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Research Article

GEOSPATIAL TECHNOLOGY BASED DETAILED MAPPING OF GEOMORPHIC LANDFORMS AND UNDERSTANDING OF MIGRATORY PATTERN OF RIVERS IN A PART OF MAHANADI DELTA IN COASTAL ODISHA, INDIA

Smita Priyadarsini Rout[1]., Palanivel K*[2]., Kumanan C.J[3]., Ramesh Kumar K[4] and Sudhakar, Ch[5]

[1,2,3]Centre for Remote Sensing, Bharathidasan University, Tiruchirappalli, India
[4,5]Atomic Minerals Directorate for Explorations Research, Hyderabad, India

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ABSTRACT

Geomorphic landforms are important repository of groundwater, economic minerals and form fertile belt for irrigation. The fluvial landforms related to Palaeochannels are pathfinders to understand the past seismic activities of the area. These Palaeochannelsare useful to recognize the resultant pattern of river migration caused by palaeo-, neo- and active - seismotectonic activities. Further, they are important as they have developed favorable locales not only for groundwater occurrence but also for heavy mineral deposits. In order to proceed with any Geologic study, the first step would be to map the geomorphic landforms. The fast emerging and advancing techniques like Remote Sensing (RS), Digital Image Processing (DIP), Digital Photogrammetry (DP), Digital Elevation Modelling (DEM), Differential Global Positioning System (DGPS) and Geographic Information System (GIS) are highly useful and efficient in detailed geomorphic mapping of an area. In this area, the fluvial, marine and intercalated fluvio-marine landforms are developed with subtle differences in their topographic elevation. Further, they are highly disturbed, eroded in nature and hindered under the vegetal cover due to their fertility and attract habitation over them. Thus, mapping of these landforms becomes more challenging task. But, with the help of newer techniques, together called 'Geospatial Technology', this task of detailed Geomorphic mapping becomes most effective and easy. This study has attempted in a coastal part of Mahanadi Delta in Odisha. Through various satellite image enhancement techniques and using GIS, more information about the existence of newer geomorphic landforms, their aerial extent, importance and the history of migration of distributaries in coastal part of Mahanadi delta have been brought out. Shaded Relief Map developed using SRTM, CARTOSAT DEMs and the 3D visualization of Basement Depth generated in GIS have further added the information content about the existence of these Palaeochannels and the possible migratory patterns of rivers. In this paper, the advanced GIS, DIP and 3D imaging methods used for better visualization of terrain through subsurface faults and basement data and satellite image interpretation, detailed mapping of Geomorphic landforms and understanding the migratory pattern of distributaries in Mahanadi Delta have been dealt in detail.

INTRODUCTION

The Mahanadi Basin is one amongst the five sedimentary basins of Indian Subcontinent. The entire Mahanadi Delta covers an area of 9,500 sq. km approximately and bounded by Brahmani River in the Northeast and Chilika Lake in the Southwest. Mahanadi delta is a complex delta formed due to the coalescence of three sub-deltas formed by Brahmani-Baitarani Rivers in the north, Mahanadi River in the center and Devi River in the south (Vinod Kumar *et al*, 2004). This delta consists of four types of major geomorphic landforms like fluvial, fluvio-marine, marine and aeolian landforms. This delta has an arcuate shape with four stages of formation due to marine transgression and regression processes (Mahalik *et al*, 1996). Four stages of the delta progradation were identified based on the strandlines and palaeo-deltaic lobes as per the research work of Vinod Kumar *et al* 2003. But, only limited and regional studies have been conducted in this complex delta using Geospatial Technology.

The Indian sub-continent has undergone many tectonic, fluvial and marine geomorphic episodes resulted into numerous

Corresponding author:* **Palanivel K
Centre for Remote Sensing, Bharathidasan University, Tiruchirappalli, India

intercalated landforms in most parts of India. But identifying and mapping of these important landforms in a large scale has been a problem because they are mostly covered with alluvium, thick vegetation and get modified by human developmental activities like built-up, agriculture, aquaculture and afforestation or by natural calamities like cyclone and floods every year and their dimensions are varying from a very narrow strip to a width of hundreds of metres and a length of hundreds of kilometres. Due to the frequently occurrence of cyclonic storms and floods every year, the landforms developed so far and the shape of the terrain have been totally affected due to either erosion or total burial by new fluvial cover over the pre-existing features. These are the important factors that have made the task of detailed Geomorphic mapping in this area a very difficult one.

