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Extraction of Watershed Characteristics using GIS and Digital Elevation Model

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Abstract: *Knowledge of watershed characteristics like aerial extent, slope, relief, aspect and drainage networks is prerequisite for watershed management. Manual computation of these characteristics from the topographic maps and stream network map of the watershed is tedious and time consuming. Geographical Information systems (GIS) with Digital Elevation model can be used for the computation of various watershed characteristics effectively and efficiently. This paper presents a case study of generating digital elevation model (DEM) and extraction of geo-morphological characteristics from DEM using GIS. While results presented in this paper can be specific to the watershed considered, the study clearly shows the applicability of GIS for the extraction of geo-morphological characteristics of a watershed.*

Keywords: *Watershed characteristics, GIS, DEM, Watershed delineation, Watershed Characteristics*

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I. Introduction

Characterization of watershed is a necessary and important step in planning and management of a watershed. Defining the geographic boundaries of watersheds and sub-watersheds helps in gathering and evaluating data for watershed management. Watershed boundary delineated by government organization is often available at 'macro level' only which is not at all suitable for watershed management at 'micro level'. Therefore, watershed delineation at micro watershed level is an essential task for effective planning and implementation of watershed management programme. Further, information on topographic characteristics of the watershed helps in determining runoff and sedimentation to the outlet of the watershed. For example, a sub-watershed with steep slopes might contribute more sediment loads to the waterbody than with flat landscapes. While characterizing a watershed, it is also essential to visualize stream networks in order to have information on their location and connectivity.

Now a day, digital elevation models (DEM) are being widely used for watershed delineation, extraction of stream networks and characterization of watershed topography (elevation map, slope map and aspect map) by using watershed delineation tool in GIS software. Digital elevation models (DEMs) are grid-based GIS coverages that represent elevation. One DEM typically consists of thousands of grid cells that represent the topography of an area. DEMs with 10m, 30m, and 90m cell sizes can be prepared by interpolation of contour lines available in contour map. The smaller cell sizes represent smaller areas and provide more detailed and accurate topographic data. The 30-meter and 10-meter DEMs are appropriate for smaller watersheds. Shuttle Radar Topographic Mission (SRTM) DEM data having a spatial resolution of 90m can be downloaded from http://srtm.csi.cgiar.org. for a particular area. The initial stream network and sub-watershed are defined based on drainage area threshold approach in GIS software. The techniques of automated watershed and sub-watershed delineation have been adopted a majority of GIS software packages including DEM Hydro-processing operation of ILWIS, ArcHydro extension package for ArcGIS, MapWindow and GIS-coupled watershed modeling software packages like HEC_GeoHMS, AGWA, and ArcSWAT.

Many researchers have used DEM and GIS techniques and for watershed delineation and extraction of drainage networks and various topographic characteristics of a watershed.Miller et al. [1] compared watershed characteristics such as width, depth and cross-sectional area of channels including channel order and watershed area measured from the field to those derived from DEM (10 m resolution) for Walnut Gulch experimental watershed in USA. They found strong statistical relationships between measured and DEM derived watershed characteristics. Singh et al. [2] extracted important watershed characteristics such as watershed drainage area/boundary, field and channel slope, aspect, and drainage network using DEM and found that DEM of 30 m resolution resulted into automatic extraction of watershed characteristics most accurately with variations less than 10%. Maathuis [3] demonstrated the capabilities of DEM hydro processing routine of ILWIS GIS for the extraction of watershed characteristics from DEM. It was concluded that the module can be used to extract a full topologically based drainage network and relevant associated attributes. Pandey et al. [4] used RS and GIS techniques for the characterization of Banikdih watershed, Hazaribagh, India. Using DEM and GIS, morphometric parameters like basin and stream length, stream order, form factor, elongation and circulatory ratio, drainage density, bifurcation ratio, relief ratio, relative relief and ruggedness number were determined. The study demonstrated the potential of RS and GIS in generating parameters for watershed management. Fu-quan et al. [5] applied GIS for the extraction of hydrological characteristics such as flow direction, flow accumulation, flow length, stream networks, and snap pour point of various streams in Ya'an city of China. It was found that spatial distribution of stream networks with catchment area threshold beyond 9900 had the maximum similarity with the actual river system**.** Srivastava et al. [6] did a morphometric analysis for Semi Urban Watershed of the trans Yamuna River Basin, Allahabad having an area of 289.41Km^2 using Survey of India (SOI) topomaps in 1:50000 scales and GIS. It was concluded that morphometric analysis based on GIS techniques is very useful to understand the prevailing geo hydrological characteristics and for watershed planning and management. Several other recent research workers from India [7,8,9,10], and abroad [11,12,13] have extracted watershed characteristics using DEM and GIS.

