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Geomorphic Regionalization of Coastal Zone Using Geospatial Technology

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Abstract

The world coastal environment is made of diversified landforms and are also potentially vulnerable to climate variability, delta sinking, extreme events and anthropogenic interferences. Sustainable management of coastal resources and transforming quality ecosystem services to future generation are the goals of Integrated Coastal Zone Management (ICZM). Geographical homogenous unit are the basic implementation locus and back bone of these kinds of integrated management strategy and activities. However, coastal zone management projects in developing world using use arbitrary land-ward and sea-ward boundaries from physical reference as unit of management. The oversimplified fixed distance approaches are not able to map the spatial and temporal changes in coastal systems. The spatio-temporal variations of coastal systems are configured in geomorphic landforms and further that work on interaction between natural forces and anthropogenic inputs. The present research work is an attempt to present a simplified method of regionalization geomorphic landforms using geospatial platforms for delineating Orissa coast into smaller homogenous geographic unit as reference point for future management. Geomorphic landforms are reconstructed using Enhanced Thematic Mapper Plus (ETM+) imagery, Survey of India topomaps, field survey and Digital Elevation Model data at geographic information system (GIS) plat form. Seventy geomorphic features covering an area of 5033.64 km2 were identified and further, regionalized into five homogenous geographic units. The need of time is to recognize unsustainable coastal systems in these homogenous geographic units by fine tuning development parameters and also same time allowing coastal systems to adapt naturally to any kind of variability. Although, the methodology applied to Orissa for delineation homogenous geographic area but it can be replicated to any coast in world.

Keywords: Coastal landforms, Geospatial technique, Geomorphic regionalization, Homogenous geographic units & Integrated coastal zone management

Introduction

The coastal landscapes of the world are under tremendous stresses from climate change, environmental change, sea level changes, population growth and developmental pressure. These coastal stretch are approximately home of 60 % of the population and also considered a symbol of human develop and inequality (UNEP, 2007; Yu et al., 2010 & Magarotto, et al., 2014). The fragile coastal natural systems are also highly dynamic in terms of diverse ecosystems, complex geomorphic configuration and a place for intensive anthropogenic activities. Again, the collision between self-regulated natural forces and constructed world aggravate the sensitive coastal ecosystem to high risk zone with characteristic spatial heterogeneity, variability and uncertainty (Kumar, et al., 2010 & Lin et al., 2013). Thus managing the coastal zone under Integrated Coastal Zone Management emphasized the role of spatial information, coherent relational data base management system for effective sustainable regional development of the area (Ya´n˜ ez-Arancibia & Day, 2004; Fresca, 2007). Majority coastal managers and decision makers in developing countries are using this term ‘coastal zone management’ as variety of development programmes and mostly land use plans with administrative boundary as the unit of delineation (OECD, 1992; CCD, 1997 & CRZ, 2011). However, integrated vision of coastal zone is possible only by defining a clear picture of spatial homogenous unit and also managed on their specific characteristics and needs. The correct way to delineate these geographical homogenous units is to map the relational space between conflicting natural forces and cultural landscapes. Thus, regionalization of geomorphic landforms is appropriate method for identifying these homogenous units and also representation of processes answering the complex problems (Dramisa et al., 2011; Vannametee et al., 2012 & Embabi & Moaward, 2014). Geomorphological mapping involves categorizing the transitional space into conceptual spatial units/entities based upon morphology (form), genetics (process), composition and structure, chronology, environmental system associations (land cover, soils, ecology), as well as spatial topological relationships of surface features (landforms) (Bishop, et al., 2012 & Embabi, 2014). Natural regionalization of coastal geomorphic landforms into geographical unit can be backbone for future management strategy in developing countries like India.

