Geomorphometry and Micro-watershed Basin Delineation using RS and GIS: A Case Study of Micro-level Geodatabase Creation of Salcete Taluka, Goa

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***Abstract*—The management of natural resources has become a complex task as more and more socio-economical activities (such as urban development, agriculture, shipping, harbor development, fisheries, oil and gas production, waste disposal and nature conservation) take place in coastal areas. Creation of micro-level database that facilitate better management and administration of coastal areas has become routine practice. Use of Remote Sensing (RS) and Geographic Information Systems (GIS) were found to be effective in preparing, maintaining and updating of databases and carrying out analysis related to natural resource management. The present paper deals with creation of micro level geodatabase particularly with reference to understanding the physiography, drainage and delineation of mico-watershed basins using the RS-GIS technology for watershed management. Salcete Taluka represents a typical dissected dendritic pattern of drainage network with low lying flat terrain in the west and hilly terrain towards the East. Beautiful beach stretches and elongated dunes in the coastal stretch and tidal mud flats are observed in the western part of the study area while hilly regions with elevation values of 350mts are observed towards the interior on the eastern side of the area. Despite heavy rainfall in the study area the observed soil erosion is moderate. In all 35 sub-watershed basins have been delineated with the total area is 102 sq.km.**

***Keywords:* Natural Resources, RS-GIS, Geodatabase, watershed, Goa**

I. INTRODUCTION

Over the past years the advancement in Remote Sensing and Geographical Information System (GIS) technology made it possible for the integrated study of the multiple themes to derive the required information in the desired format. Remotely sensed data can be utilized to provide information on space in a hydrological unit. Indeed the ability to provide synoptic coverage, while at the same time to permit point definition, is of the major asset of remotely sensed data in hydrological studies. Degradation of land and water resources, along with the spatial and temporal variations constitutes the problems of watershed. Soil erosion which in turn reduces productivity due to the loss of fertile soil, mass movements such as landslides, degradation of water quality, water logging, salinity, alkalinity, floods and droughts are some of the issues which necessitate watershed management measures. Watershed management is the process of formulating and carrying out a course of action involving manipulation of the natural system of watershed based on various thematic and resource maps to achieve specified objectives.

While, the remote sensing data is operationally being utilized for mapping resources, the need-ahead is towards integrating these resource maps with other resource information for generating action plan for a particular activity. GIS serves as an efficient system of compilation, classification, storage, synthesis, analysis or retrieval of relevant information of spatial and non-spatial origin.

In the present study, a modest attempt has been made to prepare a micro level digital database of the Salcete Taluka which includes preparation of various thematic maps such as contour maps, drainage network map, road map and soil maps and finally creation of the Digital Elevation Model (DEM) in order to get a three-dimensional view of the terrain of the study area. Except the work of De Souza(1965, 1968), Wagle and Mishra(1975), Wagle(1982), Iyer and Wagle(1982) who dealt with the geomorphic features in detail and the drainage in general, no work exist as regards the morphometric parameters of the river basins in Goa in general and in the present study area in specific. This paper discusses the coastal morphological features, the drainage network and their characteristics and provides a micro-level database of watershed basins. RS and GIS based thematic maps (Elevation, Drainage, rainfall and soil characteristics) and the related data(DEM creation, and Morphometric parameters) useful in watershed management study.

A. Study Area

Present study area (Fig. 1) the Salcete taluka is located in the South Goa District of Goa State. It is

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bounded between Latitudes 15°07'30" to 15°22'30" and Longitudes from 73°52'30" to 74°07'30". The area is represented on the Survey of India toposheet numbers 48E/15 and 48E/16 on a scale of 1:50,000. To the north-eastern portion of Salcete flows the perennial Zuari river which separates the study area from the Ponda taluka. Towards the eastern part flows the Kushwati river which is a tributary of river Zuari. The western margin of Salcete taluka is bounded by beautiful sandy beaches trending NNW-SSE, more or less in a straight line facing the Arabian Sea.