This paper describes the methodology for the preparation of DEM using contour lines and delineation of watershed and sub-watershed boundary. Various watershed characteristics have been also extracted using GIS and DEM and discussed in this paper.

II. Location Of Study Area

Considering the land and water problems the Baitarani watershed was selected as the study area for the present study. The study area is located between 85°09'42.66" to 85°44'10.42" E longitude and 21°26'52.92" to 22°11'51.65" N latitude in the Baitarani River basin of Eastern India. While flowing towards south, it meets the Brahmani River and finally joins the Bay of Bengal. Major portion of the river basin lies within the state of Orissa with an area of 13482 km^2 and a small patch of the upper reach (736 km^2) lies in the Jharkhand state [14].

III. Materials And Methods

In this study, DEM of the study area was prepared using contour lines and spot elevations available on the topographic maps of the study area. A flowchart illustrating various steps involved in the preparation of the DEM is shown in Figure 1. A vector contour map of the watershed was prepared by digitizing contour lines of 20 m contour intervals available on the topographic raster maps of the study area using ILWIS 3.3 GIS software. Similarly, a vector point map was also prepared by digitizing spot elevations available on the topographic raster maps.The vector contour map and point map were rasterized and combined together. The combined contour and point map was interpolated using Borgefors distance transform [15]) keeping pixel size as 30 m to obtain DEM of the study area as shown in Figure 2.

The 'Watershed delineator tool' of ArcSWAT watershed modeling software package was used for watershed delineation and stream-network generation from the DEM. The Watershed delineation process is based on the 'eight-pour point' algorithm (Jenson and Domingue, 1988) which includes pit filling, calculation of flow direction and flow accumulation grids from DEM. From the flow accumulation grids, stream networks are extracted. Streams are defined wherever drainage areas are greater than the defined threshold value. Sub-watershed outlets are automatically defined on the confluences of the streams and also at the user defined points. In this study, the 'threshhold area' method was adopted for the watershed delineation. In this study, 3% of the total area (53.29 km^2) was used as a threshold area to create stream networks and sub-watershed outlets. In addition to the sub-watershed outlets created by the interface, one more outlet representing the main outlet of the watershed was manually added which resulted into a total of 15 stream channel segments in 15 sub-watersheds (Figure 3). The ArcSWAT delineated stream network of the study basin exactly matches with the stream network in the toposheets of the study area as well as with the streams identified from remote sensing imagery. Finally, the geomorphic parameters of each sub-watershed and stream channel viz., area, slope, slope length, elevation distribution, stream length, stream width and stream depth were calculated by using raster-grid functions.

IV. Results And Discussion

Baitarani watershed was divided into 15 sub-watersheds whose statistics are presented in Table 1.Total area of the watershed is 1776 km^2 with perimeter of 328 km. It can be seen from this table that SWS4 has the maximum area of 297.64 km^2, whereas SWS8 has the minimum area of 8.93 km^2. The elevations of the sub-watersheds vary from 330 m (MSL) to 1120 m (MSL) while the average slope varies from 6.50% (SWS2) to 35.11% (SWS10). This indicates highly undulated nature of the watershed topography. The hypsometric curve depicting the elevation and percentage cumulative area below a particular elevation (Figure 4) indicates that 60% of area the area is below 600 m (MSL) elevation and the remaining 40% of the area has elevation between

600 and 1120 m (MSL). A classified average slope map of the sub-watersheds of the Baitarani watershed (Figure 3) shows that two sub-watersheds, SWS9 and SWS10 fall under 'steep slope' (30-50%) while ten sub-watersheds are under 'moderate steep slope' (15-30%) class. However, SWS1 and SWS3 sub-watersheds have 'moderate slope' (8-15%) and SWS2 sub-watershed has 'gentle slope' (3-8%). Drainage network map and aspect map of the watershed is presented in the Figure 5 and Figure 6 respectively. It is clear from this Figure 5 that drainage network of the watershed is in fifth stream order and drainage pattern is dendritic. Length of longest flow path and drainage density was found to be 141 km and 753 m/km^2 respectively. Aspect map presented in Figure 6 indicates that general slope of the watershed is oriented towards north east.

