APPLICATION OF THE REMOTE SENSING AND GEO-SPATIAL TECHNOLOGY IN TERRAIN ANALYSIS AND TERRAIN CLASSIFICATION IN CONTEXT OF CREATION OF SDI FOR MARINE & COASTAL REGIONS

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Abstract

The ever-increasing urbanization along the coasts resulting destructive pressures on the Marine and coastal regions. Developing area/region specific SDI's, using developments in remote sensing and geospatial technologies, will surely add strength to the National and Global SDIs. The main aim of this study to understand the topographic features which is the most important part of terrain analysis and for that develop the application of the available Geospatial Tools for the creation of datasets, which are building blocks of any SDI. The surface analysis of South Western part of India and Benthic Terrain Analysis of Eastern Arabian Sea is carried out using the NASA Shuttle Radar Topographic Mission (SRTM) data and Geospatial tools to understand the terrain characteristics. The terrain analysis of southern Maharashtra and Goa region is validated using ASTER 3D remote sensing data. The geospatial study is carried out to generate base-level information for terrain analysis and classification. Using improved e-topo2 bathymetry data and Benthic Terrain Modeller (BTM) extension of Arc GIS version 10.2, bathymetry position Index (BPI) at different resolution/scale (broad, fine and standard scale) is achieved for preparing slope, depth, and rugosity maps. Based on bathymetry derivative maps, benthic terrain map of the Eastern Arabian Sea are generated and are used to classify benthic environment of the Ocean. The study demonstrates that Geospatial technique as most efficient, cost-effective and easiest tools for surface/benthic terrain analysis and mapping provides most of the data for the development of SDIs for Coastal and marine regions.

Keywords. Benthic terrain modeller; Eastern Arabian Sea; Remote sensing; GIS; Terrain analysis.

1. INTRODUCTION

Spatial Data Infrastructure (SDI) are used to summarize activities, relationships, processes, and physical entities that provide integrated management of spatial data, information, and services and Promotes geospatial data sharing and facilitates data use. Although, there have been several definitions of Spatial Data Infrastructure (SDI) in literature (Wright, 2009), in general the SDI is defined as “the relevant base collection of SDI offers improved access to data, reduced duplication of effort in data collection and maintenance, enables interoperability between dataset, modernization of administration, risk management, and spatially enabled governance (Gourmelon et al., 2012; Strain et al., 2004). Topography refers to the surface characteristics i.e. the relief of an area. The topography of land surface is represented by digital elevation dataset in GIS which consists of elevation of a large number of sample points distributed throughout the area being represented. These sample points are commonly organized as grid points, essentially as a raster form of organization. An alternative form of representation is the Triangulated Irregular Network or TIN used in vector based system.

Surface analysis is one of the important components to understanding the geomorphological characteristics. Surfaces represent phenomena that have values at every point across their extent. The values of the innumerable number of points of the surface are derived from a limited set of sample values. These may be based on direct measurements, such as height values for an elevation surface, or temperature values for a temperature surface; between the measured locations. Surfaces can also be mathematically derived from other data, such as slope and aspect surfaces are derived from the elevation surface, a surface of distance from bus stops in a city, or surfaces showing the concentration of criminal activity or probability of lightning strikes etc. (Surface creation and analysis - http://resources.esri.com/help/9.3/arcgisengine/java/gp-toolref/geo-processing/surface creation_and_analysis.htm).

The benthic zone is the ecological region at the lowest level of a body of water such as an ocean or a lake, including the sediment surface and some sub-surface layers”. The extent of the benthic region of the ocean covers from the shoreline (intertidal or EU littoral zone) and extends downward along the surface of the continental shelf towards the sea. The continental shelf is a gently sloping benthic region that extends away from the land mass. At the continental shelf edge, usually about 200 m. deep, the gradient increases greatly and is known as the continental slope. The continental slope drops down to the deep sea floor. The deep-sea floor is called the abyssal plain and is usually about 4,000 meters deep. The ocean floor is not all flat but has submarine ridges and deep ocean trenches known as the hadal zone (http://en.wikipedia.org/wiki/Benthiczone).

GIS-based terrain analysis techniques are well established as a potential approach to marine geomorphological mapping in deep water (Wilson et al 2007). Multibeam bathymetric data can be used to generate derived quantitative variables describing the seafloor terrain. Dorschel et al (2010) detected canyons in the Irish offshore by their increased slope inclination of canyon walls (steeper than 5°) compared to the surrounding seabed (rarely steeper than 2°). Micallef et al (2012) outline a method (semi-automated) to map shallow coastal water habitats based on the high-resolution multi-beam bathymetry and backscatter data. Textural and morphometric analyses are combined in this method to map and plot the distribution of the predominant habitats offshore NE Malta. The ground-truthing with ROV and dive observations are used to confirm the validity of their approach.

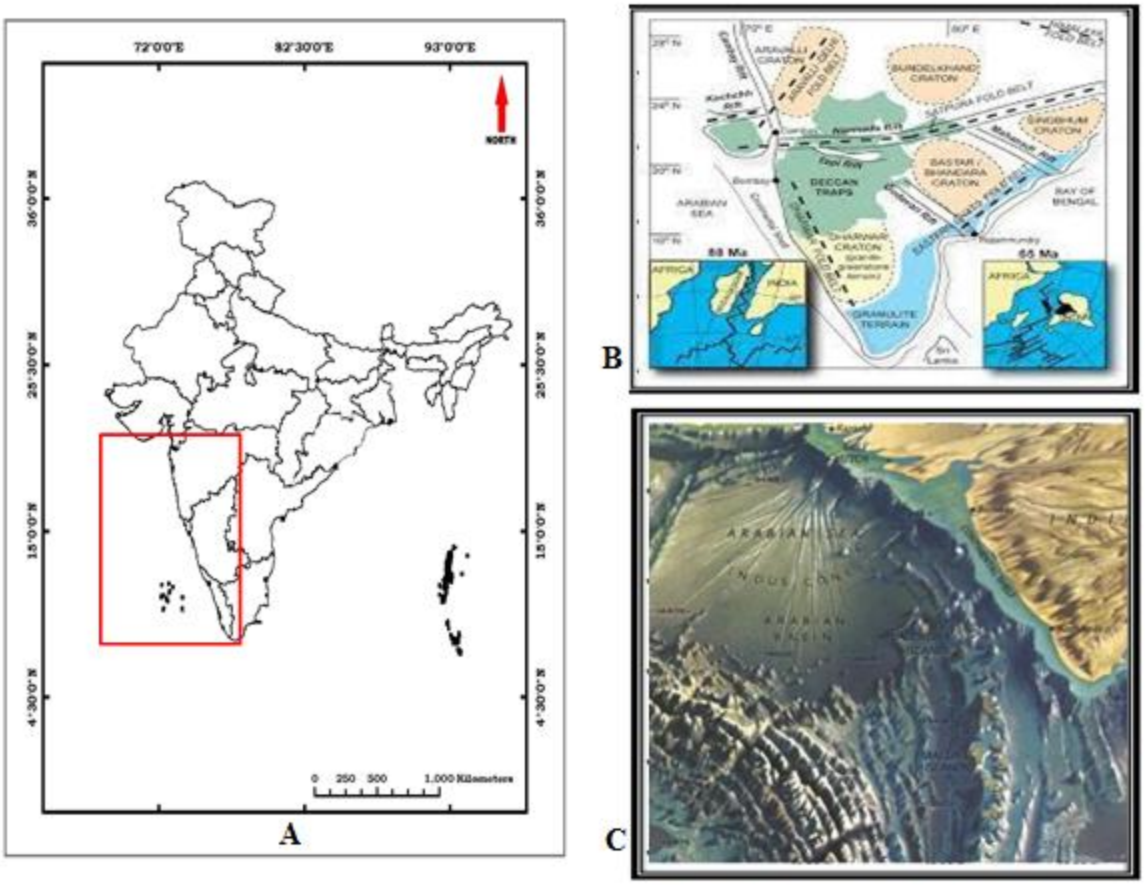
Several studies for the development of Coastal and Marine SDIs (Gourmelon et al., 2012, Strain, 2006) were attempted by different countries, which led to several SDI initiatives at different levels: local, regional, national, international and global levels (Cömert et al., 2008; Idrees et al., 2015) with varying development and progress. India with its vast coastline and the population that lives along the coast needs an immediate initiative for the development of SDIs for coastal and marine regions that facilitates the better management of these areas for promoting tourism, better facilities for fisheries, and preventing the loss due to natural hazards. Due to limited access to the scattered available comprehensive information about marine and coastal areas, the present study showcases a simple and easy way to develop small databases using the satellite data with the functions with the help of software available in public and as well as commercial domains. Therefore, the main objective of the present study is to demonstrate work as an initiative towards the creation of the database as part of developing region specific SDI with the application of Terrain Analyses of the topographic and benthic surface using the geospatial tools applied on the SRTM & ASTER datasets. For the present study, the Land and Ocean interface area enclosed within 60º E to 78º E longitudes and 7º N to 21º N and latitudes is chosen for deriving the terrain characteristics expressed in terms of several variables that help in understanding the morphology of the study area. The main purpose of benthic terrain mapping is to classify the benthic terrain and to identify the seafloor geomorphological features. The classification is used for the benthic habitat mapping and predictive mapping for the benthic environment in the studied region.