Fig. 1: Location Map of Study Area

Physiographically, the Salcete area comprises of almost flat plains along the coast with isolated hillocks in the north, north-eastern part of the study area. The northern part consists of mainly isolated flat topped hills which are gentle to steep sloping with vegetation in the form of shrubs categorizing an open jungle. Towards the north-eastern part there are steeply sloping isolated hills which exhibit a trend of NNW-SSE with fairly dense mixed jungles. The area experiences warm and humid climate as it is close to the sea-shore. Temperature ranges between 20°C to 35°C depending on the season. The humidity during monsoon period is high varying from 90 to 95 percent and for the rest of the year; it ranges between 80 to 85 percent. The annual rainfall is in the order of 300 to 350 cm/yr.

II. Materials and Methods

Data from various sources were used to carry out the study which is given below:

A. Primary Data

Satellite imagery (False Color Composite) Geocoded IRS-1C Band: 123 of the year 2001 on a scale of 1:50,000 was obtained from NRSC, Hyderabad.

B. Secondary Data

Survey of India Toposheet numbers 48E/15 and 48E/16 on 1:50,000 scale in order to prepare a Contour, Drainage and Road network maps of the Study area and Soil Survey Atlas of Goa.

C. Software Used

Erdas Imagine (version. 9.2) and ArcGIS9.3 have been used in the present study.

The methodology adopted in the present study is given Fig. 2.

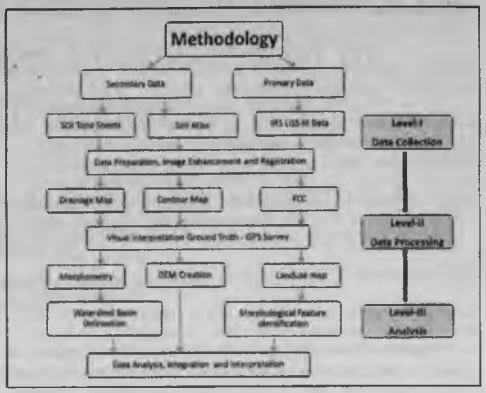

Fig. 2: Flow Diagram of Methodology

III. Results and Discussions

Coastal Morphology The coastal morphology of Salcete comprises of a narrow beach (50-80m wide) in the back-shore followed inland by a zone of sand ridges occurring in segmented manner and each segment is about 500m and forms a conspicuous part of the fragile coast. The Aeolian zone is comprised of the nearby dunes where the height of the individual dune is 0.5 to 3m and the interior dunes where the height of the individual dune is 2 to 4m. Due to the detached nature of the dune sand ridges, there is little natural protection against high tides and storm surge incursions. Further the ridges are subjected to wind deflation especially during the dry seasons. On the western margin of the coastal estuarine plain of Salcete lies the longest linear sandy beach in the state of Goa with no rocky outcrops. Further inland, the estuaries of the Sal and the Zuari meander between relict hills and through their own estuarine mudflats and flood plains.

The sandy coastal plain extends from the ocean edge to the river Sal, which meanders from Cansaulim to Cavelossim and joins the ocean at Betul. The sand dunes (Plate-1; Photo.4) along the coast of Salcete between Utorda and Cavelossim display ridges which are parallel or slightly oblique to the shore and also are elongated perpendicular to the direction of the dominant winds. Their form is asymmetrical, with steep leeward slope and gentle windward slope and often attains an altitude of 10m at some places. The various morphological features as observed from Satellite Imagery and subsequent ground truth are listed in Table-1. The land-use classified map (Fig.3) was derived from FCC of Salcete and in all six landuse classes namely mangroves (Bright red), water bodies (Sky Blue), dense vegetation(Red & Green), moderate vegetation, low-lying areas and settlement areas(Brown).