These geomorphic landforms are important as they host placer mineral deposits and ground water. Though this area has much potentials and importance, there is no proper and precise methodology has been developed so far, in order to delineate and map these variety of geomorphic landforms, that too using the latest and fast emerging advanced techniques like Remote Sensing and GIS. Hence, the present study has been conducted and developed a precise methodology for better understanding of the geomorphological processes of Mahanadi Delta and through which the migratory pattern of Mahanadi River and its economic landforms have been brought out by incorporating seismo-tectonic details using Geospatial Technology.

Aims and Objectives

Aim of this study is to delineate the migratory pattern of Mahanadi and its distributaries through a detailed mapping of geomorphic landforms and incorporating Seismo-tectonic details in part of Odisha coast using Geospatial Technology.

To fulfil this aim, the following objectives have been delineated:

1. Detailed mapping of fluvial, fluvio-marine, marine and aeolian landforms of a part of the coastal Mahanadi Delta by interpretation of normal colour high resolution satellite images, CARTOSAT-1A Stereo images, FCC satellite images and digitally enhanced satellite images, DEM based Shaded Relief Maps, and through updating the geomorphology map using field survey data.
2. Generation of seismo-tectonic maps such as 3D Basement Depth and Basement faults in GIS and
3. Bringing up of relations between the Geomorphology and Seismotectonic Maps and to understand the history of development of fluvial landforms, migratory pattern of Palaeochannels.

Brief Methodology

For this study, different types of satellite data have been collected (Landsat TM, Landsat 8, IRS P6 LISS IV and Cartosat-1A Images); enhanced and processed images have been generated in ENVI software for better interpretation. Shaded Relief Map and vertical profiles have been developed by using SRTMDEM & fine resolution CARTOSAT DEMs of the study area from which the terrain elevation of various subdued coastal landforms and Palaeochannels are distinctly visualized and easily interpreted. This gives information about the Geological processes that are shaping up the area. After the onscreen interpretation and the field verification of the geomorphic landforms, the Geomorphology map has been finalized. Subsequently, the DEM generated using the Basement Depth Contour and Fault Maps by referring the Seismotectonic Atlas of India. The migratory pattern of the Palaeochannels has been recognized with the help of vertical profiles, Basement Depth DEM and Basement Faults.

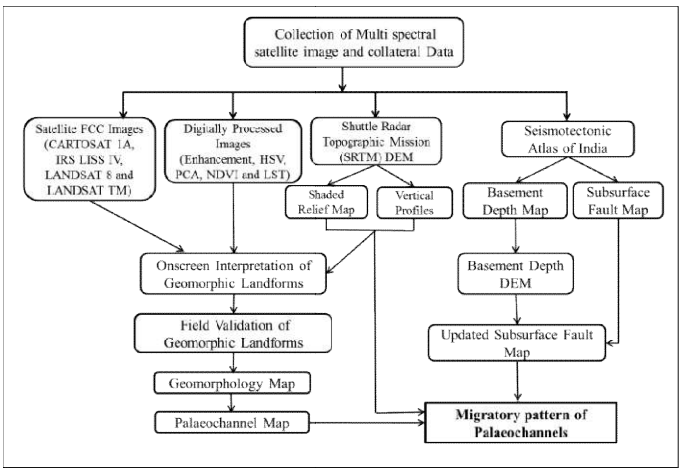

Figure 1 Methodology flow chart

Study Area

The study area is extending from Puri city in the Southeast to Hukitola Island in the Northeast of Odisha with a coastal length of 128 km covering an area of 3,208 sq km. The major river flowing in the northeastern portion of this area is Mahanadi. The major distributaries of Mahanadi flowing in the northeastern part of the study area are: Paika, Chitrotpala and Nuna Rivers; and in the southwestern part of the study area are: Devi and Kushabhadra and Nuanai Rivers. The major towns / cities such as Puri, Sakhigopal, Biswanathpur, Konark, Kantilo and Kakatapur are located in the southwestern half and Kujang, Chandanpur, Patia, Paradip, Hukitola are located in the northeastern half of the study area (Fig. 2). The study area gains importance due to the existence of mangroves in Hokitola island and its surroundings, a famous