Recent advancement in geospatial technology, numerical modeling and geocomputational algorithms have revolutionized the field of geomorphology and allowed geoscientists to go beyond traditional mapping (Bishop et al., 2012). The availability open source Landsat Imagery and GIS software have allowed new insight of rapid mapping of landforms in developing countries that would otherwise uneconomic and time consuming processes. Advances in spatial and temporal resolution in satellite imagery have helped to produced spatio-temporal geomorphic mapping at different scale used by coastal managers around the world (Silva et al., 2007; Costa et al., 2008; Henriques & Tenedorio, 2009 & James et al., 2012). Majority of the coastal landforms are delineated by onscreen digitization manually or digital image processing by superimposing DEM or google earth (Evans, 2012; Seijmonsbergen, 2012). However, semi-automated extraction methods are used now days for geomorphological mapping (Qin et al., 2009; Moawad and Khidr, 2011; Seijmonsbergen et al., 2011; Bishop et al., 2012; Evans, 2012; Seijmonsbergen, 2012; Wilson, 2012). Thus, modern digital geomorphological map consists layers of spatial and non-spatial data base stored in GIS platform which can be used for visualization, analysis and thematic mapping.

With above background, this paper tries to develop new method of delineating coastal zone into smaller geographical unit that can provide possible answer in managing theses vulnerable ecosystems in a sustainable way. This study introduces a methodology of geomorphic regionalization i.e. classification of coastal zone into homogenous geographical unit based on geospatial technology. The study area chosen is the most unexplored coast of Orissa, India. The spatial homogenous units should be further integrated with stronger conservation plans and will be tool of Integrated Coastal Zone Management (ICZM) of the state for achieve sustainable regional development.

Study Area

The chosen coastline for the study, Orissa is located on the eastern coast of India and has a coastline of 480 km with co-ordinates of 17° 48'N, 81°24´E to 22°34´N, 87°29´E including immense natural resources (Fig. 1).

The coastal plain belong to post-Tertiary period are combination of several deltas of varied size and shapes (Sinha, 1971). Further, it is bulged out in middle portion from Brahamagiri in Chilika lake (SW) to Chandabali (NNE) making convexity of the coast by three major river Brahmani, Baitarni and Mahandi showing recent delta formation. Again, the coastline is dotted with bay bars, spit, hook made by offshore long currents and estuaries in mouth of major rivers. The study area attracts international tourists and pilgrimage because it is having a world heritage site. It is gifted with Asia’s largest natural brackish water lagoon (Chilika) and world’s largest known nesting beach of Olive Ridley sea turtles (Gahirmatha and Rusikulaya). The coast is impregnated with one natural harbor Paradeep and number of minor ports.