2. AREA OF STUDY

The study area extends from 60º E to 78º E longitude and 7º N to 21º N latitudes and covers Eastern Arabian Sea, Sourashtra, Gujarat, western Maharashtra, Goa, Karnataka and Kerala states of India (Figure 1). Benthic terrain analysis and topographic terrain analysis is carried out only in the Eastern Arabian Sea and South-western part of India respectively. The Western Ghats, a mountain range of about 1600 km, that runs almost parallel to the western coast of the Indian peninsula, is an important feature that forms the catchment area for complex riverine drainage systems that drain almost 40% of India. Except a small part of the

area around Mumbai, and along the eastern limits, the State of Maharashtra presents a monotonously uniform, flat-topped skyline. The Eastern part of Arabian Sea extends from the lower part of Gujarat to southern part of India and consists of Arabian Basin, some part of the Chagos-Laccadive Islands and ridges, Laccadive Plateau. In the South-Western part of the Arabian Sea, some part of the Carlsberg Ridges are covered in the present study area.

Figure 1 A) India map showing study area. B) Structural and topographic map of South India. C) Map showing sea bottom topography of Eastern Arabian Sea.



3. MATERIALS AND METHODOLOGY

3.1 Data

The materials used in the present study is essentially the satellite-derived elevation data available free from various sources and the GIS software tools.

The NASA Shuttle Radar Topographic Mission (SRTM) data available at http://www.cgiar-csi.org website with a resolution of 90m (mosaicked 5^0 x 5^0 tiles) is used to carry out the topographic analysis of the western India to derive the terrain variables slope; terrain variability (rugosity) and relative position (Benthic Position Index (BPI)) from the bathymetric data. The ASTER 3D remote sensing data also with 90 m resolution is been taken from http://www.landcover.org site is used to validate terrain analysis of southern Maharashtra and Goa region.

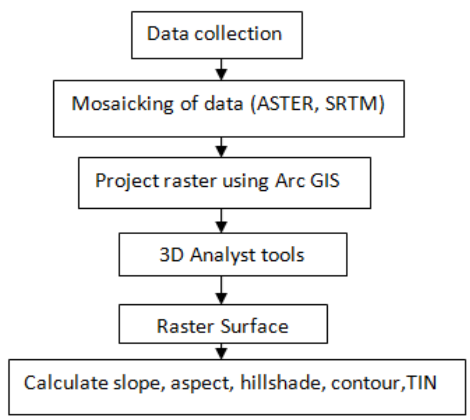
The Bathymetry data (ETOPO) was downloaded from the Intranet web-site (http://colva.nio.org) of CSIR-National Institute of Oceanography, India. The ETOPO bathymetry data set is based on satellite altimetry digitization of depth contours greater than 200 m. Hence, data is not useful for shallow water regions. An improved shelf bathymetry for the Indian Ocean region (20°E to 112° E and 38°S to 32°N) is derived by digitizing the depth contours and sounding depths less than 200 m from the hydrographic charts published by the National Hydrographic Office, India. The digitized data are then gridded and used to modify the existing ETOPO5 and ETOPO2 data sets for depths less than 200 m (Sindhu et al 2007).

The study makes use of the spatial analyst tools in Arc GIS 10.2 software and the Benthic Terrain Modeller extension of Arc GIS 10.2 version is used to obtain slope, depth, and rugosity maps using broad scale BPI, fine scale BPI, standardized BPI'S to the classification of benthic terrain using the above-mentioned derivatives. Slope calculations provided information on the characteristics of the seafloor and indicate regions of the flat and undulating seabed and helped in identifying 51 areas of rock outcrop and seafloor structures such as sandbanks and other bedforms. The rugosity analysis helped to identify areas with potentially high biodiversity by describing a topographic roughness with a surface area to planar area ratio.

3.2 Methodology

The general workflow of on the methodology adopted in the present study is given in Figure 2. The following paragraph discusses the steps involved in surface analyses for generating a surface model of the study area.