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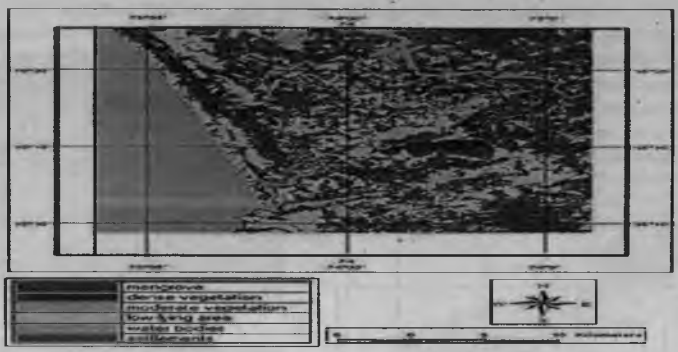

Fig. 3: Landuse Map of Salcete

TABLE I
MORPHOLOGICAL FEATURES OF SALCETE AS OBSERVED FROM FCC AND GROUND TRUTH

	Morphological Features	Typical Characteristics
1	Sandy Beaches	Western margin of the coastal estuarine plain, adjacent to the coast, white tone with smooth texture, fine sand particles, broken shells, etc. (Plate-1; Photo.1).
2	Elongated dunes	Half a kilometer inwards from coast, located behind beach, on the land-ward side stabilized by vegetation with red/ white tone, linear in shape and smooth texture.
3	Spit	Seen in southern end of coastline as narrow embankment, consists of sand/ gravel; white tone, smooth texture, associated with the open coast. (Plate-1; Photo.2).
4	River Sal	flows with a meandering course parallel to the beach stretch for about 4-5 km, dark blue tone
5	Mangrove swamps	a typical bright red tone with a smooth texture and are irregular in shape, usually located in the low-lying flats or inter-tidal areas, are evergreen grow on substrate where the percentage of mud is more. (Plate-1; Photo.6).
6	Tidal mud flats	Located along the Sal river show a brown/ black tone with irregular shape and are smooth textured, found along the lowest water line and low energy coasts, clayey, silty support vegetation at places (Plate-1; Photo.5).
7	Turbid waters	Turbid water comming from the northern side where the sediment dispersion is more and flowing towards south
8	Vegetation	Red colour tone for dense vegetation, seen towards the north-eastern and southern portion and around the Chandranath hill.

D. Drainage Map

The *drainage network* (Fig. 4) of the study area resembles a dendritic pattern. The dendritic network of streams is mainly localized around the hillocks in the eastern, north-eastern and southern portion of Salcete taluka and generally these streams disappear in the plain coastal areas before reaching any major drainage network due to higher permeability of the rocks in the plains, absorbing most of the surface run-off. Further, the drainage density decreases from east to west, when the rivers flow from the highlands to the midlands and then to the coastal tract. The major Rivers, Zuari flows along the north-eastern borders and the River Sal in the southern portion of the study area drains into the Arabian Sea. The Kushwati river which is an important tributary of River Zuari, flows along the eastern margin. It is perennial and meets the Zuari river near Chandor draining an area of 240sq.km. in a length of 45 km. The River Sal drains an area of 286sq.km. and has a length of around 40 km.

Fig. 4: Drainage Map of Salcete

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E. Contour Map

The contour values (Fig. 5) rise up to 170m with the highest peak in the northern part being of 178m above MSL situated between Nuvem and Loutolim. There are also high peaks encountered in the eastern portion of Salcete around Curtorim and Guirdolim with average elevation values going as high as 140m.

Fig. 5: Contour Map of Salcete

Moving further towards the south-eastern portion, one encounters the highest peak value of 350m which is observed at the Chandranath hill which is thickly vegetated comprising of fairly dense mixed jungle while the close spacing of the contours is indicative of Plate: 1 The Geomorpholoical Features of Salcete Area.