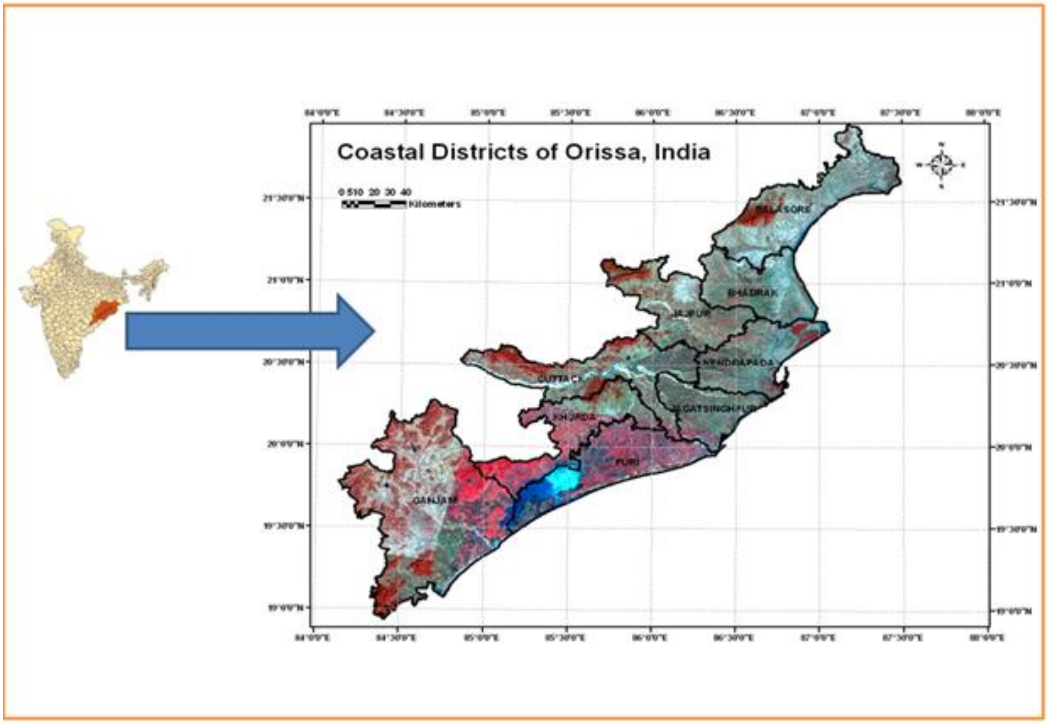

Figure 1: Location of study area with administrative division of coastal Orissa

The study area having a tropical climate and summer temperature ranges between 35°- 45°C and seasonal low of 12°- 14°C. The monsoon cyclones are directly responsible for high annual rainfall measured above 140 cm. These areas are also vulnerable to multiple disasters like cyclonic storms, storm surge, high tide, floods, delta sinking and sea level changes. The threats to these kinds of extreme events have increased many folds due to high population growth and unplanned investments. Super cyclone 1999 has caused massive damage and destruction of life and property in Jagatsighpur district. Loss of land to shoreline changes are a common phenomenon in the study area. Witnessing these changes in last two decades, Government of Orissa started Integrated Coastal Zone Management project sponsored by World Bank to deal with these kind of crisis. The present study is an attempt to naturally regionalize coastal landforms in to smaller geographical unit, which can facilitate the district administration for developing stronger conservation plan for future policy making processes.

Materials and Methods

Advance geospatial platforms are ideal tools not only for delineating coastal landforms but also scan spatial and temporal variability processes. The following data bases were used for identification of geomorphic landforms and also natural delineation of coastal geomorphic landforms.

Survey of India OSM sheets having scale of 1:50,000 were scanned at 500 dpi using HP Scan Jet 3300 C scanner and saved in Tagg Image File Format (TIFF) before geo-referencing. The ETM image and scanned survey of India OSM sheets were rectified using 300 – 400 ground control points taken from field survey using Pro-XT DGPS. The pixel coordinates of ETM images and OSM sheets were substituted with GCP using affine transformation representing the real world with overall RMSE of less than 1 meter. All the geo-referenced images were projected to UTM system, WGS-84 and Zone 45 North and clipped, stacked to match the boundary of entire area. On screen image interpretation techniques were used for mapping coastal land forms in the study area. Additionally, false colour composite visual interpretation, principal component analysis and image enhancement techniques were applied to highlight the coastal geomorphic feature (Mishra & Sharma, 2009; Kumar et al., 2010; Kaliraj and Chandraseka, 2012 & Mishra, 2013,). False colour composite were used for better visual representation of micro features in the study area. A standard FCC choose three original bands in red, green and blue as RGB. However, it was found that 73 % of image variance in FCC but 97 % variations was found in PCA than original images. Therefore, algorithms of PCA were correlated with two multispectral bands for identifying potential geomorphic landforms information. Further, first three PC images (PC 1, 2, 3) contains 98 % of variations of originals six ETM bands representing significant compression of the data. The other bands showed only 2 % of original variations. The first principal component contains maximum information combined with PC2 image because it shows better interpretation value. ETM images were enhanced to visualize image detection and also improve the geometric details of the study area. Linear edge enhancement techniques were applied to delineate geomorphic landforms edge, shape by using brightness of pixels of two adjacent features. Images were interpreted using digital image process and landforms were classified and extracted.

Table 1. Source of databases used for analysis for study

Name of Data	**Year of Publication**	**Scale/Resolution**	**Source**
Landsat 8 (ETM+)	2010	30 m (WRS – 2, Path – 139, Row – 46)	http://earthexplorer.usgs.gov/
Open Series Maps (OSM)	2010	1: 50,000	Survey of India
SRTM	2010	90 m	http://earthexplorer.usgs.gov/
Geological map	1997	1:125,000	Geological Survey of India
Google Earth	2010	8 m	https://www.google.com/earth/
Field survey using Trimble Pro- XT DGPS	2010	>1m	Field Survey

Three dimensional or terrain data are one of the best data for geo-analysis of landforms. Shuttle Radar Topography Mission (SRTM) data with 90 m and resample to 1km were used to create digital elevation model. DGPS ground truth data and SRTM fill free software were used for patching null data hole and progressive infilling of surrounding data. The relief and dissection pattern of landforms were analyzed using DEM and Survey of India OSM sheets. Hillshading with different azimuths and sun elevation angle were used for mapping structural changes in the study area. Further, geomorphic landforms generated were over laid with DEM using ESRI 3D Analyst to map and classify the cliff area. Ancillary data like GIS map, existing geomorphological map, google earth were used for analysis and updating geo-information. A classification scheme and legends were used (Table 3) for balancing the specificity of geomorphic features for reasonable accuracy and also translated to cater needs of wide range of user community. A detail methodology flow chart is given below in Fig. 2.

