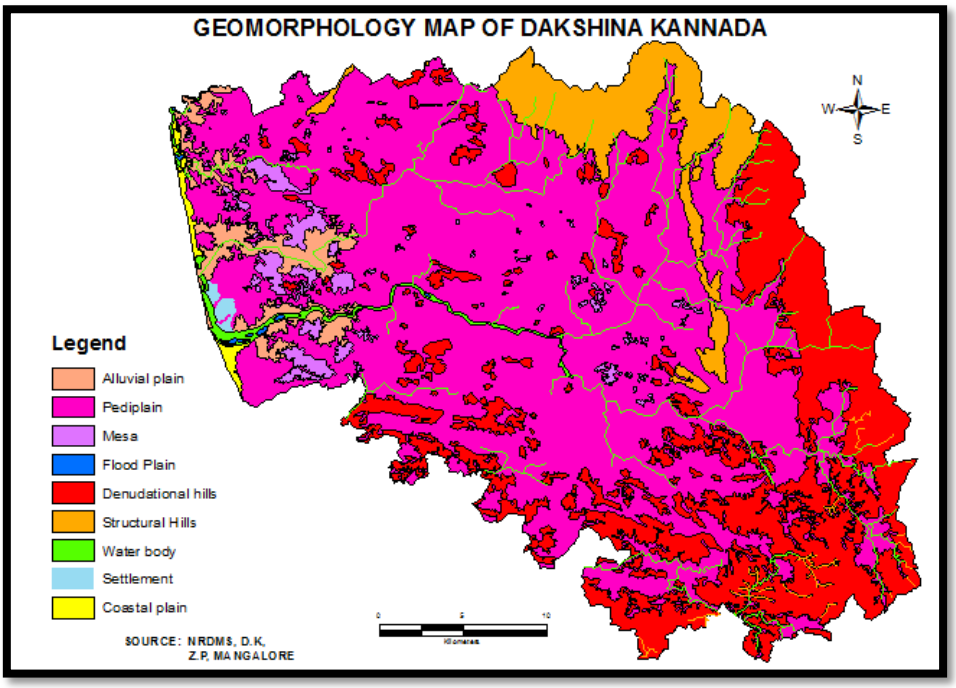

Plate 4 Geomorphology map of Dakshina Kannada, adopted from NRDMS Centre

The upland pediplain area is interspersed with low hills between the Western Ghats and the coast, which is moderately cultivated with a considerable extent of fallow land.The eastern part of the district is hilly with thick forest cover, which forms part of the Western Ghats. The hills of the area range in elevation from 1200 to 1500m above mean sea level and are capped with laterite and red soil. The hill ranges are dissected by numerous streams and rivulets (CGWB, 2012).

Geomorphology mainly comprises of morphology (appearance of the landforms) and morphometry (drainage network, form and slope analyses). For the coastal landform analyses Indian Remote Sensing satellite images and Google images have been used. The important coastal landforms identified along the coastal areas are Beach, Estuary, spits, shoals, tidal flats/mudflats, sand/beach ridges (elevated sand ridges), swales (depressions) and near shore islands. Geomorphometry related information like DEM. TIN, aspect, slope, and shaded relief have been derived from Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) data. The important landforms and the significant terrain aspects of the studied coastal areas are discussed below.

Coastal landforms

The important coastal landforms identified in the study area are: coastal plains, Beach, Estuary, spit, beach ridges/sand dunes, swales, tidal flats, mudflats, lagoons, shoals etc. A brief description of the coastal landforms is given below:

Coastal plains

According to Colquhoun (1968), coastal plains are the result of continuing erosional and accretional processes through time and are bounded landward by highlands and seaward by the continental slope. Coastal plain are the landforms which comprises of estuaries, flood plains, swamps, dunes, beaches,beach ridges, bars, tidal flats, and mudflats. Some of these feature form in transitional environment, where both marine and continental processes are operating.Coastal plain in the study area is wider in the central and northern portion and becomes narrower towards the southern ends and has an average width of about 8-10 km. It gradually elevates and coalesces with the pediplain to the east. At places, lateritic mesas are noticed on these plains. Most of the coastal plains in the study area lie between 20m contour/elevation (Plate5,6, &Plate7)