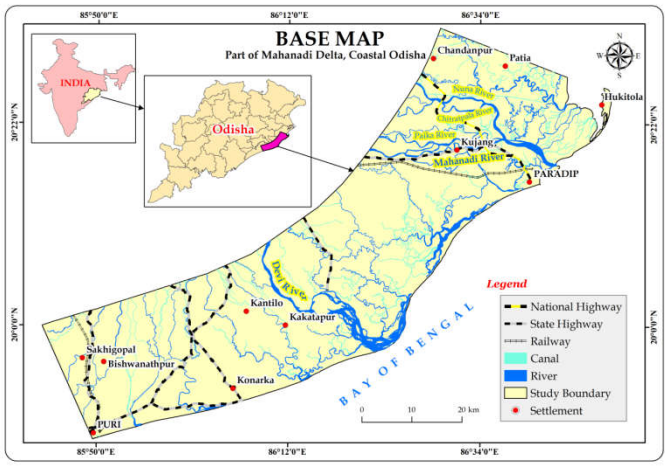

Figure 2 Base Map of the Study Area

port town known as Paradip located just 30 km southwest of it in the northern half separated by Devi river, and Konark, a small town where the Sun Temple a world renowned

Archeological site and a place of worship called Puri are located in the southern half of the study area.

Mapping of Landforms using Satellite Data

Use of Raw and FCC Satellite Data

The remote sensing satellite data provides a panoramic view. For the entire study area, by mosaicking multiple images pertaining to the same satellite having adjacent paths and rows, mosaicked satellite data for the entire area have been prepared (for example, LISS IV image shown in Fig. 3, center). In order to visualize these multispectral satellite data with better clarity, it is a common practice to generate a standard FCC. i.e.,False Colour Composite (Fig. 3, center) and the geomorphic landform mapping have been initiated. Mapping of geomorphic landforms using satellite raw, FCC and digitally enhanced images involved the interpretation keys such as tone, texture, shape, size, shadow, site, association and pattern and the geotechnical elements such as drainage pattern, lithology, and land use/land cover of the study area (Lillysand and Kiefer 1987). For example, the Palaeochannels have typical sinusoidal patterns, characterized by slightly darker tone due to the presence of moisture content along with stagnant water patches which are associated with oxbow shaped lakes and agricultural lands and/or plantations that are arranged in similar sinusoidal patterns and at certain stretches have formed like disjointed parts of meandering channels. These geomorphic features does not have shadow element as they form along deltaic plains. Thus, by using the combinations of interpretation keys mentioned above, the denudational, fluvial, marine or Aeolian landforms of different environment or the combination of them have been clearly brought out. The important elements involved in geomorphic interpretation are:

- High Reflectance of alluvial sand along the river beds and beach, dunes and beach ridges in coasts, with or without plantation over them having an average elevation of 5m from their adjacent area
- Low reflectance values in the Infrared (IR) bands due to the presence of high moisture content in certain landforms like swales, mudflats, tidal flats, salt flats, swamps consisting of mud/clay, clayey sand and sandy clay deposits and with or without mangroves.
- Linear, partly meandering, elongate, lobate, sinuous, ribbon like and curvilinear patterned fluvial landforms
- Association of these patterned landforms with vegetation or covered with agricultural lands aligned in the similar pattern and
- Accompanying water bodies of similar pattern with varying size and distribution.

The palaeo fluvial landforms are normally fertile, forms highly saturated shallow aquifers with greater vertical thickness, maintaining moisture conditions in the soil surface and subsurface and thus they are mostly being used as irrigable lands by the farmers. These channels have a lot of sediments as layers of sand, silt, clay and their combinations and these layers are relatively elder at the bottom and younger towards the top surface. Further, these landforms allow rapid movement of groundwater flow through sandy layers and supports tapping of groundwater by the local people during dry and summer seasons for agriculture and domestic purposes. These properties together with their landform shape are helpful in recognizing the existence of palaeochannels both in the satellite images as well as through field surveys.