Coastal managers, policy and decision makers require a high quality map for delineation of coastal zone management units and conservation purpose. Quality checks were carried at every stage of interpretations like preliminary interpretation checks, on screen digitization checks, validation checks using DGPS and estimation of classification and control accuracy. As coastal geomorphic mapping are quite detail and exhaustive in nature, there is high probability of typology errors while digitizing different themes. Therefore, classification accuracy tests were conducted on sample basis using binomial distribution for checking the success and failure of control points. Sample size and segmentations were chosen using look up table and presence of predominant class on each segment respectively (Arnoff, 1982, Nayak, 1991 & Theenadhayalan, 2012). These segments were validated using a Performa by help of Pro-XT DGPS and also Survey of India OSM sheets. Finally, accuracy of the map was calculated using confusion matrix drawn from the Performa. Control accuracy was calculated using four control points to improve the geometric quality of the maps.

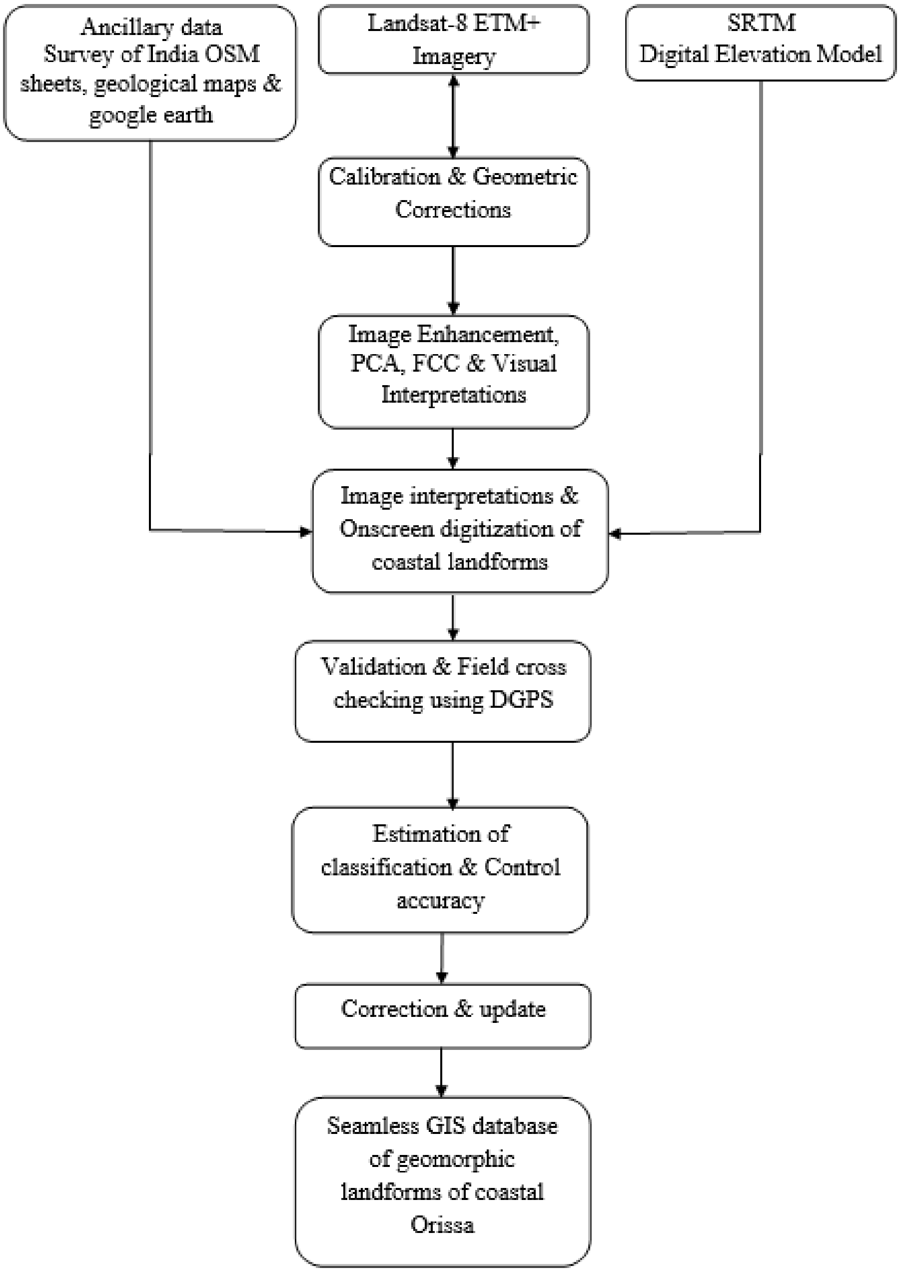

Figure 2: Methodology framework used coastal geomorphic mapping in the study area

Results

The study areas were classified using Jenks methods for each and every pixels of the study area to define the homogenous geomorphic units. The basis of classification were derived using ordinal scale, where the minimum value (1) highlighting the highest relevance from sensitive point of view and maximum value (5) indicate the lowest relevance. Table 1 shows the thematic classification of coastal landforms indicating the relevance of spatial-temporal contribution of different units in regionalization of coastal management processes in the study area.

Table 2: Geomorphic Regionalization of coastal landforms

Spatial Units	**Geomorphic Code**	**Landforms**
