DERIVATION OF MORPHOMETRIC PARAMETERS USING CARTOSAT-1 DATA

Apurna Kumar Ghosh[1]✉ and Vaibhav Garg [2]

(1) Lecturer, Department of Mining Engineering, Western Australian School of Mines, Curtin University, Australia

(2) Scientist, Water Resources Division, Indian Institute of Remote Sensing, Dehradun, India

✉ Corresponding author

Address correspondence to:

Apurna Kumar Ghosh, PhD

Lecturer

Department of Mining Engineering

Western Australian School of Mines

Curtin University

Locked Bag 30

Kalgoorlie 6433

Australia

Tel.: +61 8 9088 6108; Mobile: +61 469 772 874

Facsimile: +61 8 9088 6151

E-mail: apurna.ghosh@curtin.edu.au

ABSTRACT

Cartosat-1 data helps to generate digital elevation model (DEM) with 2.5 m ground sampling distance (GSD). It can provide details topographic and morphometric parameters, thus been applied to a sub watershed. The drainage basin is fundamental geomorphic unit of land and all flow of surface is governed by its properties. In this paper several drainage basin characteristics are analyzed scientifically with the use of Cartosat-1 data in the ERDAS and ArcGIS software tools. The analysis reveals that subwatershed assumes pear shaped characteristics, high degree of integration, high infiltration, flatter peak of flow for longer duration and easy for flood control. Morphometric parameters can help in decision making process for water resources management. By understanding the morphometric parameters, appropriate attention can be paid towards soil conservation and flood control measures in the subwatershed.

Keywords: Cartosat-1, DEM, morphometric parameters, watershed.

1. INTRODUCTION

Digital elevation models (DEM) are of fundamental importance for remote sensing. With a DEM the three-dimensional positioning, requiring a stereo model can be reduced to a two-dimensional solution just based on a single image. With the free of charge availability of the Shuttle Radar Topography Mission (SRTM) height models, covering the land area from 56° southern up to 60.25° northern latitude a nearly worldwide coverage is given. But especially in mountainous regions and dry sand deserts the original SRTM DEMs have gaps in the original SRTM data. Now with the free of charge available ASTER GDEM the area from 83° southern up to 83° northern latitude is covered. For areas where both height models exist, it is the question which height model should be preferred. Outside the USA the SRTM height data have a spacing of 3 arcsec (nearly 90m), while the ASTER GDEM has a spacing of just 1 arcsec (nearly 30m). The decision for the selection of the DEM is based on accuracy, homogeneity, reliability, completeness and morphologic details.

The nearly worldwide coverage by the free of charge available ASTER GDEM height model, covering the world from -83° upto 83° latitude extends the possibilities of the also free of charge available SRTM height model, limited to -56° up to 62.5° latitude. Of course not the same accuracy and details as with the high resolution stereo sensor Cartosat-1 having 2.5m ground sampling distance (GSD) can be reached[1]. With Cartosat-1 stereo pairs standard deviations of DEM-heights up to 2m can be reached, while with SPOT 5 High Resolution Stereo (HRS), having 5m GSD in orbit direction, up to 4m standard deviation for open and flat areas is possible[2, 3].

A drainage basin is the part of the earth's surface that is drained by main stream and its tributaries. The drainage basin is fundamental geomorphic unit of land and all flow of surface is governed by its properties. It is an open system into which and from which energy flows. Drainage basin is a fundamental, precise and usually ambiguous unit that is recognized as a reliable and useful planning unit. It has now formed a framework for human activities like agriculture and has guided river navigation towards sustainable agriculture[4]. The scientific approach to the hierarchical classification of streams and basin area was initiated by Horton[5], who defined several drainage basin characteristics that were measurable on topographic maps. Today, these characteristics can be measured not only on topographic maps but also on satellite imageries. These characteristics include stream order, stream length, bifurcation ratio, basin area and length, perimeter, drainage density, stream frequency, elongation ratio, circularity ratio, texture ratio and form factor ratio[6]. Today, more efficient technique of Geographical Information System (GIS) has been put in place to boost the work of Horton[5] in measuring drainage basin characteristics. It is a technique used for spatial analysis of spatially referenced data. Prior to this era, the application of GIS in drainage basin analysis has not been widely used.