Use of Digital Image Processing of Satellite Data

Due to the agricultural activities, habitation development, monsoon floods and disturbed soil cover, the raw and the standard FCC images may not be providing sufficient base to clearly map the geomorphic landforms in certain areas. In order to tackle this problem, the Digital Image Processing techniques such as, Image Enhancement of Raw satellite data, Colour Transformations, Normalized Difference Vegetation Index (NDVI), Land Surface Temperature (LST), etc., need to be adopted for enhancing the satellite data digitally so as to clearly depict the geomorphic landforms in a better way.

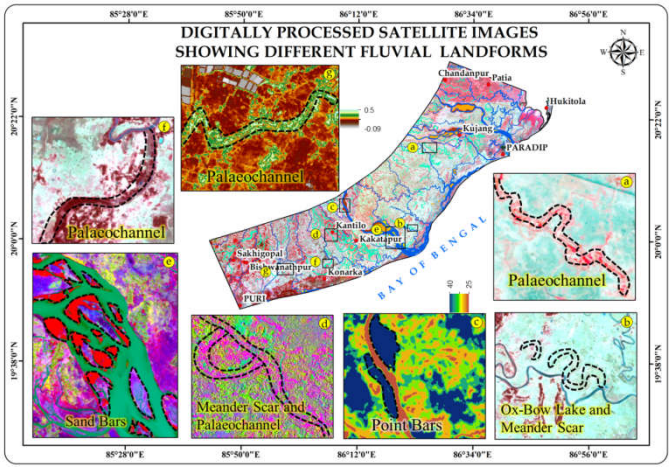

Figure 3 IRS P6 LISS IV FCC (standard) at the center and the Digitally Processed satellite Images showing Geomorphological landforms of the Study Area as insets in clockwise are: (a) Gaussian Stretching (GS432), (b) Hue-Saturation-Value Transformation (HSV543), (c) Land Surface Temperature (in Deg. Celcius), (d) Principal Component Analysis (PC678), (e) Minimum Noise Fraction (MNF357), (f) HSV Transformation -543, (g) NDVI Image.

Linearly Stretched Images

In this study, the raw and stacked satellite images were subjected to various Linear Stretching techniques like, Gaussian Stretching, Contrast Stretching, Histogram Stretching and Equalization Stretching, etc. As the Gaussian Stretching gave better output compared to other enhancement techniques for the study area, the same is given as a sample in Figure 3a. From this enhanced image, different geomorphologic landforms have been mapped using GIS.

HSV (Hue, Saturation & Value) Transformed Image

Meanders Scars and Ox-bow lakes are more clearly visible in the HSV transformed output image of the Lands at TM data of the study area (Fig. 3b & f).

LST (Land Surface Temperature) Image

The output image of the Land Surface Temperature (LST) has shown the temperature of the study area varies between 25˚c to 40˚c. The low temperature features are shown with orange colour and the high temperature features are shown with blue in colour. As the water bodies and the vegetation covered areas will radiate less heat than the other features like sand bodies and rocks, the Palaeochannels are represented with orange

colour having little lower temperature due to presence of moisture content. On the contrary, the Sand Bars, Beach Ridges and Beach are little hotter with 5-10^{o}C higher temperature as these sand bodies absorb more heat (shown with blue colour in Fig. 3c). Thus, the ability of Land Surface Temperature images in differentiating the fluvial and coastal geomorphic landforms, mapping them becomes easy in GIS.

Principal Component Analysis Image

Through this DIP technique, several Palaeochannels and Meander Scars found in different parts of the study area and the other fluvial landforms like Sand Bars are made clearly visible (Fig. 3d).

MNF (Forward Rotation) Image

The features like Sand Bars, Point Bars, and Beach Ridges have been more enhanced in this type of transformation. Figure 3e shows the Sand Bars in Devi River.

NDVI (Normalized Difference Vegetation Index) Image

As most of the Palaeochannels contain moisture content and thus they have vegetation cover, NDVI image can show the features such as Palaeochannels, meander scars and beach ridges that are vegetated. The NDVI map prepared using Red and Infrared bands of LANDSAT 8 is shown in Figure 3g, using which several Palaeochannels and other fluvial economic landforms are mapped and updated clearly.

3D Visualization using DEM and its product in Geomorphic Mapping

The effective tools like CARTOSAT DEM, Shaded Relief Map and the vertical profiles prepared from SRTM DEM can give more details about the presence of the geomorphic features about one region. Thus these tools were used in this study to improve the geomorphic mapping.