Homogenous Geographic Unit - 1	90200	Young Coastal Plain
	90201	Beach Ridge (YCP)
	90202	Beach Ridge Complex (YCP)
	90203	Swale (YCP)
	90204	Young Mud Flats (YCP)
	90205	Brackish water Creeks(YCP)
	90108	Coastal Sand Sheet
	90210	Beach Young Coastal Plain
	90211	Spit(YCP)
	90212	Offshore Island (YCP)
	90216	Channel Island Bar
	90217	Island
Homogenous Geographic Unit - 2	90100	Old Coastal Plain
	90101	Paleo Beach Ridge(OCP)
	90102	Paleo Beach Ridge Complex(OCP)
	90103	Swale (OCP)
	90104	Older Mudflats(OCP)
Homogenous Geographic Unit - 3	80100	Deltaic Plain(UP)
	80101	Abandoned Channel (UDP)
	80102	Buried Channel(UDP)
	80105	Point Bar(UDP)
	80106	Channel Bar(UDP)
	80107	Natural Levee(UDP)
	80108	Back Swamp(UDP)
	80109	Flood Basin(UDP)
	80200	Deltaic Plain(LW)
	80201	Abandoned Channel(LDP)
	80202	Buried Channel(LDP)
	80204	Cut-Off Meander(LDP)
	80205	Point Bar(LDP)

	80206	Channel Bar(LDP)
	80207	Natural Bar(LDP)
	80208	Back Swamp(LDP)
	60000	Alluvial Plain
	60100	Alluvial Plain (Old Upper)
	60103	Oxbow Alluvial Plain (Older)
	60104	Abandoned Channel (All Old)
	60200	Alluvial Plain (Young Low)
	60201	Buried Channel(Young Low)
	60202	Migrated River Course(Young Low)
	60204	Abandoned Channel (Young Low)
	60207	Meander Scar (Young Low)
	70100	Flood Plain
	70101	Buried Channel(FLP)
	70103	Cut-Off Meander(FLP)
	70104	Point Bar(FLP)
	70105	Channel Bar(FLP)
	70106	Natural Levee(FLP)
	70107	Back Swamp(FLP)
Homogenous Geographic Unit - 4	10100	Structural Hill
	10104	Intermontane Valley
	10200	Structural Hill Small
	10204	Intermontane Valley Small
	10205	Linear Ridge/Dyke
	20000	Denudational Hills
	20200	Denudational Hills(large)
	20300	Residual Hills
	30403	Latertic Undisected
	40000	Piedmont Zone
	50101	Shallow Weathered Pediplain
	50102	Moderately Weathered Pediplain
	50103	Deeply Weathered Pediplain
	50104	Filled in Valley
	50105	Gully Eroded
	50300	Pediment-Inselberg Complex
	50301	Valley Floor
	50302	Inselberg
Homogenous Geographic Unit - 5	99999	Water Bodies