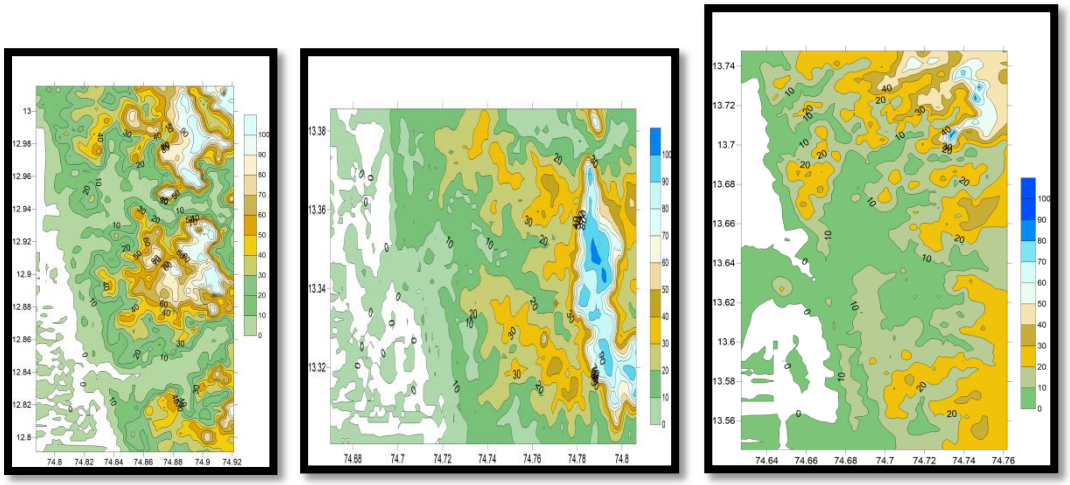

Plate5, Plate 6, & Plate7 :Contour maps of the coastal area generated based on ASTER data

Beach

Beach may be defined as an area with a gently sloping zone of unconsolidated sedimentsthat extends landward from the low - waterline to the place where there is a definite change in material or physiographic form. Beaches are formed by wave action. These are identified on the satellite images by their linearity and light tone. The important beaches falling in the study area are Someshwara, Ullal, Bengre, Tannirbavi, Panamboor, Surathkal, Kaup, Malpe, St. Mary's Islands, Trasi and Maravanthe. The satellite image indicated that beaches are found sandy except for Someshwara, Kaup and St. Mary's Island where the beach is rocky for a small stretch. St. Mary's Island is made of dacite and ryodacite columnar structures which are a unique experience for the visitors. Bengre, Panamboor, Kaup and Malpe beaches are wide whereas Someshwara, Ullal, Trasi and Maravanthe are narrow. It is noticed that the beach materials consist of coarse to fine sand, shell fragments, magnetite and sillimanite (Gangadhara Bhat et al2009) It is observed that beaches in the study region become narrow during monsoon months (June to September) and start expanding/accreting during post monsoon months (October to May). The beaches which are popular among the tourist in the study region are Someshwara, Tannirbavi, Panamboor, Kaup, Malpe, St. Mary's Island and Maravanthe.

Estuaries

The term estuary, derived from the Latin 'aestus' meaning tide, refers to a tongue of the sea reaching inland. A definition that is widely used describes an estuary as 'a semi-enclosed costal body of water having a free connection with the open sea and within which sea water is measurably diluted with freshwater derived from land drainage' (Cameron and Pritchard, 1963). In other words, estuary refers to the place where the riverand ocean water meet. Estuary is usually the lower part of the river course, where salt water mixes with fresh water. The important estuaries noticed in the study area are the Nethravati- Gurupurnear Mangalore, Pavanje - Shambhavi near Mulki, Udyavara near Udupi, Swarna-Sita near Hangakatta, and Chakra-Haladi-Kollur river estuarynear Gangolli. The modification of the river estuaries is noticed in the satellite images caused by sediment movement and distribution. The enormous sediments brought by the Nethravathi – Gurupur river network resulted in the development of shoals. The increased siltation in the river mouth caused navigational problems in Nethravati-Gurupura, Udyavara and Gangolli estuaries. The Breakwater is constructed at Nethravati-Gurupur estuary and at Udyavara river estuary to avoid the siltation in the navigational channels.

Spit

A spit is defined as "a small point or low tongue of narrow embankment of land commonly consisting of sand or gravel deposited by longshore drift and having one end attached to the mainland and the other terminating in open water, usually the sea, a finger like extension of the beach"(Campbell, 1972; Evans 1942).There are spits noticed at Nethravati-Gurupur estuary(northern spit is called Bengre and southern spit is called Ullal); Pavanje-Shambhavi estuary (northern spit is Hejamady and southern spit is Sasihitlu); Udyavaraspit(northern spit is Malpe and southern spit is Udyavara); Swarna-Sita estuary (northern spit is Kodi Bengre and southern spit isOdduBengre); Gangolli estuary seen in Plate 4.50 (northern spit is Gangolli and southern spit is Kundapura).

Beach ridges / Sand dunes and swale

Beach ridges are identified based on their linear feature and light tone. The beach ridges indicate the position of the sea in the past. The study identified number of beach ridges alternating with swales are found between Malpe and Kundapura area. These ridges are of varying width which ranges from 150 to 200m. At places the beach ridges are found to be stabilised with good vegetation cover as indicated with bright red colouron False Colour Composite (FCC). The presence of stabilised ridge and swale topography in the northern part of the study area (between Malpe and Kundapur) has potential for coastal tourism development. Stabilized sand dunes are noticed along the Kundapur coast near Bijadi, Tekkatte and Kota.