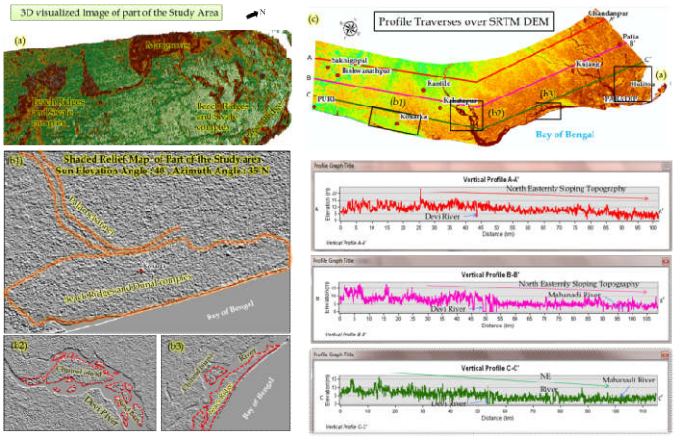

Figure 4 (a) CARTOSAT DEM, (b1, b2, b3) Shaded Relief Map (40˚ & 35˚N) and (c) Profile Traverses on SRTM DEM and Vertical Profiles

Cartosat Dem

High resolution Digital Elevation Model (DEM) for a part of the study area has been prepared where there are complexities existed (Paradip area), using the CARTOSAT-1 Stereo images by incorporating the accurate elevation and location data collected by conducting Differential Global Positioning System (DGPS) surveys. Using this fine resolution CARTOSAT DEM, 3D models have been developed showing different types of coastal landforms, classified based on their elevation differences (Fig. 4a).

Shaded Relief Map (SRM)

This is a method of representing relief on a map by depicting the shadows that would be derived by high ground if a light beam hits from a certain direction (mentioned as azimuth angle) and elevation (sun elevation angle). A shaded relief image developed with lower elevation angle enhances the topographic features having subtle elevation differences in deltaic plains and coastal plains and hence this SRM is very much useful for extracting spatial information about the surface fractures, faults, and drainages, linear & curvilinear depressions as Palaeochannels and coastal landforms. In this study, a sample SRM generated with 40^{o} sun elevation angle and 35^{o}N azimuth angle using the SRTM DEM data which has 30m spatial resolution is shown as an example (Fig. 4b).

Beach Ridges and Swale Complexes, Palaeochannels, Sand Bars, Channel Islands and water bodies have been identified and interpreted in various places in the study area.

Vertical Profiles

Three vertical profiles, parallel to the coast of the study area have been derived using SRTM DEM in GIS. From the profile C-C' traversing near coast, it is clearly seen that the area just in the north of Puri city is comparatively elevated than the area near Hukitola. Similar is the overall sloping nature of the ground as depicted through the other two inland profiles along A-A' and B-B'. That means all these 3 profiles have showed an overall gently tilting topography towards Northeast (Fig. 4c).

Geomorphology

The four major coastal landforms having positive relief mapped in the study area are: Beach Ridges (106.46 sq.km, 3.31%), Beach Ridges and Dunal Complex (57.62sq.km, 1.79%), Planated Beach Ridges (78.08sq.km, 2.43%) and Beach Ridge& Swale complex over printed by Delta (872.12sq.km, 27.15%). The other minor coastal landforms are: Beaches (10.98sq.km, 0.34%) and Relict Beach Ridges (16.75sq.km, 0.52%), four kinds of tidal flats such as Sub-tidal flats (1.73sq.km, 0.05%), Inter-tidal flats (1.44sq.km, 0.04%)& Supra-tidal flats (0.94sq.km, 0.03%) and Mangrove Swamp (33.56sq.km, 1.04%), and Mud flats (30.99sq.km, 0.96%), Salt flats (9.02sq.km, 0.28%), Swales (69.34sq.km, 2.16%), Backwaters(0.5sq.km, 0.01%) and Spits (2.8sq.km, 0.09%). The fluvial landforms are: Deltaic Plain (1405.84sq.km, 43.76%), Flood Plain (152sq.km, 4.73%), Point Bars(16.92sq.km, 0.53%), Sand Bars (25.57sq.km, 0.8%), Palaeochannels (80.53sq.km, 2.51%), Meander Scars (0.62sq.km, 0.02%),and Palaeo Swamps (5.1sq.km, 0.16%).The intercalated Fluvio-Marine geomorphic landform mapped in this area is Beach Ridge and Swale Complex overprinted by Delta.