Photo 1: Mouth of the River Sal

Photo 2: Spit at the Mouth of River Sal at Mobor

Photo 3: Vegetation along the Beach Stretch of Salcete

Photo 4: Elongated Sand Dune Seen at Cavelossim, Salcete

Photo 5: Low-lying Areas in Colva, Salcete

Photo 6: Mangroves along River Kushwati at Macasana, Salcete

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Steep slopes. The southern boundary of Salcete comprises of elongated relict hills trending due NNE-SSW nearly in E-W direction with average contour values of 110m. The hills are steeply sloping and the topmost parts consisting of shrubs with cashew plantations.

F. Soil maps

The spatial distribution of various soil characteristics (texture, depth, drainage and erosion) of Salcete Taluka are presented in Fig.6(A, B, C & D). *Surface soil texture map* (*Fig. 6A*) was sub-divided into 5 classes(Sand; Sandy loamy clay loam; Loam-sandy clay loam; Gravelly clay-clay; Gravelly scl-gr-clay-gr.sl). *Soil depth map* (*Fig.6B*) was sub-divided into 5 classes (Deep; Moderately deep; Very deep; Moderately shallow depth and Very shallow depth). *Soil drainage map* (*Fig.6C*) was sub-divided into 5 classes (Poor soil drainage;

Imperfect soil drainage; Moderate soil drainage; Well drained; Some what excessive soil drainage); *Soil erosion map* (*Fig. 6D*) was sub-divided into 3 classes (Slight soil erosion; Severe soil erosion; Moderate soil erosion).

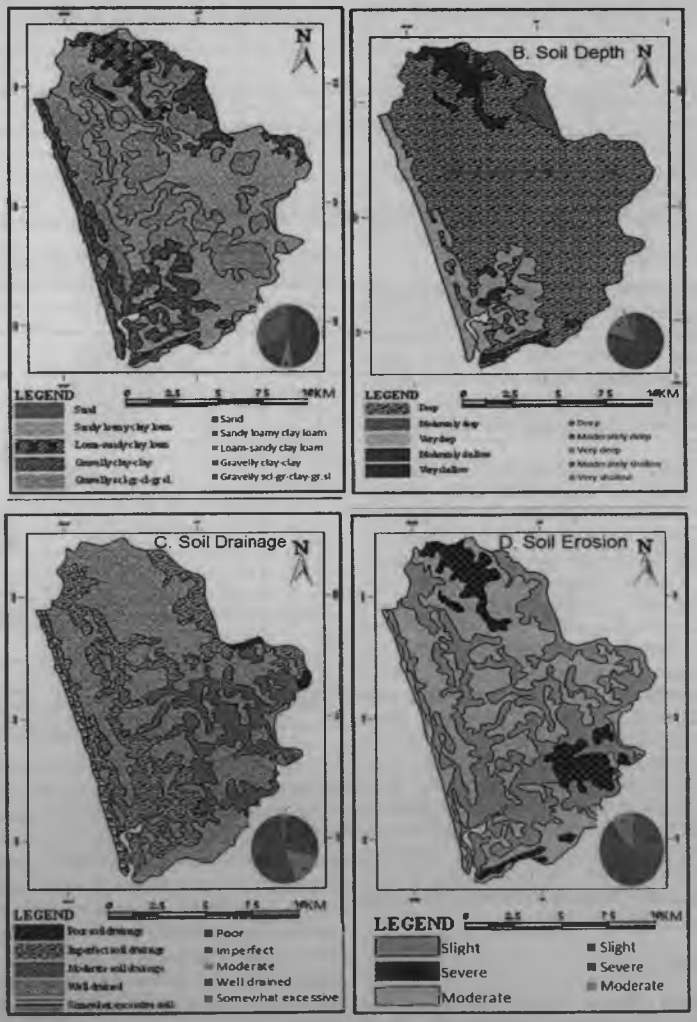

Fig. 6: Soil Characteristic Maps of Salcete

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TABLE 2
VARIOUS MORPHOMETRIC PARAMETERS