The present work provides a framework for simplifying and delineating the immense range of variations encountered in examining landforms across coastal Orissa. Although, the stability of coastal systems depends upon many stakeholders but the output of interactions is imprinted in geomorphic landforms. Again, the geomorphic landforms of Orissa coast are quantitatively complied from SAC shown in table 2. The fundamental function of geomorphological mapping is to understand natural and cultural landscapes through time. The five homogenous geographic unit naturally regionalized geomorphic landforms are described in details below.

Table 3. Coastal landforms (Km^2) of Orissa coast (Complied from SAC, 1992)

Coastal Landforms	Area (Km^2)	Coastal Landforms	Area (Km^2)	Coastal Landforms	Area (Km^2)
High tidal/Supratidal mud	56.6	Dense Mangroves	108.5	Flood plain areas	530.1
Intertidal mudflats	74.6	Sparse Mangroves	84.4	Ox bow lake	5.3
Subtidal mudflats	120.1	Other vegetations	143.3	Salt pans	14.4
Sandy beach	120.3	Lagoon	790	Point bars	11.1
Bars/Barrier islands/month bars	31.6	Other water bodies	7.7	Meander scar	11.1
Beach ridges/swale	75.1			Paleo-mudflats	2405.2
Tidal flats	34.7			coastal dunes	64.7
				Paleo-channels	19.4
				Abandoned channels	12.5
				Paleo-beach ridge	332.6
Total Area			5033.64		

Homogenous Geographic Unit - 1

The landforms found in this unit are beach ridges, beach ridges complex, swale, young mud flats, brackish water creeks, beach and spit which are of recent origin. The width of this zone varies along the coastal areas but it typically consists of young coastal plains, with a contour of 10m depth in the sea. This is the most dynamic region where the interaction of different coastal processes likes waves, tidal surge, storm surge and current takes place. This is also the most sensitive area of coastal zone. The boundary of HGU - 1 can be used as the boundary of regulation zone. In order to regulate this zone, it is necessary to have an understanding of present land use conditions and precise delineation of HTL (high tide line) and LTL (low tide line). Severe cyclonic events are mainly responsible for modifications of the landscape in this zone in coastal Orissa. Extreme weather events result in severe shoreline changes, Thereby, affecting coastline configuration: beach and dune erosion, modifications of dune complexes, dune breaching, over wash, inlet formation and at many places, complete elimination of sand-dune complexes. Coastal policy should have some mechanism to adopt against extreme events like protection and conservation of ecological sensitive areas, managed retreat and accommodate. Managed retreat means constructing setback zones, shifting of buildings, no development in susceptible areas, relocation, realignment, creating upland buffers, hazard insurance, appropriate land use, regulation of hazard zones and an improved drainage system.

Ecologically sensitive areas like mangroves, sand dunes and brackish water lakes are required to be quantitatively (size, area etc) and qualitatively (characteristics, function) defined for carrying out proper conservation and protection in these critical ecosystems.

Homogenous Geographic Unit - 2

The geomorphic landforms found in this zone are of late origin (Late Quaternary) and products of dominant coastal processes of marine-fluvio in origin. Landforms are paleo-beach ridges, paleo-beach ridges complex, swale and coastal sand sheets. The coastal plain is a raised, wedged shaped sedimentary platform containing signature of marine influences. It run almost parallel to present shoreline and it is moderately to poorly drain. This region has well defined salt tracts along the coast next to young coastal plain making agriculture impossible. In addition, innumerable sluggish and blackish streams make this region suitable for shrimp culture. The unscientific methods of shrimp and prawn culture (construction of embankment in middle of river) have resulted in the change in coastal dynamics in Orissa in recent times. This zone requires a proper scientific study and remedial action before opening for development. The coastal policy makers have to seek alternative livelihood and employment opportunity in this zone.