Tidal flats

The term 'tidal flat' is very broad and covers a range of generally muddy low-gradient intertidal or supratidal surfaces. Intertidal flats are sandy to muddy flats emerging during low tide and submerging during highest tides. While the supratidal flats are near-horizontal flats that occur beyond the regular reach of the tides and are rarely inundated except under extreme storm-surge conditions. Tidal flats are noticed in and around Netravathi-Gurupura estuary, Mulki-Pavanjeestuary,Udyavara estuary, Sita -Swarna estuary and Gangolli estuary.These landforms are covered with thin vegetation at places. One of the features of the tidal flats is that, during the high tide, the features will be submerged and the same are exposed during low tide.

Lagoons

Coastal lagoons are water bodies impounded by a sand barrier, they represent an extreme form of barrier estuary (Cooper, 1994; Isla, 1995). Water bodies /Coastal lagoons are transitional zones between land and sea. Lagoons are the shallow inland water bodies, separated from the ocean by a barrier, connected to the ocean by one or more restricted inlets which remain open at least intermittently (Kjerfve and Magill, 1989). Coastal lagoons are modified by erosion and deposition. Talapady, Padubidri, Pithrody and Hangaluru are the main lagoons seen in the study region. The lagoons are affected by floods and wind-waves which influence the circulation and sediment movement in large lagoons. The lagoons are also susceptible to changes in the rate of sediment supply as a result of human factors such as land use change in the catchment area.

Shoals

Ashoal is a natural submerged ridge, bank, or bar that consists of, or is covered by, sand or other unconsolidated material, and rises from the bed of a body of water to near the surface. Often it refers to those submerged ridges, banks, or bars that rise near enough to the surface of a body of water as to constitute a danger to navigation. Shoals are also known as sandbanks, sandbars, or gravelbars. Two or more shoals that are either separated by shared troughs or interconnected by past and or present sedimentary and hydrographic processes are referred to as a shoal complex. (Rutecki et al, 2014; Duane, 1980). Shoals are found near the estuaries and along the coast in the study area

INTERPRETATION OF THE SATELLITE IMAGES

The Indian Remote Sensing satellite images (LISS-III, LISS-IV and PAN)have been interpreted/analysed through visual and digital image analysis techniques. In the visual image interpretation techniques various recognition elements like tone, texture, colour, shape, pattern, and associated features criteria have been used to delineate various geological, geomorphologic and land use/and cover classes. In the digital image analysis techniques, the satellite data has been analysed using ERDAS Imagine software. Various enhancement techniques like contrast stretching, False Colour Composite (FCC) generation, Filtering techniques, Principal Component Analysis (PCA), Intensity Hue Saturation (IHS), transformation, band rationing, convolution, Normalised Vegetation Index (NDVI) etc., have been applied on the digital data. The extracted information has been utilised in the generation/updating of various thematic maps. Enhanced images have helped in delineating various coastal geomorphological, geological, LULC categories in a better way.

To analyse the geomorphometry of the study area, Digital Elevation Models (DEMs) are used in the present study. DEM derived geographic surfaces are generally used for studying various geomorphological features like slope, aspect, shaded topographic relief or hill shading, flow directions, basins and other features. The DEM derived output is found useful in depicting geological information.

Slope

Slope mapswere generated for Mangalore,Malpe andKundapura sectors. The map displayed the grade of steepness expressed in degrees for the study areas. The degree of the steepness for Mangalore area is in the range between 0 -1.293 in the lower regions to 21.4082-36.6383 in the upper regions. The degree of steepness for the Malpe area are in the range between 0-1.0975(lowest) to 19.0705 - 34.9855(highest) while the degree of steepness in the Kundapura area varies between 0-0982 (lowest) to 16.4547-31.3132(highest). From this it is

observed that the degree of steepness is highest in Mangalore area compared to Malpe and Kundapura area. The slope also revealed the structural lineaments, fault scarps, fluvial terrace scarps in the study area. The degree of steepness or flatness of a coastal region determines the susceptibility of the coast to inundation by flooding (Thieler, 2000). Coastal areas having gentle slope were considered as highly vulnerable areas and areas of steep slope as areas of low vulnerability.

Aspect

DEM derived aspect map identifies the down-slope direction besides enhancing the landforms such as fluvial networks, alluvial fans, faceted fault related scarps, etc. Various aspect categories are symbolised using the hues. (red, orange, yellow, etc) Aspect maps were generated for Mangalore, Malpe and Kundapura sectors.