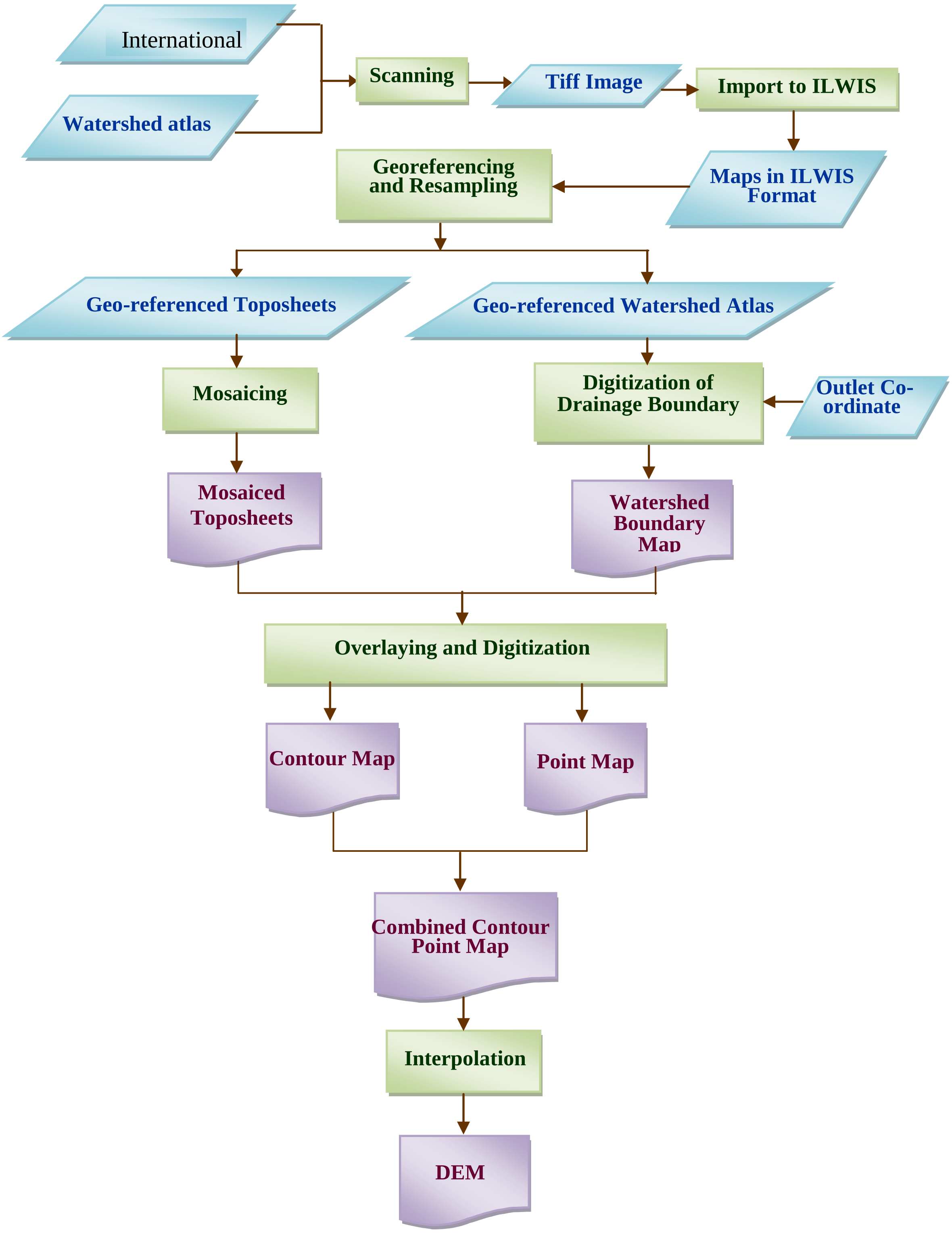


Figure 1: Steps Involved in the Preparation of Study Area DEM.