Thus, this technique would be used to measure the morphometric characteristics of the subwatershed and the present study aimed at: i) generation of Digital Elevation Model (DEM) with the help of Cartosat-1 stereopair data. ii) identification of the morphometric parameters in the given area. iii) analyzing and mapping drainage density using digital terrain data.

2. MATERIALS AND METHODS

The study area is located within latitude 30.04° to 30.30°N and longitude 77.73° to 78.02°E (Figure 1). Its elevation ranges from 255m to 927m. The subwatershed is situated on a rugged terrain of medium high land. The watershed is highly noted for its drainage network made up of streams which form the tributaries of the River Ganga.

In the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) digital height models have been generated by automatic image matching with least squares method. Digital elevation model (DEM) data quality is paramount for accurate representation of the land surface and drainage network. This issue was investigated within the subwatershed area. A DEM is created by using of a stereopair images of Cartosat-1 data.

Martinez et al.[7] reveal that as DEM grid size increased, average slope gradients decreased and the drainage network became increasingly simplified. Geomorphic descriptors such as the width function, cumulative area distribution and hypsometric curve appear largely insensitive to DEM scale. The area-slope relationship loses definition in the diffusive region of the curve at large grid scales; however, the fluvial region appears largely insensitive to the changes in DEM resolution.

Figure 1. Location Map of Subwatershed

The whole work is broadly classified into two categories, viz. i) generation of DEM using Cartosat1 data with the help of Leica Photogrammetry Suite (LPS) of ERDAS software and derivation of different morphometric parameters in GIS with the help of ArcInfo software. The methodology of the first part is shown in Figure 2.

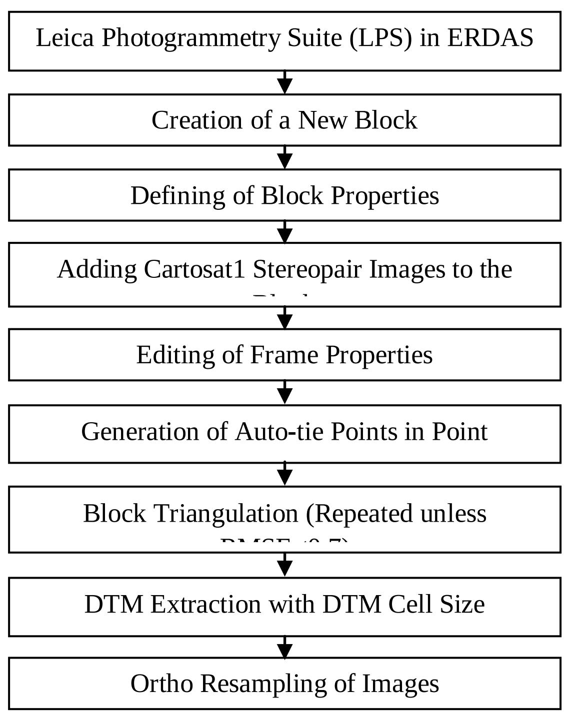

Figure 2. Methodology of DEM Generation from Stereopair Images of Cartosat1 Data

After DEM is generated the Watershed modeling is done. The flow diagram is shown in Figure 3. The basic input for the watershed modeling is the DEM raster. With the help of **Fill** Sink function, small imperfections of the DEM raster are eliminated and a surface raster is created.

Flow Direction: creates a raster of flow direction from each cell to its steepest downslope neighbor. The input raster is a Fill sink raster of Digital Elevation file which represents a continuous surface.

Flow Accumulation: Creates a raster of accumulated flow to each cell. The input raster that records the direction of flow out of each cell. This can be created with Flow Direction function.

To avoid clumsiness, stream accumulation beyond 2000pixels are considered in this study.

Stream link: Assigns unique values to sections of a raster linear network between intersections. This can be created with Flow Direction and Flow Accumulation Functions.

Stream Order: Assigns a numeric order to segments of a raster representing branches of a linear network. This can be created with Flow Direction and Stream Link Functions.