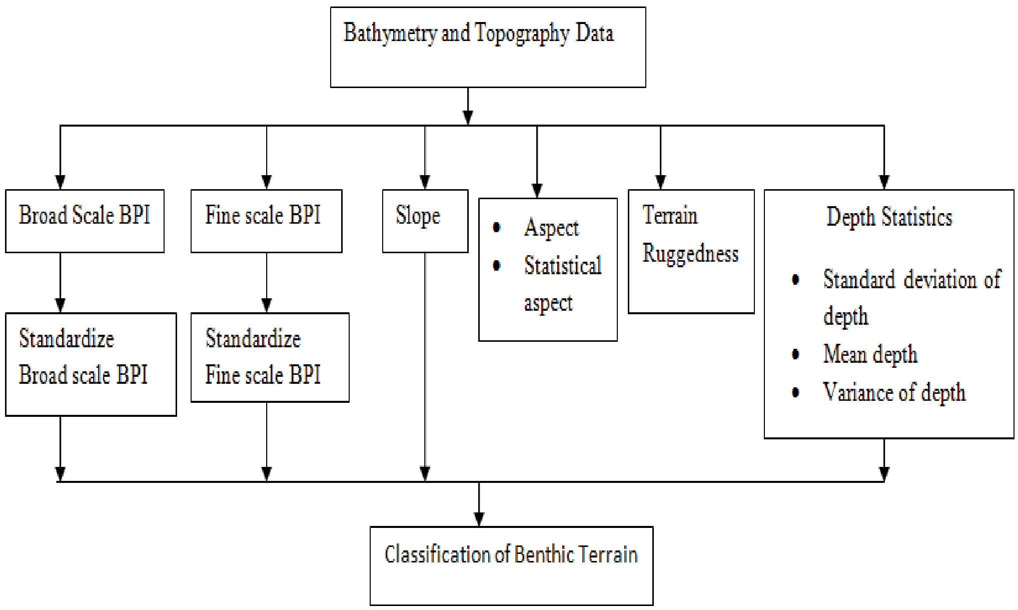
Figure 2. Methodology flow chart



3.2.1 Surface Analysis

The surface analysis involves several kinds of processing, including extracting new surfaces from existing surfaces, reclassifying surfaces, and combining surfaces. For this analysis, we have used spatial analyst Extension and 3D analyst extension of Arc GIS 10.2. This methodology is described in the steps to create a surface model with Triangulated Irregular Network (TIN) command in ARC/INFO toolbox. The model will focus on steps to calculate the independent variables of topography i.e. Slope, Aspect, and Elevation. Surface analyses using the mosaicked tiles of SRTM data and ASTER data were carried out to generate the surface. Since, Slope and Aspect play a vital and role in terrain analysis, hill shading and 3D view, the Topographical functions were run to derive the two important terrain parameters, i.e. slope and aspect. The Slope tool calculates the maximum rate of change from a cell to its neighbours, which is typically used to indicate the steepness of the terrain. The ASPECT tool calculates the direction in which the plane fitted to the slope faces for each cell. The aspect of a surface typically affects the amount of sunlight it receives (as does the slope); in northern latitudes, places with a southerly aspect tend to be warmer and drier than places that have a northerly aspect. Hill shade shows the intensity of lighting on a surface is given a light source at a particular location; it can model which parts of a surface would be shadowed by other parts. After calculating slope, aspect, and elevation, it is necessary to convert the DEM type data into the functional TIN format. TIN store slope and aspect information as attributes of the TIN facets. Rather than deriving slope and aspect for TIN surfaces (as one does with raster terrain models, which only store the elevation values), one simply needs to extract that information from the facets to a set of polygons (Figure 3).

Figure 3 Flow chart depicting classification of Benthic Terrain model



3.2.2 *Benthic Terrain Classification and Mapping of Eastern Arabian Sea*

The Benthic Terrain Modeler (BTM) algorithm originally developed by Lundblad et al. (2006) which available as an ArcGIS Tool was adopted in the present study for the classification of benthic features. The tool was developed in 2005 to facilitate the mapping and characterization of benthic morphological features that are sometimes associated with some kinds of marine species. Rockfish, for example, is commonly found on or near hard complex structures, sand eel is normally associated with sand banks. Following Sidhu et al., 2007 the ETOPO2 data set has been used in the Benthic Terrain Modeller for ArcGIS functions to calculate the following parameters from the Bathymetry Data that are shown in Figure 3.

<u>Bathymetric Position Index (BPI) Grids</u>: Terrain analysis applications used for mainly to understand the topographical features and to find out its suitability for habitat mapping. To understand the topographical features in marine environment it's important to generate the Bathymetric position index. So that it can be further used for habitat mapping. Without identifying the topographical features its nearly impossible to map the marine habitats. Creation of Bathymetric Position Index (BPI) data sets at two different scales is central to the methods behind the benthic terrain classification process. BPI is a derivative of the input bathymetric data set and is used to define the location of specific features and regions relative to other features and regions within the same data set. Bathymetric position index is normally determined at three scales:

- **Broad-Scale BPI** (broad-scale BPI data set is created that allows identification of the larger regions within the benthic landscape);

- **Fine-Scale BPI** (a fine-scale BPI data set to identify smaller features within the benthic landscape) and the
- **Standardized BPI** (a standardized BPI data sets that actually is used to classify/ identify various benthic zones and structures.

The derived benthic parameters for mapping the study area include the *Aspect* and *Slope* (the raster maps to be used for classification tools), slope and aspect has been calculated to understand the topography of the ocean floor and it will help us in habitat mapping. Due to slope habitats of certain species has been changed. The *Curvature* (surface of 'slope of slope' raster, that can be used optionally to calculate plan and profile curvature), *Depth Statistics* (mean, variance and standard deviation, over a set neighbourhood size which are useful predictors in understanding the benthic zones in analyses tasks like habitat classification). Depth statistics are very useful parameter to understand the depth variation which occurred due to the variance in topographic features. The marine habitats are mostly dependent on depth variance. Species variation in ocean mostly occurred by the changes in the depth.

The Classify function of Benthic Terrain Modeller creates a user-defined structures layer based on BPI's, slope, standard deviation breaks, and depth. The benthic zones in the output layer include various features (crests, depressions, flats, and slopes) of geomorphologic interest. The identified benthic structures in the output layer include narrow depression, local depression on flat, lateral mid-slope depression, depression on crest, broad depression, broad flat, shelf, open slopes, local crest in depression, local crest on flat, lateral mid-slope crest, narrow crest, and steep slope (Figure 3).

Terrain Ruggedness (VRM) function measures terrain ruggedness, or rugosity, as the variation in the three-dimensional orientation of grid cells within a neighbourhood. Terrain ruggedness is an important parameter for analysing the terrain classes because due to the rugosity the depth varies and which influence the marine habitats. Vector analysis is used to calculate the dispersion of vectors normal (orthogonal) to grid cells within the specified neighbourhood. This method effectively captures the variability in slope and aspect into a single measure. Ruggedness values in the output raster can range from 0 (no terrain variation) to 1 (complete terrain variation). Typical values for natural terrains range between 0 and about 0.4.

4. RESULT AND DISCUSSION

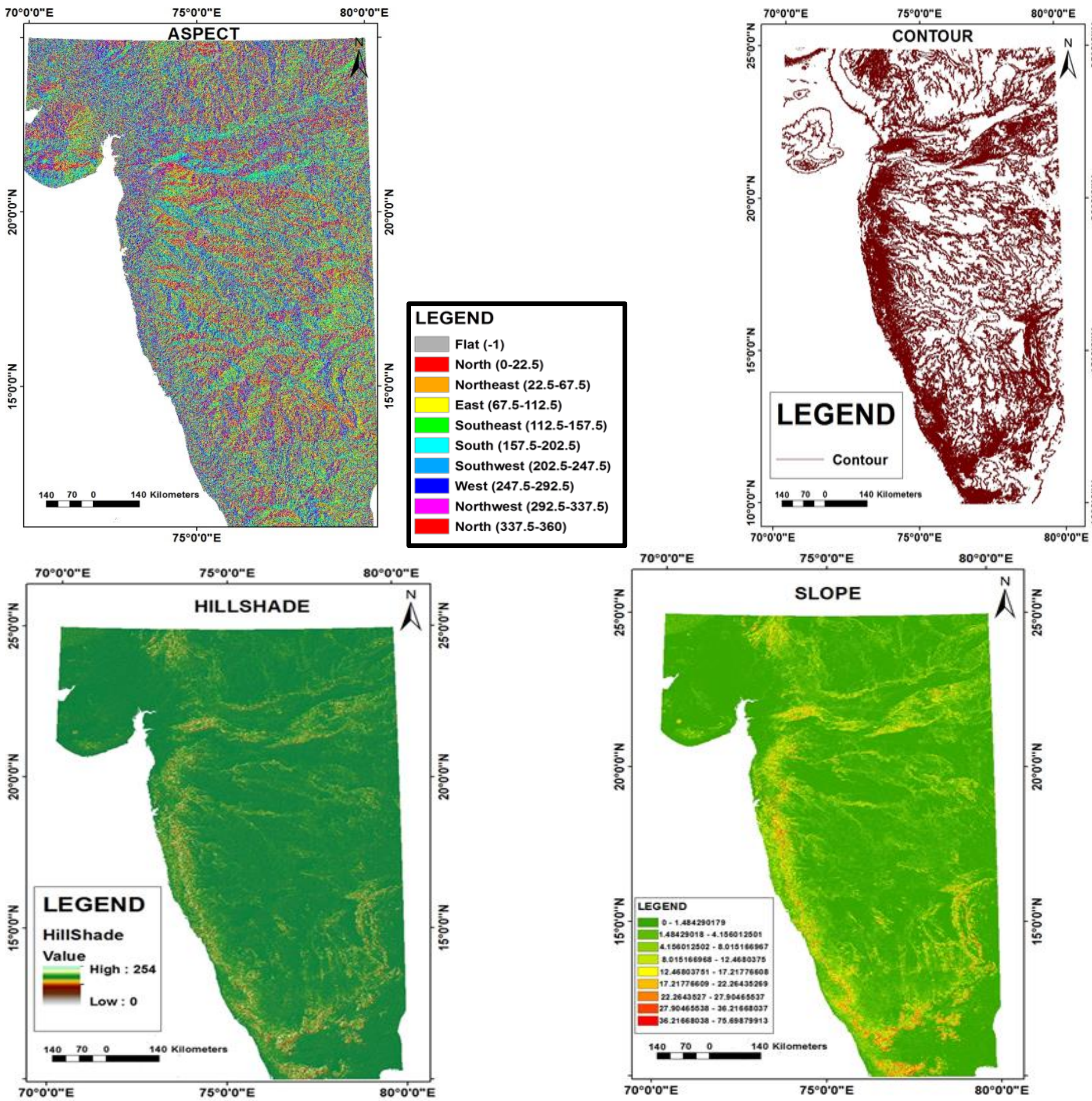
The results obtained from the Terrain analysis using the SRTM, ASTER and ETOPO data for identification of the various Geomorphologic features have been summarized in the following paragraphs