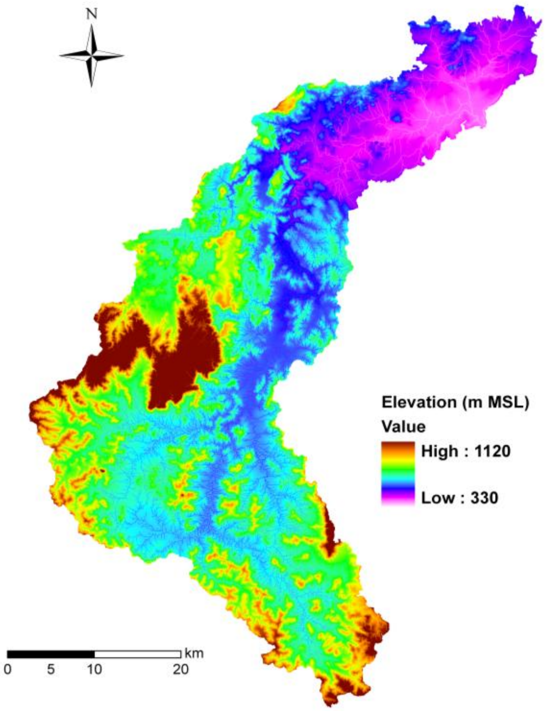


Figure 2. Digital Elevation Model of the Study Area

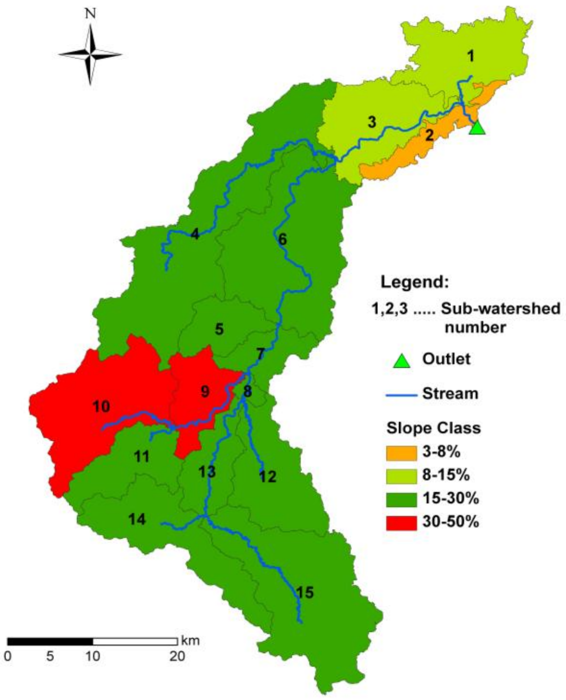


Figure 3. Classified Slope Map of the Sub-watersheds

Table 1: Topographic Characteristics of the Sub-watersheds

Sl. No.	Sub-watershed	Area (km^2)	Minimum Elevation (m MSL)	Maximum Elevation (m MSL)	Area (%)	Average Slope (%)
1	SWS1	114.78	338	530	6.46	10.09
2	SWS2	40.50	330	470	2.28	6.50
3	SWS3	118.46	338	860	6.67	12.30
4	SWS4	297.64	367	1120	16.76	25.63
5	SWS5	53.39	430	986	3.01	28.61
6	SWS6	234.64	367	760	13.21	20.78
7	SWS7	45.76	430	883	2.58	23.74
8	SWS8	8.93	449	680	0.50	22.46
9	SWS9	66.70	449	980	3.75	30.62
10	SWS10	170.81	490	1120	9.62	35.11
11	SWS11	79.71	490	880	4.49	26.58
12	SWS12	114.44	450	1062	6.44	27.06
13	SWS13	64.92	450	880	3.65	29.03
14	SWS14	131.62	470	880	7.40	26.94
15	SWS15	234.09	470	1009	13.18	28.80
WS		1776.34	330	1120	100	23.62

Note: SWS1 to SWS15 represent sub-watersheds and WS represents the whole watershed.