Stream Order(u)	Stream No. (Nu)	Stream Length (Lu)	Mean Stream Length (Lu)	Bifurcation Ratio Rb=Nu/N(u+1)	Length Ratio RL=Lu/L(u-1)
I	523	225112.94	430.43		
				5.62	1.59
II	93	63519.22	683.00		
				5.47	3.05
III	17	35441.23	2084.78		
				4.25	3.68
IV	4	30700.07	7675.02		
	€=637	€ =354773.46	€=10873.23	€=15.34	€=8.32
Ratio Parameter					
Arithmetic Mean Bifurcation Ratio: [Total of Rb/ Number of Ratios]					5.11
Weighted Mean Bifurcation Ratio: [Rb1×(N1+N2)+Rb2×(N2+N3) +…) Total No. of streams involved in all the ratios]					6.52
Arithmetic Mean Length Ratio: [Total of RL / Number of Ratios]					2.77
Weighted Mean Length Ratio: RL1×(N1+N2)+RL2×(N2+N3)+…)/Total number of streams involved in all the ratios]					2.19

G. Morphometric Analysis

The various morphometric parameters were calculated using the Drainage Network analysis of Strahler's (1957) System. The parameters viz., *Mean Length, Bifurcation Ratio, Length Ratio* together with *Arithmetic Mean Bifurcation Ratio*, Weighted *Mean Bifurcation Ratio*, *Arithmetic Mean Length Ratio* and *Weighted Mean Length Ratio* are calculated using the standard formulae and area are given in Table-2.

The distinct linear relationship depicted (Table-2) between the mean length and stream order satify Horton's (1945) second law of stream length. The varying character of the geometric series is expressed by the *Bifurcation Ratio* which is higher for elongate channels fed directly by large numbers of 1st order channels and lower for more intricately branching networks. The Bifurcation ratio is a dimensionless number varying only between about 3.0 and 5.0 for networks formed in homogenous rocks, but exceeding 10 where pronounced structural control encourages the development of elongate narrow drainage basins. In the present study, the calculated *Mean Bifurcation Ratio* is 5.11 suggesting a more or less homogenous lithological control with less of structural control. In all 32 micro-watershed basins have been delineated (Fig.7)and the area and perimeter of each basin is calculated and given Tabel-3. The Total area of the sub-basins is 102439420.9 sq.m. and the total perimeter calculated is 247904.71 meters. The main inferences that have been made using the various morphometric parameter ratios have been presented in the Table-4.

H. Digital Elevation Model

Digital Elevation Model (DEM)) is any digital representation of the continuous variation of relief overspace. By creating a TIN Surface, it is possible to get a 3-Dimensional display of the landforms in the study area.

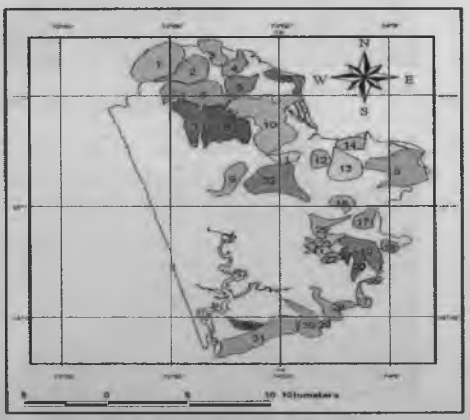

Fig. 7: Watershed Sub-basins of Salcete

In the present study, the different elevation zones for the study area were derived using the contour data in order to generate the vector based elevation model TIN (Fig. 8). The highest peak with an elevation of 350 m is seen in the south-eastern portion is of the Chandranath hill (inset Fig.8). The western margin of Salcete shows lower contour values because of the linear coastal stretch having few parallel alignments of contours due to the presence of sand dunes Steep slopes can be seen in the eastern region as compared to flat area in the western margin of the study area where the elevation hardly exceeds 10 m with sand dunes.