The entire study area has got several small patches of severely disturbed Relict Beach Ridges surrounded by Deltaic Plain. Similarly, there are Beach Ridges and Swale complexes over printed by Delta are located in the middle coastal zone, i.e., NE of Devi River. So many Palaeochannels of varying widths and lengths along with Point bar sequences, Meander Scars, Oxbow lakes are located on either side of Devi and Mahanadi rivers.

These Palaeochannels are clearly depicting the past tectonic history and the formation of vast deltaic plain of Mahanadi. It is also easy and interesting to trace the migratory pattern of the river Mahanadi through these Palaeochannels. These Palaeochannels and the Point bar sequences are important locales for the accumulation of heavy placer minerals.

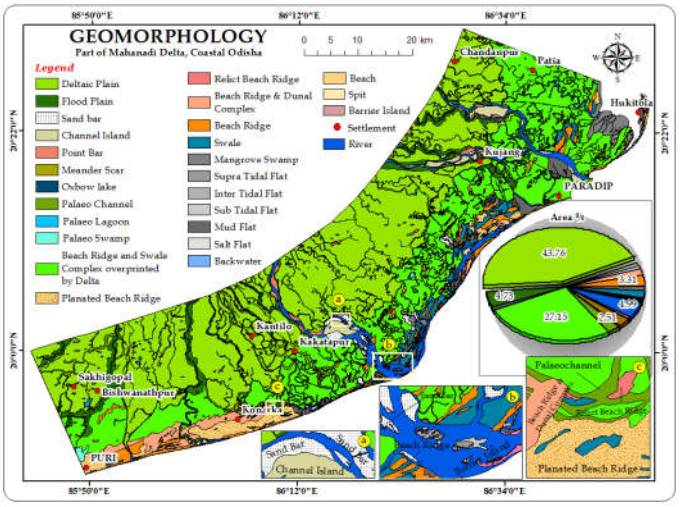

Figure 5 Geomorphology Map of Study Area

RESULTS AND DISCUSSION

While understanding the Geomorphic setup of the study area, it is very clear to observe the Geomorphic Anomalies that are representing the ongoing seismotectonic activities and further responsible for the formation of the present day landforms. The Eyed drainages forming many Channel Islands and the Meander Scars seen in both Mahanadi and Devi River courses are the primary evidences for such seismotectonic activity. According to K. Somanna2016, the anastomosing nature of ancient channels and abandoned meander lobes show major shifts in river courses as the delta is built up.Mahanadi offshore basin contains a series of structural highs and depressions (Subrahmanyam *et al* 2008); which may be formed due to the subsurface faults. Ramasamy 2007 and Ramasamy *et al* 1999, observed that the active seismo-tectonism have triggered the formation of braided pattern and eyed shaped drainage pattern in South Indian River systems and created Channel Islands. In the Geomorphology Map of the study area, the River Devi shows braided pattern of flow till its mouth. But, this is absent or minimum in the mouth of Mahanadi river course. Similar braided pattern is also seen with the Palaeochannels located in the SW part of Devi River. This suggests that the Devi River is migrating towards NE due to the ongoing tectonic tilt and slow subsidence towards that direction. In the same way, the Palaeochannels mapped in the Southwestern part of the Mahanadi River having nearly half of the width than the Devi River have also suggested the similar direction of migration, i.e., towards NE. The vertical cross sections made parallel to the coast line are showing the overall northeasterly slope of the terrain. This has confirmed the ongoing tectonic tilt and the resultant Northeasterly migration of the Devi and Mahanadi rivers. All the three major rivers such as Devi, Mahanadi and Nuna are taking a deviated course towards NE at a distance to a minimum of 15 km to a maximum of 25kmin land from the coast. All these three rivers are showing anomalous deviations from their regular direction of flow and splitting into two obtusely aligning over a NE direction which is parallel to sub-parallel to the coast. These deviation locations are matching with the subsurface faults published in Seismotectonic Atlas of India-2000by Geological Survey of India. It is also observed that the Planated Beach Ridges and Dune Complexes in Konarka and in Paradip areas located just southwest of the Devi and Mahanadi rivers accordingly are abruptly terminated and absent for a distance of 15 km. Due to the Northeasterly migratory actions of these rivers, the early existed portion of the Planated Beach Ridges and Dune Complexes were almost completely eroded away leaving the series of meander scars and Palaeochannels. These left out channels of rivers are representing the said Northeasterly migratory patterns in this area. Though there is a broad convexity seen in the coast from Puri to Ramtara village located 25 km southwest of Paradip, this might have been attributed to the huge deposition of sediments brought by the Devi River and its distributaries and further shaped up by the littoral currents.