4.1 Results from SRTM and ASTER datasets

Surface characteristics derived from the SRTM data have been interpreted to understand the Geomorphology of a part of Gujarat, Maharashtra, Goa, and Karnataka. The higher/steep slopes (higher values shown in yellow, Figure 4) have been observed that correspond to the Western Ghats region, along the Tapi rift the slope. Some part of the Karnataka Plateau also is showing high values in slope. Hillshade maps are interpreted to understand the intensity of lighting on a surface, given a light source at a particular location that can model which parts of a surface would be shadowed by other parts. Hillshade map of the Western Ghats region, Tapi rift the Hillshade value is low, showing the shadows of the hill due to the high range of the slope. The aspect of a surface typically affects the amount of sunlight it receives (as does the slope). Along the Western Ghats, Tapi rift the slope direction varies from southeast to North West (Figure 4). The aspect values depend on upon the slope of that area. A clear demarcation of the geomorphological setting is observed from the TIN surfaces wherein the regions of the Western Ghats, Deccan trap and the

Tapi Rift showing higher values and the west coast with lower slopes showing the very low TIN values. The prepared contour map based on the SRTM data at 100 meters' interval is quite sufficient enough to differentiate the mountainous regions from that low-lying coastal areas for the study area. Comparable results have been obtained from the slope, aspect and Hill shade surface derived from ASTER data. (Figure 5). The entire Goa region shows relatively low values in contours (Figure 6).

Figure 4. Maps like slope, aspect, counter and Hill shade deduced from Digital Terrain model using SRTM dataset.



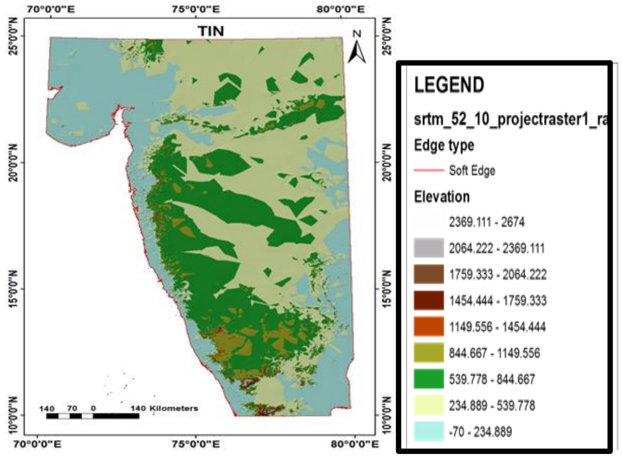
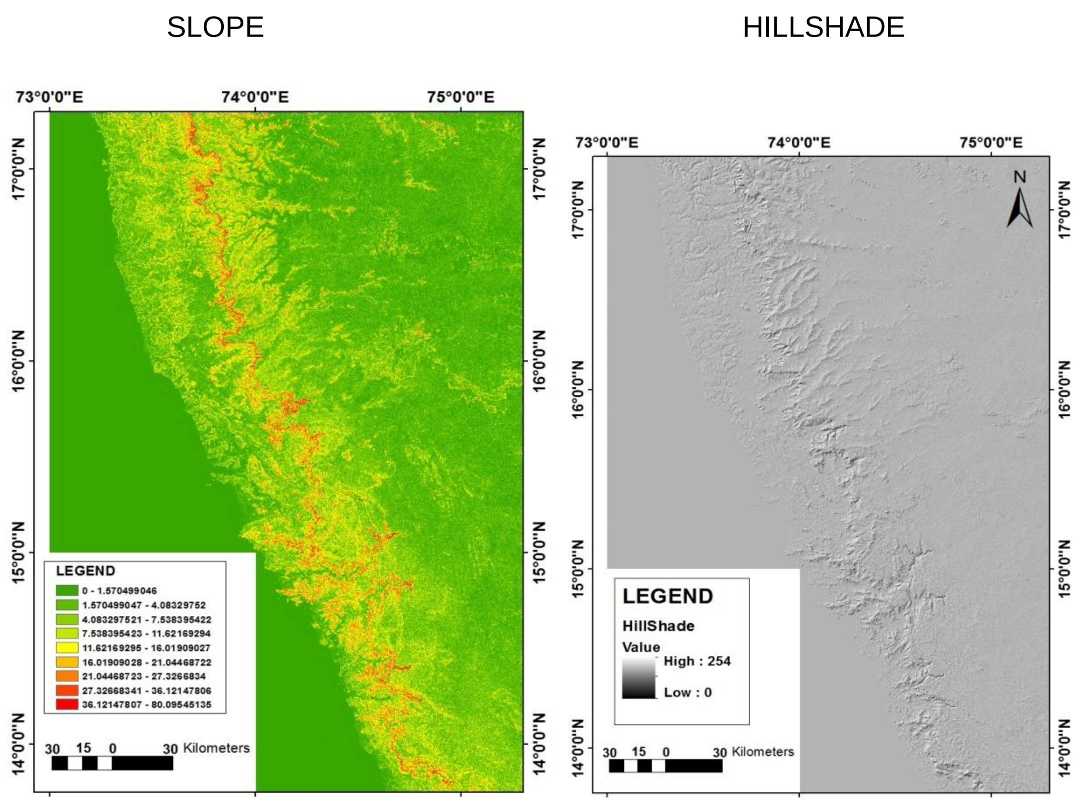


Figure 5. Slope and Hill-shade maps of south-west India derived using ASTER data.



4.2 Bathymetry and Topography Data

For the Classification of Benthic Structures of the study area, the digitized ETOPO2 dataset is used to identify and understand the various terrain features present. The study area has been classified into following 7 different structures (1. Broad flat terrain, 2. Depression, 3. Mid-slope Ridges, 4. Open slopes, 5. Upper slope ridges, 6. Mid-slope depressions and 7. Lower bank shelf) based on the general classification scheme of benthic terrain (Figure 7)

The land portion of the study area depicted as a broad flat terrain. The Arabian Basin area classified as the depression because of the low slope value. Along the west coast, the continental slope area classified as the lower bank shelf area. Chagos-Laccadive ridges and some part of the Carlsberg ridge and minor ridge such as Laxmi ridge classified as upper slope ridges. Indus cone area classified as mid-slope areas with ridges and depressions.