Homogenous Geographic Unit – 3

The lower deltaic plain is confined to the zone where fluvial action dominates over the marine processes. It lies within marine realm of marine-riverine interaction and extend landward to the limit of tidal influence. It consists of the area between upper deltaic plain to lower deltaic plain. The geomorphic units are channel bar, deltaic plain, abandoned channel, buried channel, channel bar, natural bar and back swamp. The deltaic plains of Orissa stretch from the Subarnarekha in the north-east to the Rushikulya in the south-west. This fertile region is also known as the “rice bowl” of Orissa. As discussed earlier, this is narrow in the north, widest in the middle, narrowest in the Chilka coast and broad in the south. This deltaic plain is a gift of six major rivers. The formations of the coastal plains depend on the rivers and their catchment area. The North Coastal Plain comprises the deltas of the Subarnarekha and the Budhabalanga rivers and bear evidences of marine transgressions. The Middle Coastal Plain comprises the compound deltas of the Baitarni, Brahmani and Mahanadi rivers and bears evidences of past 'back bays' and present lakes. The South Coastal Plain comprises the lacustrine plain of Chilka lake and the smaller delta of the Rushikulya River. Most of the rivers have failed to develop true deltaic characteristics because of the strong offshore current which moves from Chennai to the Andhra coast and passes through Orissa coast. These areas are extensively used for agriculture and settlement purpose. The Mahanadi is subjected to heavy floods, causing extensive damage to life and property in this zone. This zone requires effective monitoring and observation, which is crucial for understanding and critically analysing the protective and preservation methods for all coastal communities. Time scale for coastal zone environmental monitoring is from short (days) to long (decades) to discriminate between inherent natural variability and anthropogenic impacts. The main challenges before the coastal policy-maker for this zone are to disseminate effective scientific knowledge for publication.

Homogenous Geographic Unit - 4

This is the meeting zone of the arable tract and the spurs of the Eastern Ghats. It is termed as the 'zone of transition. Soil erosion is rampant here. The landform found in this zone are structural hills, intermontane valley, linear ridge/dyke, denudation hills, residual hills, lateritic undisected, piedmont zone, deeply weathered pediplain, filled in valley, pediment-inselberg complex and inselbergs. Under this predominating red soil, blocks of laterite are buried and at times these crop up to the surface, turning the area barren and desolate. Low levels lateritic are formed in this zone. Flow ever patches of fertile area are not uncommon that have rich vegetation. The natural vegetation varies from prickly thorns and stunted shrubs to Sal forests. The absence of a coastal forest belt is most striking. This is because of the lack of a marshy strip due to higher topography.

Therefore, the most ideal step in this zone for coastal managers would be to recognise coastal geological processes, preserve natural landforms, and promote afforestation.

Homogenous Geographic Unit - 5

Water bodies include river, lakes, creeks, wetlands, estuaries and water ways. This zone is most sensitive and lifeline of coastal population of Orissa. The rivers from North to South are the Subarnarekha, the Budha Balanga, the Baitarni, the Brahmani, the Mahanadi and the Rushikulya. The most important reservoirs are at Balimela, on the river Sileru, Rengali over the Brahmani, Mandira over the Sankh, a tributary to the Brahmani near Rourkela and upper Indravati in the river Indravati. Among the natural ones, Chilka Lake is the most famous lake in India. The lake level fluctuates in different seasons. The primary task of coastal policy-maker in this zone is to use inter-disciplinary method and tool to monitor water quality, integrated industrial pollution control and environmental risk assessment.