Further, the barrier islands and spits formed by the interface dynamics of Devi River and waves in its mouth can also be further induced aggressively by the horst effect of the two parallel to subparallel NW-SE faults on either sides, as revealed from the 3D visualized basement depth map. The two major depressions, can also be called as grabens formed on either sides of the horst mentioned above in the study area (Fig. 6), are formed due to the subsurface faults with ongoing tectonic movements and concurrently filled up with sediments of fluvial and marine activities. Prabhu Prasad Dash (2016) referred that there is an upliftment in between these two depressions and mentioned it as Nimapara-Balikuda uplift. Though, most of the rivers in the study area show a Northeasterly deviated tract before joining with the Bay of Bengal and this behaviour may be attributed to waves and the littoral current activities, the active tectonic movements have also played major role here. The remnants of Beach Ridges located on either sides of the Devi River near the coast are having varying widths. The Beach Ridges located amidst the anomalous and deviated river course of Devi are with very narrow width (< 0.5 km), while comparing with their continuation components located in the SW bank side of Devi river near coast with > 1 km (Fig. 5, inset b). This is described by the combined effect of not only the tidal / littoral currents and heavy winds that are pushing the water through the swales and might have eroded the loose sand in Beach Ridges by widening the courses and inundating them, but also the effect of tectonic tilting of the coastal terrain towards NE and uplifting along the horst area.

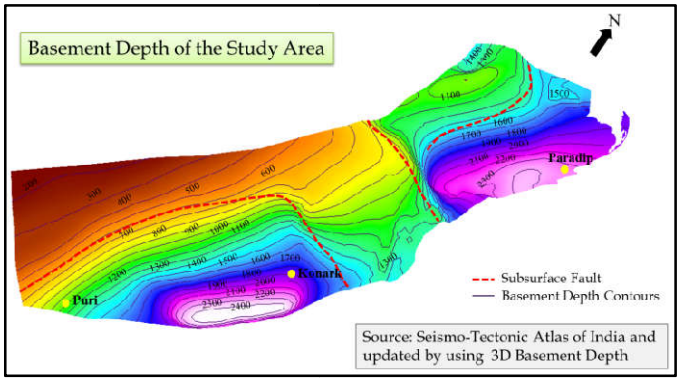

Figure 6 3 D-Basement Depth DEM of Study Area (meters below MSL)

The big inland Channel Islands of Mahanadi and Nuna Rivers, made by the diverted river channels are merging at points located near the villages namely Patlipanka and Baulpara, along the NE bank sides of these rivers accordingly. In this area, the fault planeis exposed (Fig. 7) and thus forms the reason for the tapering end of these Channel Islands where the diverted rivers are merging due to the gravitational effect gained by the ongoing subsidence of land. These alignments of Channel Islands along the fault plane can be correlated with the presence of strandlines of Early Upper Pleistocene age (Mahalik 2006) in that region which are further disturbed due to the riverine activities. On the contrary to the Mahanadi and Nuna rivers, the big inland Channel Island made by the river Devi is tapering and the diverted courses are merging with a lot of braiding effects near the village Padaruan. Further, the merged Devi river course has got a lot of braided channels all along the flow path till its mouth. Moreover, the other minor rivers along the NE of Devi river shows compressed meandering (Fig. 7). This is seen mainly in between the two NW-SE faults where the horst is located as discussed earlier. The existence of horst and its ongoing uplifting effect might be the reason for all these anomalous behaviours of Devi River in this area.