The steps for modeling of watershed, flow accumulation, stream link and stream order are shown in Figure 3.

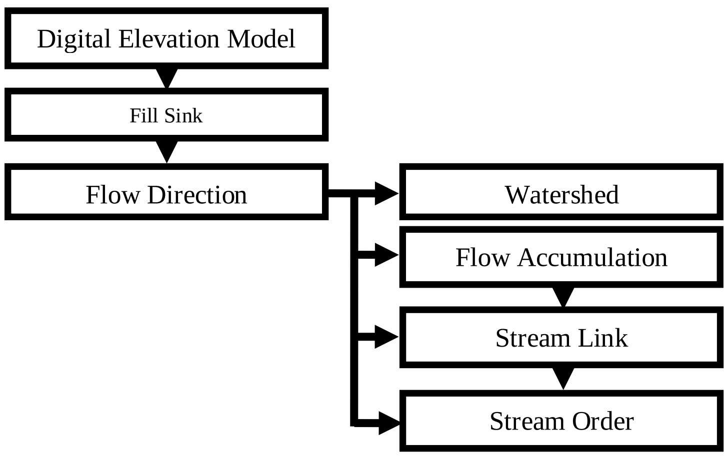

Figure 3. Watershed Modeling

3. RESULTS AND DISCUSSIONS

Various morphometric parameters such as stream order (N), stream length (L), bifurcation ratio forming the linear properties and drainage density (D), elongation ratio (R), circularity ratio (R) form factor ratio (R) comprising the area properties of the drainage basin were computed, forming the basis of analysis of the drainage basin. The drainage density map is shown in Figure 4.

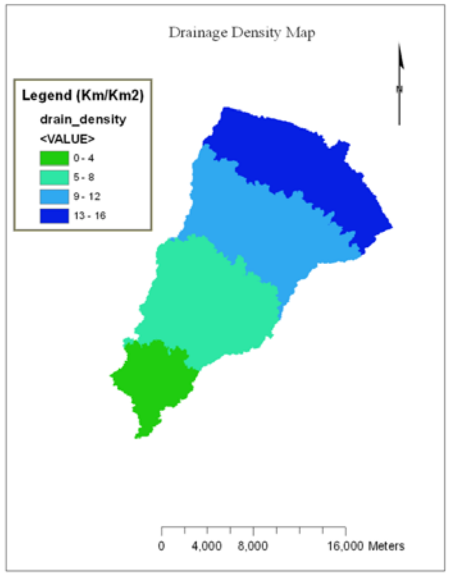

Figure 4. Drainage Density Map

The aerial aspects of the drainage basin such as drainage density (D), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) were calculated and results have been given in Table 1.

The linear aspects of drainage network such as stream order (N), bifurcation ratio (R), stream length (L) results have been presented in Table 2 and Table 3.

Stream Order (Nu): In the drainage basin analysis the first step is to determine the stream orders. The channel segment of the drainage basin has been ranked according to Strahler[8], stream ordering system using ArcGIS 9.3. The study area is 6 order subwatershed. The total number of 1297 streams were identified of which 609 are 1st order streams, 378 are 2nd order, 126 are 3rd order, 129 are 4th order, 40 are 5th order and 15 are 6th order streams. The total number of streams for each of the order as shown in Table 2. Drainage patterns of stream network from the basin have been observed as mainly dendritic type which indicates the homogeneity in texture and lack of structural control. This pattern is characterized by a tree like or fernlike pattern with branches that intersect primarily at acute angles. The properties of the stream networks are very important to study the landform making process[11].

The order wise total number of stream segment is known as the stream number. Horton[5] laws of stream numbers states that the number of stream segments of each order form an inverse geometric sequence with plotted against order, most drainage networks show a linear relationship, with small deviation from a straight line. This means that the number of streams usually decreases in geometric progression as the stream order increases.