4.2.1 Bathymetric Position Index

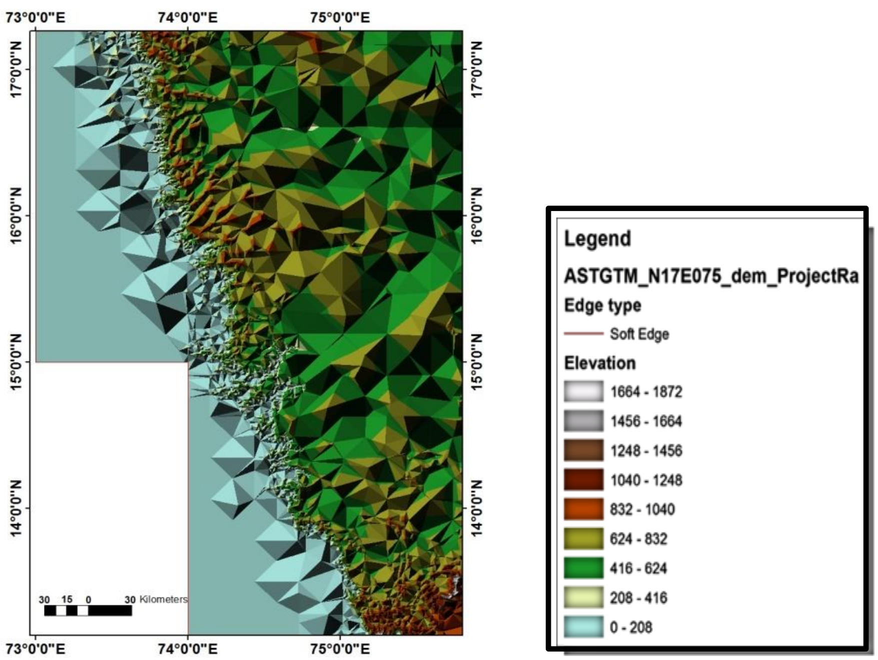
The creation of Bathymetric Position Index (BPI) data sets at two different scales is central to the methods behind the benthic terrain classification process (Figure 8). BPI is a derivative of the input bathymetric data set and is used to define the location of specific features and regions relative to other features and regions within the same data set.

The results of BPI are scale dependent, different scales identify fine or broad benthic features. To achieve the best BPI zone and structure classifications grids were created for study site. The broad scale grid created with a scale factor of 250 is used to identify the broad-scale features of the Eastern part of the Arabian sea extension of the area is 60°0'0" E to 80°0'0" E and 0°0'0N to 20°0'0N, and also the broad-scale features of the entire study area. The broad scale BPI for the Arabian basin area is shown in purple colour. The BPI value ranges between 4080 to -3078. Depressions and depth areas are showing the lower values.

Ridges and broad flat terrain areas are showing higher values. The Fine-scale BPI grid was created with a scale factor of 20. The main features identified from the fine scale BPI is the continental slope area along the west coast shown in brown colour (Figure 8) wherein values range between 2661 to -1503. With the major feature like continental slope, mid-slope, and upper slope ridges, Abyssal plain area can also be identified. High values indicated steeper slope areas and lower values indicated the depression and flat areas. For the present study, the Standardized BPI dataset is used to identify various benthic zones and structures.

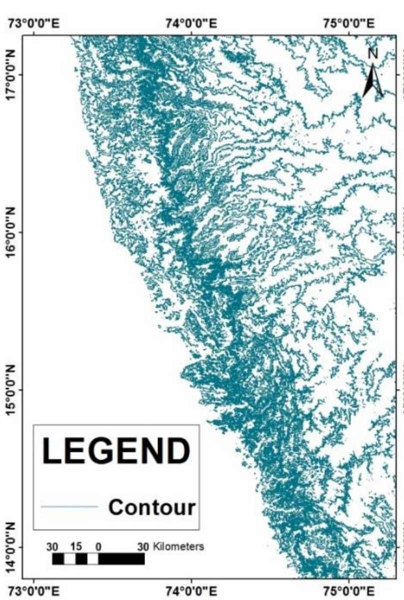
Figure 6. Contour, Aspect and Tin maps of south-west India derived using ASTER data.

TIN



CONTOUR

ASPECT



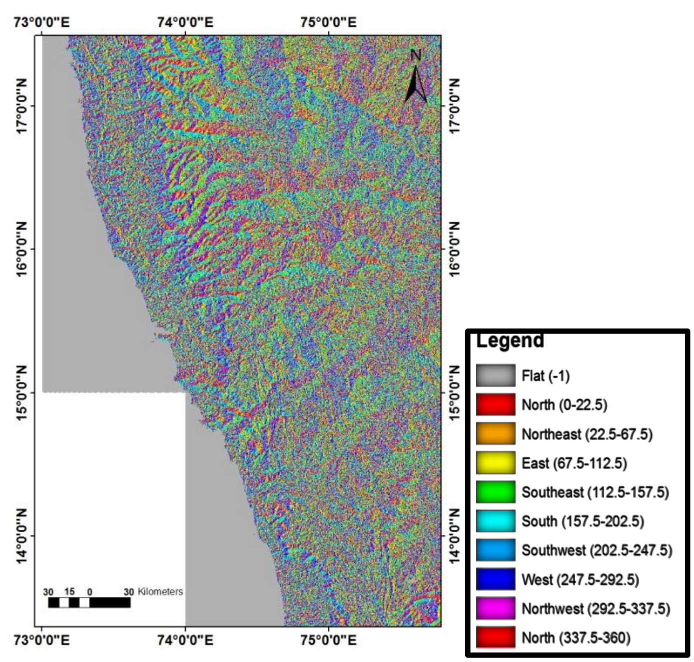
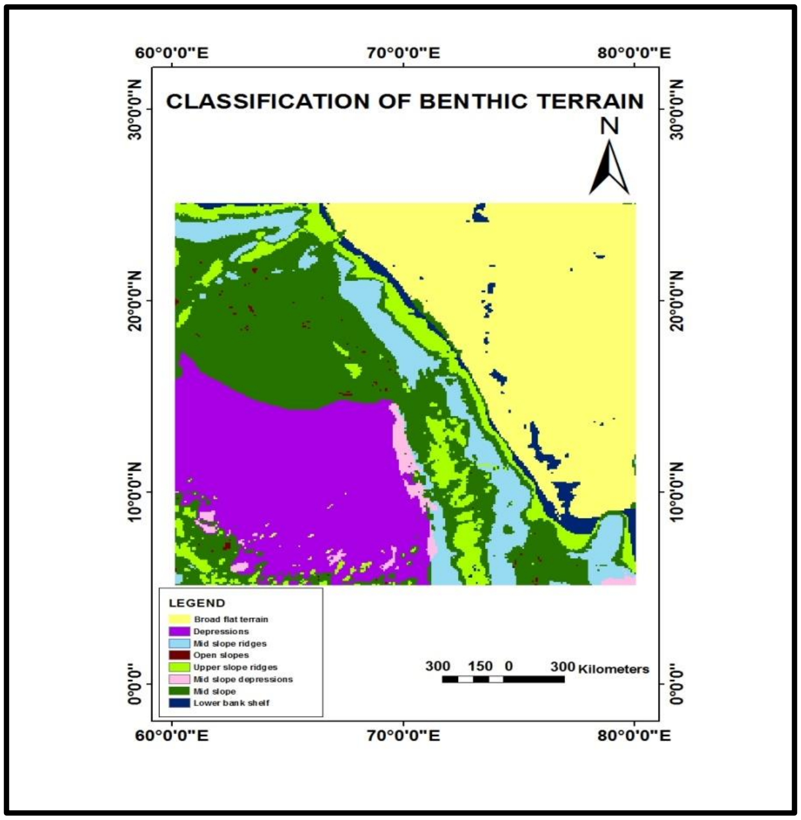


Figure 7. Benthic terrain classification map of Eastern Arabian Sea.