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TABLE 3
Watershed Basins Data (Area and Perimeter)

Basin No.	Area (in sq.m)	Perimeter (in Meters)	Number of Streams (Nu)			
			1st	2nd	3rd	4th
1	6891470.7	8910.57	27	7	1	0
2	4010026.4	8940.63	13	3	1	0
3	2192321.8	6341.83	8	2	1	0
4	1817623.1	5688.95	7	2	1	0
5	6439391.2	12851.67	34	8	1	0
6	2706906.1	6604.88	14	3	1	0
7	4165702.1	10099.46	24	8	2	1
8	6982743.6	11814.48	37	8	2	1
9	2650482.1	8393.16	8	3	0	0
10	11404704.8	18205.31	41	7	1	1
11	1180292.8	4054.50	13	2	0	0
12	1408611.2	4046.31	7	1	0	0
13	4035583.3	7464.00	12	3	0	0
14	1567213.3	4669.26	5	2	0	0
15	7560637.7	12999.26	13	3	0	0
16	1451562.1	4485.28	11	1	0	0
17	1672194.2	5085.29	15	2	0	0
18	847354.9	3223.91	9	1	0	0
19	3313826.0	8490.84	24	5	1	1
20	1226589.5	5469.14	11	2	1	0
21	545251.3	3213.06	10	2	0	0
22	702949.2	3026.01	12	3	1	0
23	1449026.7	6106.72	19	5	1	0
24	409320.1	2758.62	7	2	0	0
25	2057364.0	7562.03	13	3	0	0
26	147744.1	1507.20	4	1	0	0
27	999186.5	5079.40	6	3	0	0
28	2578592.8	10020.34	12	2	1	0
29	232911.8	1759.14	4	1	0	0
30	2824463.2	8592.02	16	2	0	0
31	6779415.4	13059.06	29	4	1	0
32	6816010.6	11436.18	8	2	0	0
33	1770839.9	7780.83	3	1	0	0
34	1181578.2	5249.45	2	1	0	0
35	419530.5	2735.92	2	1	0	0
Total	102439420.9	247904.71	480	105	17	4

TABLE 4
GEOMORPHOLOGICAL FACTORS AND THE INFERENCES DRAWN

Factor	Inferences That can be Drawn	Inferences Made
Shape factor	Hydrological behavior of the basin.	No uniform shape
Drainage Network	Lithology and structure of basin.	Uniform Lithology and no structural control.
Stream order Number	Size of contributing watershed.	Medium to large.
Bifurcation Ratio	Geological control to produce extended or sharp peaks.	Could not interpret.
Basin Area	Relationship between stream length and stream discharge.	Medium to large.
Drainage density	Permeability of area and a measure of dissection of watershed.	Decreases as we move from east to west.
Stream sinuosity	Straightness of river channel.	Straight to moderately sinuous.

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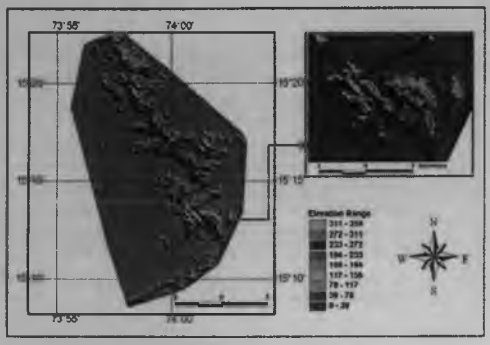

Fig. 8: DEM (TIN) of Salcete (with Inset of Chandranath Hill)

IV. Conclusion

RS-GIS based approach has been found to be a very convenient and time-saving method for the creation of micro-level database of watershed basins for better management. The present study on Salcete Taluka provides all the required resource maps for administration and management of natural resources in general and watershed management in particular. Salcete Taluka represents a typical dissected dendritic pattern of drainage network with low lying flat terrain in the west and hilly terrain towards the East. Despite heavy rainfall in the study area the observed soil erosion is moderate. The calculated total area of the 35 sub-watershed basins is 102439420.9 square meters.

Acknowledgement

We express our sincere thanks and gratitude to the officials of the DSTE, Goa and Soil Survey Department and local administration of Salcete Taluka for providing the necessary help in completion of the work. The Satellite data was obtained from NRSC, Hyderabad.

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