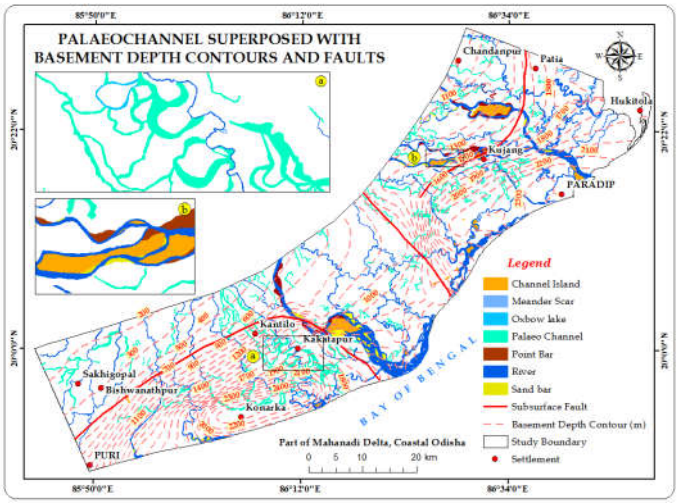

Figure 7 Palaeochannels and Basement Depth contours of Study Area

CONCLUSION

The advanced tools available with the Geoinformatics Technology such as Remote Sensing, Digital Image Processing, Global Positioning System and Geographic Information System have been effectively used to prepare a very detailed Geomorphic Landform mapping of the part of Odisha coast. It is clear from this map that the fluvial landforms are dominantly covering the area than the coastal landforms. The existence of an intercalated landform, i.e., Beach Ridge and Swale Complex overprinted by Delta suggests that the area has undergone several episodes of marine transgression and regressions during the past.

From this map, varieties of anomalous landforms were identified. Further, using the Geoinformatic tools, the secondary data were also visualized in 3 D platform and wrapped with the other layers such as Geomorphology and Rivers so as to bring out the migratory patterns of rivers, their relations with the faults, basement depths and brought out the ongoing tectonic activities prevailing in this area.

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References

1. Mahalik, N.K., C. Das and Wataru Maejima. 1996. "Geomorphology and evolution of Mahanadi Delta," India. *Journal of Geosciences*, Vol-39, pp. 111-122.
2. Mahalik, N.K. 2006. "A Study of the Morphological Features and Bore Hole Cuttings in Understanding the Evolution and Geological Processes in Mahanadi Delta, East Coast of India", *Journal Geological Society Of India,* Vol.67, pp.595-603.
3. Prabhu Prasad Dash, H.K Sahoo and P.P Mahapatra. 2016. "Assessing the effects of regional tectonic activity on groundwater flow in a coastal aquifer in India," *Environmental Earth Science*, 75, 1331 pp. 01-15.
4. Ramasamy, S. M. and C. J. Kumanan. 2000. "Eyed drainages observed in IRS imagery in Tamil Nadu, India and their geological significance," *International Journal Remote Sensing,* Vol. 21, pp. 475-481.
5. Ramasamy, S.M. 2007. "Whirling (Buckling) and Fracturing Indian Plate and its consequences – A Remote Sensing appraisal," *Journal of Geological Society of India*, Vol. 70, pp. 682-685.
6. Somanna, K., T. Somasekhara Reddy, and M. Sambasiva Rao. 2016. "Geomorphology and evolution of modern Mahanadi Delta using the Remote Sensing data," *International Journal of Science and Research*, Vol. 5, Issue-2, pp. 1329 - 1335.
7. Subrahmanyam, V., A.S. Subrahmanyam, G.P.S. Murthy and K.S.R Murthy, 2008. "Morphology and Tectonics of Mahanadi Basin, Northeastern continental margin of India from geophysical studies," *Marine Geology*., Vol. 253, pp. 63-72.
8. Vinod Kumar, K., Asis Bhattacharya. 2003. "Geological evolution of Mahanadi Delta, Orissa using high resolution satellite data," *Current Science*., VOL. 85, NO. 10, pp. 1410 -1412.
9. Vinod Kumar, K., AsisBhatacharya. 2004. "Remote Sensing of Delta Progradation Mahanadi Delta, Orissa," *Journal of Geological Society of India,* Vol.64, pp. 227-230.

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