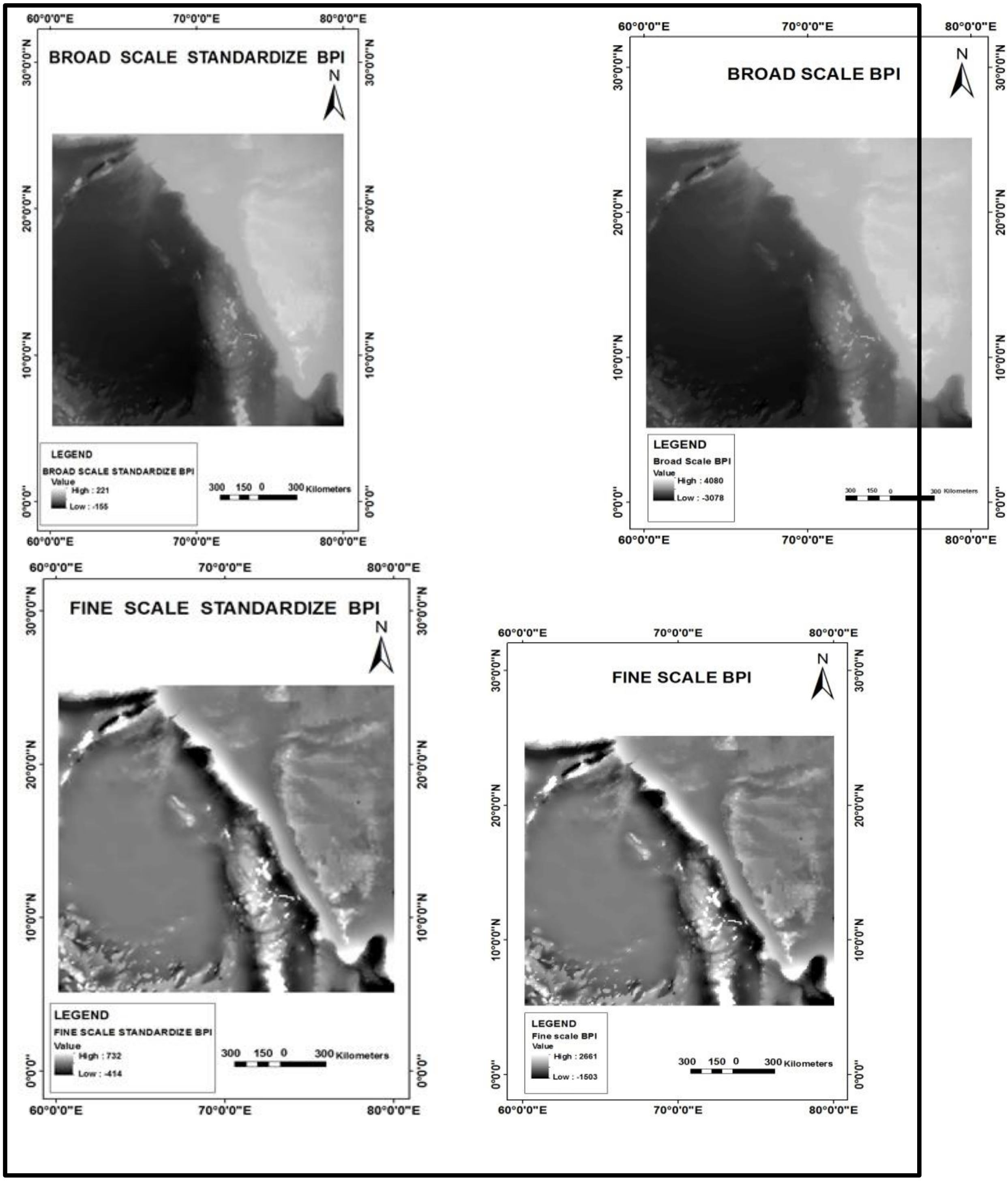


4.3.2 Slope: The_Slope, representing a terrain's angle of inclination in relation to a flat surface at sea level, expressed in degrees is the measure of the steepness of first-order derivative, which has been derived using the ArcGIS BTM spatial analyst extension, was used for the classification benthic structures. The Arabian basin area is clearly identifiable with its lower values suggesting a relatively lower/gentler slope (Figure 9).

4. 3.3 *Curvature:* Curvature is used to determine the slope of the particular slope. It can be different types profile curvature or plan curvature. For this study, we prepare curvature map which was used in the classification scheme of benthic terrain (Figure 9).

4.3.4 *Aspect:* Aspect was used to describe the direction of slope of the study area. Aspect raster had been used for the classification of benthic structures (Figure 10).

Figure 8. Maps showing the benthic terrain classification using Bathymetric Position Index (BPI) data sets at fine, broad and standardized scale



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4.4 Statistical Aspect

4.4.1 Sin (Aspect) raster

It is the sine function of input surface aspect. In this output surface aspect values range between -1 and 1. The Arabian basin area is showing higher values whereas the ridges and continental slope areas are showing in lower values and relatively darker in colour than the Basin area or flat areas (Figure 11).

Figure 9. Slope and curvature of slope maps of Eastern Arabian Sea.