Hill shade

The shaded topographic relief or hill-shading image depicts relief by simulating the effect of the sun's illumination on the terrain. The direction and the altitude of the illumination can be changed in order to emphasize faults, lineaments, etc. Shaded relief maps were generated for entire study area using DEM. This has helped in understanding the correlation between geology and topography in the study area. The Hill shade value for Mangalore coast varies between 97-161 (lowest range) to 193-235 (highest range). The value for Maple coast lies between 112-165 (lowest range) to 190-226 (highest range) while for Kundapura coast hill shade value is between 109-167 (lowest range) to 191-230 (highest range).

Flow direction

Flow direction map shows the direction of flow by finding the direction of the steepest descent or maximum drop. The DEM derived 3D maps of the surface depicted the drainage network as well as flow directions of the drainage networks in Mangalore,Malpe andKundapur areas.

Basin

The basinmap function uses a grid of flow direction (output of flow direction) to determine the contributing area.

In a GIS environment, a DEM is commonly modeled and visualized using two main data structures. They are:

1. Rectangular grid or elevation matrix (GRID) and
2. Triangulated Irregular Network (TIN).

The GRID DEM is typically stored as a raster map (or image), where each pixel carries the information on elevation or terrain parameter. The TIN DEM is based on the triangular elements with their vertices at the sample points and the advantage of TIN DEM compared to the GRID DEM is that it can incorporate structural features such as peaks, slope breaks and conic pits, and by some is considered a more accurate structure for terrain parameterisation especially when contour data is used (http://www.geol-amu.org/notes/rs12-4-1.html). Although the gridded DEM-data model is non-adaptive and commonly over-samples in low-relief areas and under samples in high-relief areas, it is somewhat more attractive than the TIN DEM due to its simple data structure and high possibilities of GIS operations. (http://www.geol-amu.org/notes/rs12-4-1.html).

LULC Analysis

The LULC study in the three sectors of the study area is combined to understand the overall LULC in the entire study area. Table 1provides the statistical distribution of LULC classes.

In a nutshell out of 480.88 km^2 of total geographical area covered in this study, the LULC change and the distribution pattern for the year 2016 shows that the urban / built-up class which includes residential, commercial, industrial, and mixed urban land increased considerably from 164.58 km^2 (34.22%) in 2006 to 254.88 km^2 (53%) in 2016. This means that about 90.3 km^2 of additional land was converted into built-up land in the last ten years creating additional pressure on the natural environment. Similarly, the agriculture land formerly occupied an area of 229.75 km^2 in 2006 dropped to mere 107.67 km^2 in 2016. The mixed forestcover during the study period show significant growth from 7.23% in 2006 to 13.24% in 2016 is a good indication of aforestation in selected coastal areas especially in Mangalore sector. There is a small positive change in water bodies and forested wetlands whereas non-forested wetland and barren land area declined during the study period.

LU/LC in Mangalore, Malpe and Kundapura Sector for the Year 2006 & 2016

Level 1	Level 2	Area in km^2 2006	% of TGA	Area in Km^2 2016	% of TGA	Change in Area Km^2
1 Urban / Built-up Land	11 Residential	0.43	0.09	1.22	0.25	0.79
	12 Commercial & Services	0.67	0.14	2.50	0.52	1.83
	13 Industrial	14.67	3.05	32.52	6.76	17.85
	16 Mixed Urban or Built-up	148.81	30.95	218.64	45.47	69.83

	Land					
2 Agricultural Land	21 Cropland	88.06	18.31	37.11	7.72	-50.95
	21a Fallow Land	66.85	13.80	41.47	8.62	-24.88
	24 Other Agricultural Land	74.84	15.56	29.09	6.05	-45.75
4 Forest Land	43 Mixed Forest Land	34.77	7.23	63.67	13.24	28.90
5 Water	51 Water Bodies	42.72	8.88	44.45	9.24	1.73
6 Wetland	61 Forested Wetland	4.22	0.88	6.58	1.37	2.36
	62 Non- Forested Wetland	1.87	0.39	1.40	0.29	-0.47
7 Barren Land	74 Bare Exposed Rock	0.16	0.03	0.14	0.03	-0.02
	77 Mixed Barren Land	3.31	0.69	2.09	0.43	-1.22
	Total	**480.88**	**100**	**480.88**	**100**	

III. CONCLUSION

The ten-year period under study analysed the geology and geomorphological features in the selected coastal areas in the southwest coast of Karnataka. The coastal landforms and processes are dynamic in nature and the study identified major landforms, coastline changes and the LULC change detection. The study revealed significant changes in the land use pattern particularly in the category of urban/built-up land and agricultural land. The increased pressure on coastal resources indicated the vulnerability and risk to the environment and the society in the coastal areas. Therefore, the coastal management authority should take adequate measures to prevent/mitigate the damage to life and property due to possible occurrences of any natural disasters in the future.

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