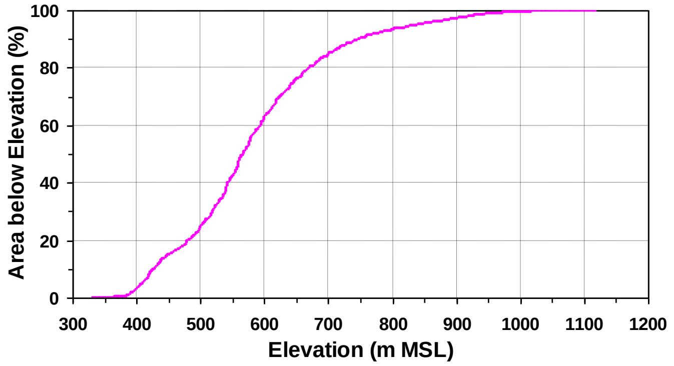
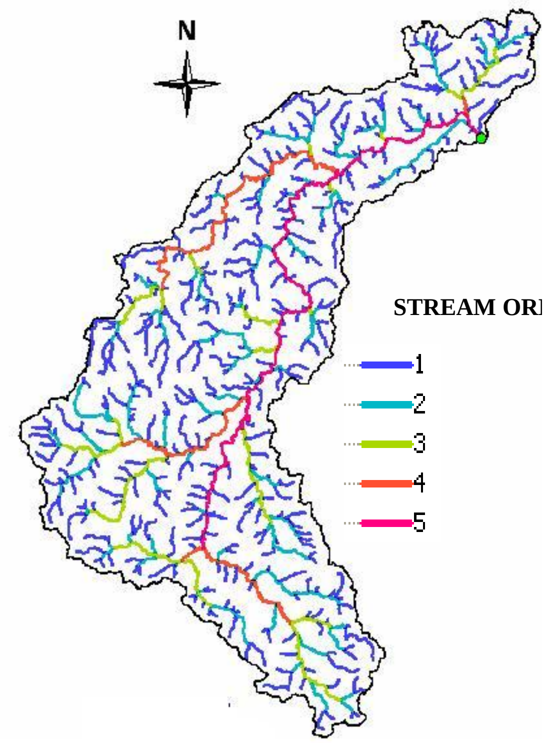


Figure . 4: Hypsometric Curve for the Elevation and Percentage Cumulative Area Below the Elevation



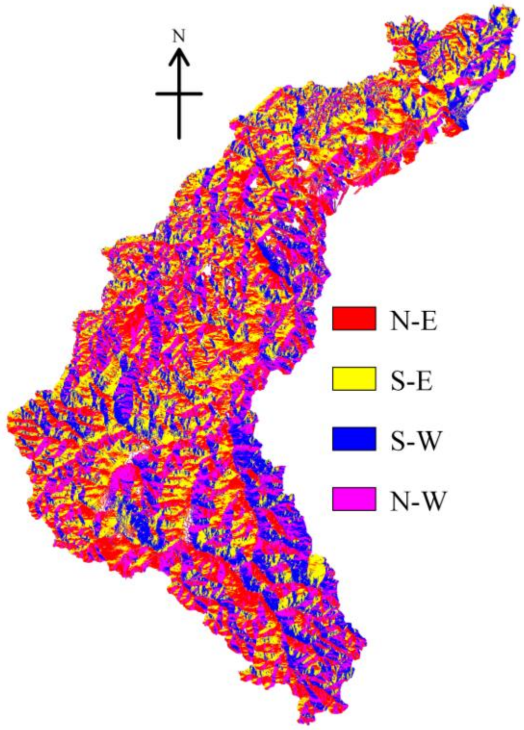


Figure 5. Drainage Network Map of the Watershed **Figure 6.** Aspect Map of the Watershed

V. Summary and Conclusions

Aim of this study was to extract watershed characteristics with the help of GIS using DEM. Hence the work was carried out for the preparation of DEM using contour lines of the topographic maps related to the study area and delineation of watershed and sub-watershed boundaries along with delineation of drainage lines. Based on the results of the study area and perimeter of the watershed was found to be 1776 km^2 and 328 km respectively. Elevation map derived from the DEM revealed that altitude in the watershed ranges from 330m to 1120 m above MSL. Drainage pattern in watershed was dendritic. The drainage density was found to be 753 m/km^2 with fifth order stream. Length of longest stream was 141 Km. The average slope of the watershed varies from 6% to 35% with maximum area under the slope between 15 to 30%. Information on watershed characteristics of the study area is very helpful to other researchers and decision makers involved in planning and management of the watershed. Although the results obtained from this study are specific to the study watershed but it clearly demonstrates the applicability of GIS to extract watershed characteristics using DEM.

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