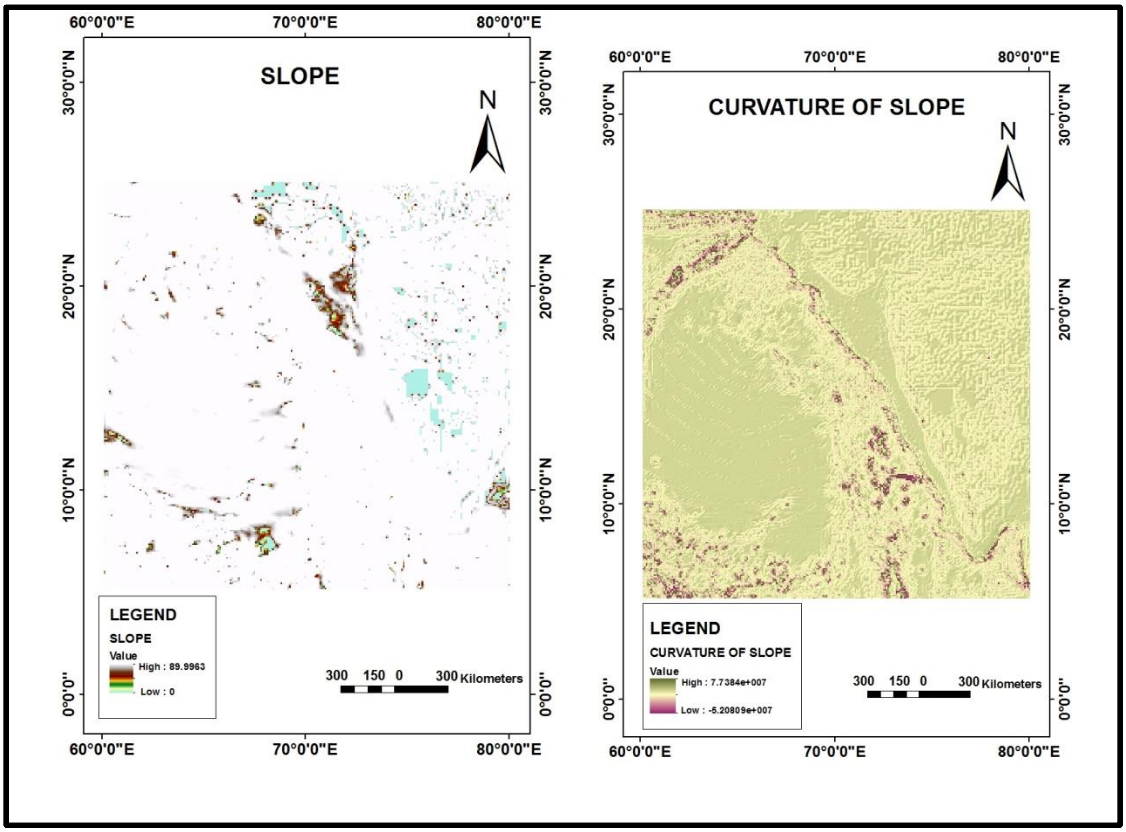
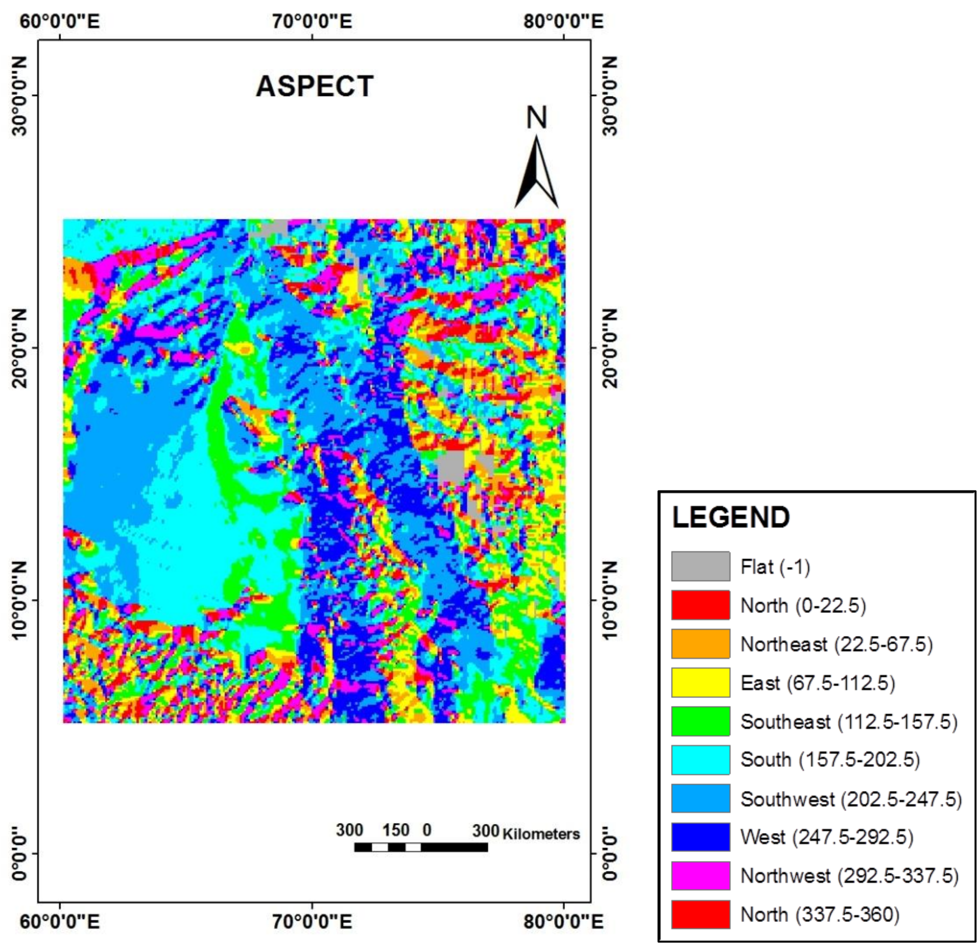


Figure 10 Aspect map of Eastern Arabian Sea



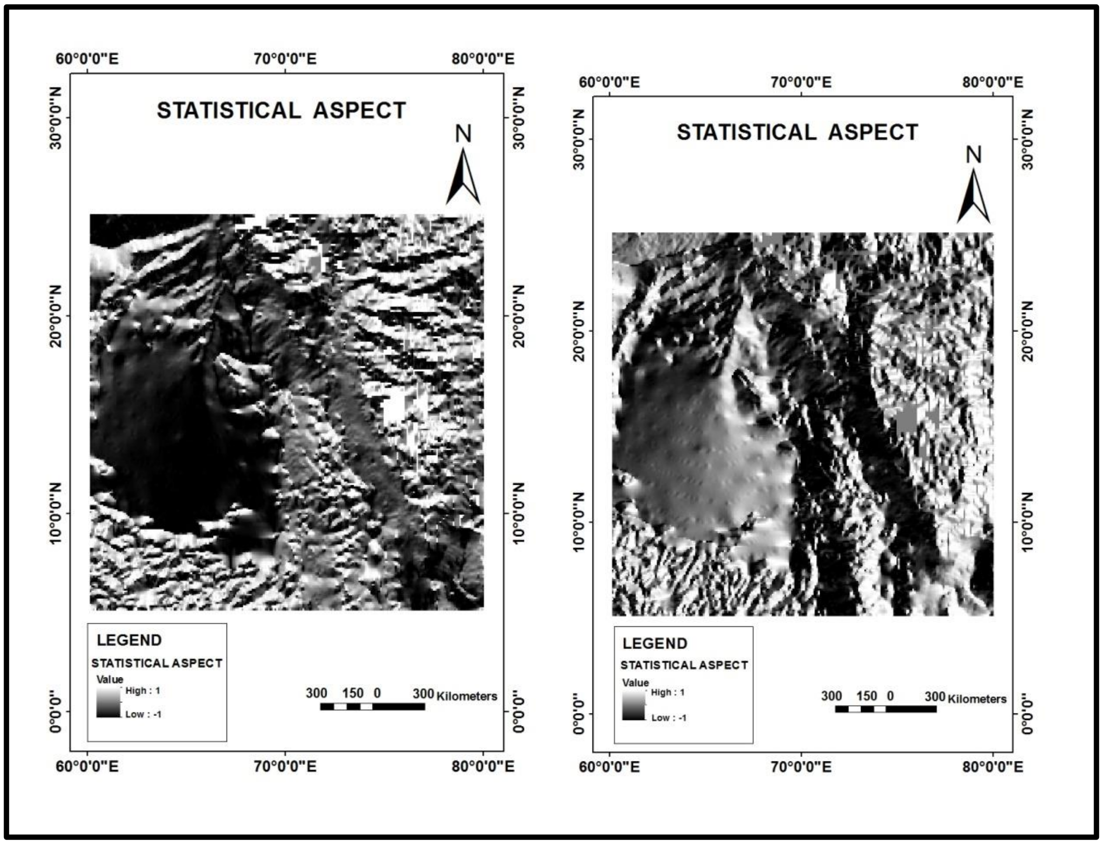
4.4.2 Cos (Aspect) raster

It is the Cosine function of the input surface aspect. In this output surface aspect values varies from -1 to 1. In this statistical aspect calculation, it is showing the opposite to the sine function. The flat areas and depressions are showing low values and relatively darker than Ridges and slope areas. Chagos-Laccadive ridges, Carlsberg ridges, and slopes are showing higher values and lighter in tone than the depressions and Basin areas.

4.4.3 Depth Statistics

Depth statistics, such as mean, variance, and standard deviation, over a set neighbourhood size, has been calculated for the study area. These statistics used as predictors in understanding the benthic zones in analyses tasks in benthic structures classification.