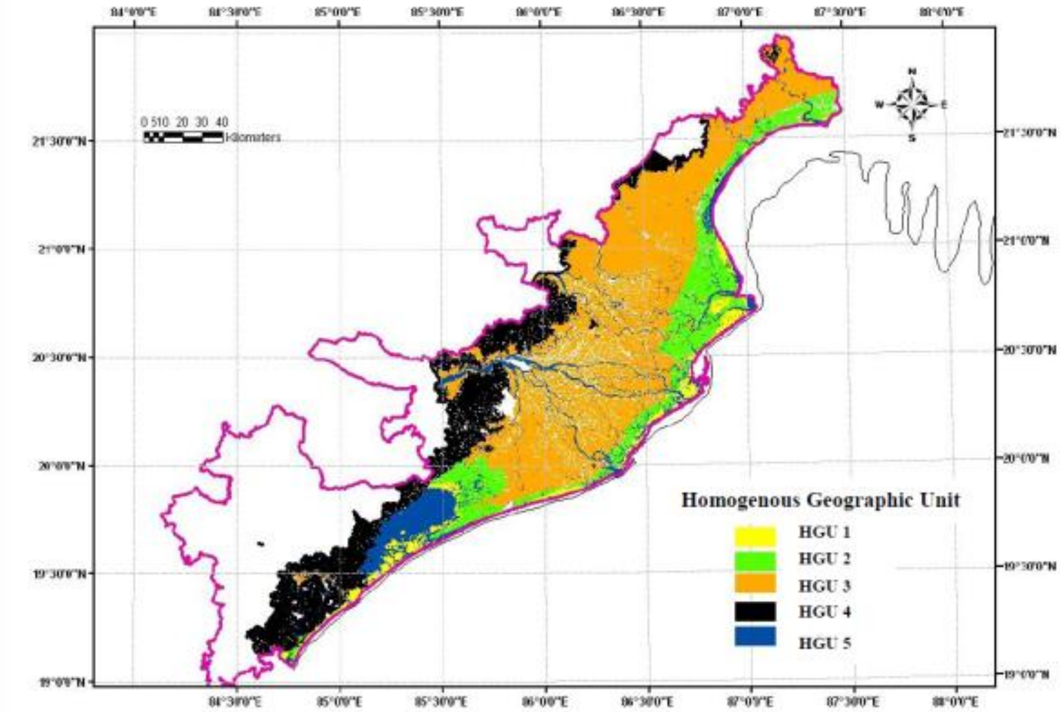

Fig. 3 Homogenous geographic unit of Orissa coast

Discussion and Conclusions

To date the research on coastal zone are more on implementation of ICZM and pratical objectivity are more driven by global problems of climate change and global warming (Pethick et al., 2003 & IPCC, 2013). Costal managements in developing countries are more highlighting the concept integrated assessment of large scale complex problem in oversimplified manner without practical solution. The present unsustainable conditions of Orissa coast reflect the unregulated development in last four decades affecting the amount sediment use to circulate within the systems (Syvitski, et al., 2009 & Kumar et. al, 2010). The adhoc delineation of coastal zone into CRZ and CZM in Odisha coast are done arbitrarily without giving clear picture about internal stakeholders, interactions and sensitivity of coastal systems. This study has attempted to provide a rational regionalization of geomorphic landforms response to perturbations, which is the critical component of coastal managements. Although, mapping the highly complex systems in micro scale in a cumbersome job but advance geospatial platforms has made it easy and also efficient tool for delineating homogenous unit without errors and misclassification. This approach used open sources data like Landsat ETM+ imagery, ancillary data bases, DGPS field survey data and also digital image processing at ERDAS & ARC GIS platforms to map the coastal geomorphic landforms at micro-scale. Addition of digital LIDAR coastal changes product and 3D geophysical data sources are able to identify coastal landforms with high precision and accuracy (Zhou & Xie, 2009 & Allen et al., 2012). These geospatial methods can be replicated in other coastal region depending upon specific management objective and set goals of national coastal policy.

The prediction about changes in dynamic and complex coastal systems should entail more on long time period geomorphic data and further to remain elusive goal of sustainable coastal zone management policy. In summary, homogenous geomorphic management unit based regionalization should be starting point for ICZM strategic plan. Rational regionalization of landforms of Orissa coast to five homogenous units should be integrated with socio-economic characteristics of each unit for developing overall integrated value and will be spatial tool for implementation of coastal zone management at micro-scale. Future, coastal policy and programme should not depend upon more protection and preservation but mapping and identifying the spatial sensitive coastal zone followed remedial measures in time. Therefore, the task of coastal mangers in developing countries is to locate and manage these kinds of changes in coastal systems but allow these systems to adjust naturally within the ecosystems. The job of scientific community is to provide society with a carefully constructed spatial data base with a defining precise limit of tolerance of coastal systems for utilizing the resources in sustainable manner in longer time periods.

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