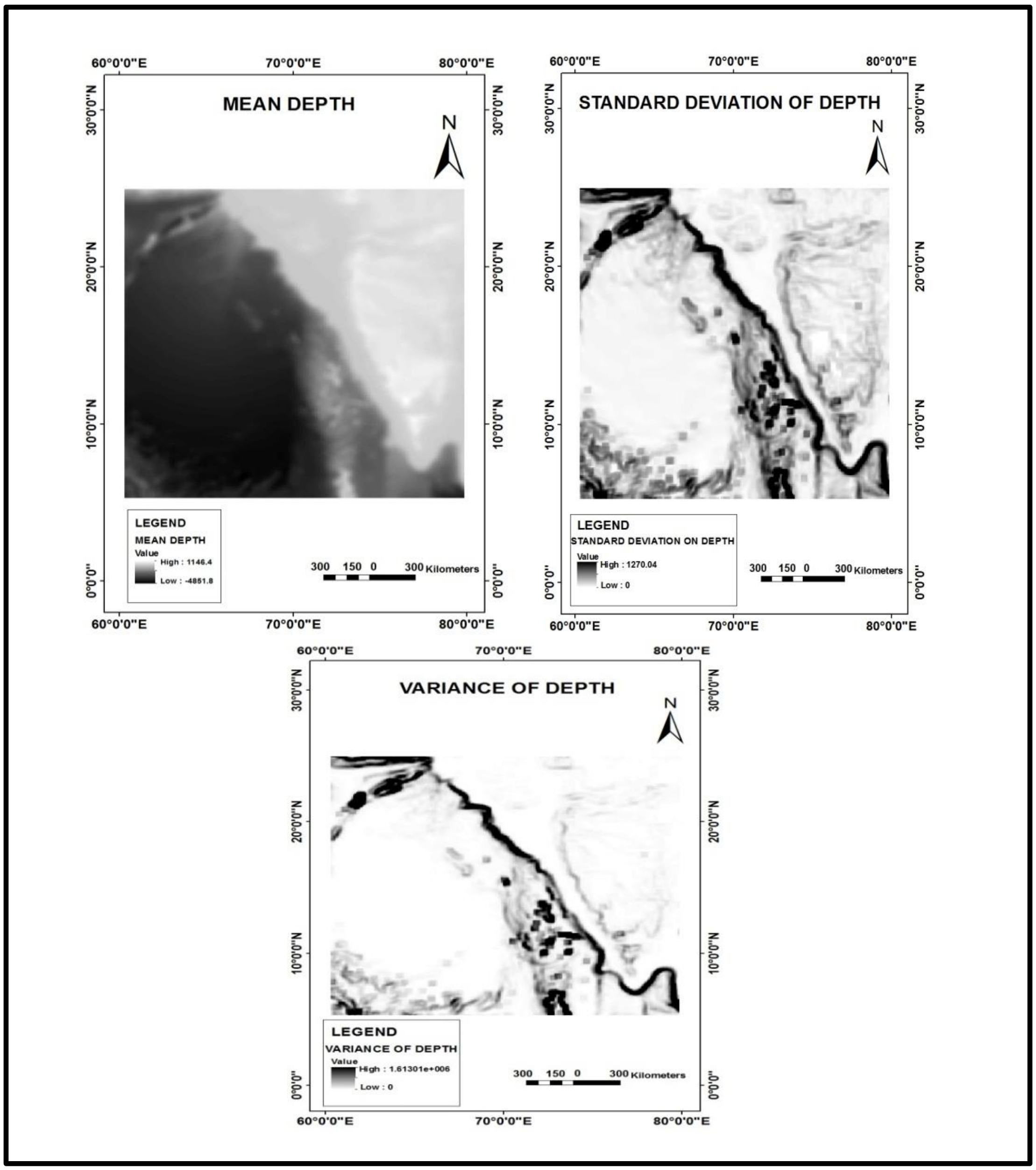
Figure 11. Statistical (Sin & Cos) Aspect map of Eastern Arabian Sea



Mean Depth: Mean of depth has been calculated on the average over the neighbourhood, ranges between 1590.25 to -4992. The Arabian basin area is showing negative values and in a darker tone. The flat terrain and Chagos-Laccadive and some part of Carlsberg ridges areas are displaying positive values and relatively lighter in tone than compared to Basin areas.

Standard Deviation and Variance of Depth: Standard deviation and Variance are two forms of the same statistical measure. It is used to identify the differences/variation within the data. The value of standard deviation of the depth of that area varies from 0 to 912.909. The Basin area is showing lower values and the continental slope areas and Chagos-Laccadive ridges and other ridges are showing higher values relatively darker tone. The Basin area is showing lower values and the continental slope areas and Chagos-Laccadive ridges and a part of Carlsberg ridge are showing higher values (Figure 12). Carlsberg ridge is showing higher values and relatively darker tone.

Figure 12. Standard deviation and Variance depth maps of Eastern Arabian Sea



Terrain Ruggedness measures rugosity, as the variation in the three-dimensional orientation of grid cells within a neighbourhood. Ruggedness values in the output raster can range from 0 (no terrain variation) to 1 (complete terrain variation). Rugosity values near one indicate flat, smooth locations; higher values indicate areas of high-relief. Rugosity calculated using this technique is highly correlated with the slope. The highest rugosity values show a relationship with the high slope and lower rugosity with a low slope. In the Arabian basin area, rugosity is low because it related with the low slope. But along the oceanic ridges of Chagos-Laccadive and Carlsberg and minor ridge along the northern part of Arabian Sea Laxmi ridge the rugosity value is high and it is related.

5. CONCLUSIONS

The classification scheme developed introducing the concepts of BPI zones at a broad resolution (depressions, slopes, flats) and structures (finer features within zones) around the study site provides an important dataset for understanding the Geomorphology of the benthic terrain. The terrain was classified by measuring rugosity, slope, depth at a broad scale, small scale, and standardized BPI'S. Benthic Terrain analysis of deep-water bathymetry is complicated by the fact that on the continental slope we obtain data at different resolutions. We have shown that a variety of methods exist for terrain analysis on these data and these have been successfully applied to the generation of a suite of quantitative descriptor variables of relevance to benthic terrain classification. Using the Benthic Terrain Model in Arc GIS 10.2 version the methodology adopted in this work can be easily transported to the study of other areas and other types of terrain classification. It constitutes an interesting alternative for the good exploration of pre-existent data which could be re-analyzed seeking regional scale habitat prediction. Increased awareness and availability of multi-scale and Multibeam Hydrosweep echosounder data methods should help promote their use in terrain analysis using bathymetric data for terrain classification mapping and related work.

This benthic terrain modelling can be used for identification of marine resources and habitats. It can be useful for identifying different ecosystems in the marine environment. Benthic terrain mapping can be useful for the spatial planning of marine and coastal areas. It can be done at regional and national level planning for management purposes. For better management purpose it can be correlated with sediment data, geology data, distribution of different marine species and fisheries data. This will help to improve the socio-economic level of the coastal and marine areas.

Terrain analysis is a key element in 3D Visualization, Flight Simulation, Project Cost Estimation, Cut and Fill Calculations, Route Feasibility, Environment and Risk Assessments, Line of Sight Analysis, Surface Analysis, Watershed Analysis etc. At present, it seems GIS-based methods are the most readily available to the scientific community. However, further development of wavelet methods may yield more efficient and flexible computation in the future. The study demonstrates that Geospatial technique as most efficient, cost-effective and easiest tools for surface/benthic terrain analysis and mapping provides most of the data for the development of SDIs for Coastal and marine regions.

5.1 Suggested Work plan for Developing Coastal and Marine Spatial Data Infrastructure (CMSDI)

Identify data holder's/service providers, conduct training/awareness programs, determine user requirements (formats for distribution, metadata required, data needs, areas for focus), Develop roadmap for SDI implementation, Developing, and implementation and finally to Establish support and engagement.

6. ACKNOWLEDGMENTS

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