Bifurcation Ratio (R_b): The term bifurcation ratio (R_b) is used to express the ratio of the number of streams of any given order to the number of streams in next higher order (Schumn, 1956). Bifurcation ratios characteristically range between 3.0 and 5.0 for basins in which the geologic structures do not distort the drainage pattern. Strahler[8] demonstrated that bifurcation ratio shows a small range of variation for different regions or for different environment dominates. The mean bifurcation ratio value is 2.3 for the study area (Table 3) does not fall within the standard range and indicates that the basin disconforms to the characteristics of a natural stream which suggests that the geological structures are disturbing to the drainage pattern. Deviation from its general behavior between the third and forth orders indicate that the terrain is characterized by variation in lithology and topography

Stream Length (L): Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics streams of relatively smaller lengths are characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradients. Generally, the total length of stream segments is maximum in first order streams and decreases as the stream order increases. The number of streams of various orders in the basin were queried and summed in ArcGis 9.3 environment (Table 2)

Areal Aspects of the Drainage Basin: Area of a basin (A) and perimeter (P) are the important parameters in quantitative morphology. The area of the basin is defined as the total area projected upon a horizontal plane contributing to cumulate of all order of basins. Perimeter is the length of the boundary of the basin which can be drawn from topographical maps. Basin area is hydrologically important because it directly affects the size of the storm hydrograph and the magnitudes of peak and mean runoff. It is interesting that the maximum flood discharge per unit area is inversely related to size[12].

Drainage Density (D_d): It is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of mi/sq. mi or km/sq. km. It has been observed that a low drainage density is more likely to occur in regions of highly resistant of highly permeable subsoil material under dense vegetative cover and where relief is low. High drainage density is the resultant of weak or impermeable subsurface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture[8]. The drainage density (D_d) of the study area varies from 0-16 km/sq. km (Figure 4). This value indicates that for every square kilometer of the basin, there is 0-16 kilometer of stream channel. According to Strahler[8], drainage density values under 12 are low density, those with values of between 12 and 16 are medium density basins while basins with values above 16 are high density basins. From this classification, the subwatershed covers all the drainage density classes. It is suggested that the low drainage density indicates the basin is highly permeable subsoil and thick vegetative cover[13]. The type of rock also affects the drainage density. Generally, lower values of D_d tend to occur on granite, gneiss and schist regions. This corroborates the low drainage density observed in the drainage basin. High drainage density indicates that the region is weak and consists of impermeable subsurface material, sparse vegetation cover and mountainous relief.

Elongation Ratio (R_e): Schumn[9] defined elongation ratio (Re) as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. It is a very significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin.

Circularity Ratio (R_c): Miller[10] defined a dimensionless circularity ratio (R_c) as the ratio of basin area to the area of circle having the same perimeter as the basin. He described the basin of the circularity ratios range 0.4 to 0.5 which indicates strongly elongated and highly permeable homogenous geologic materials. The circularity ratio value (0.30) of the basin does not corroborates the Miller's range which indicated that the basin is elongated in shape, low discharge of runoff and highly permeability of the subsoil condition but rather the basin of the studyarea is pear in shape with high level of integration.

Form Factor Ratio (R_f): Quantitative expression of drainage basin outline form was made by Horton[5], through a form factor ratio (R_f), which is the dimensionless ratio of basin area to the square of basin length. Basin shape may be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length[14]. The form factor value of the basin is 0.37 which indicates lower value of form factor and thus represents oval shape tending towards elongation. The oval basin tending towards elongation with low form factor indicates that the basin will have a flatter peak of flow for longer duration. Flood flows of such elongated basins are easier to manage than of the circular basin

Table 1. Morphometric parameters of the watershed

Form Factor	**Elongation Ratio**	**Circularity ratio**	**Compactness Coefficient**
0.33	**0.6489**	**0.30**	**1.826**

Table 2. Number of Streams in Each Order

Stream Order	**Number of Streams in Each order**					
	1	**2**	**3**	**4**	**5**	**6**
Number of Streams	**609**	**378**	**126**	**129**	**40**	**15**

Table 3. Bifurcation ratio Calculation

$1^{st}/2^{nd}$	$2^{nd}/3^{rd}$	3^{rd}/4th	$4^{th}/5^{th}$	$5^{th}/6^{th}$	Average
1.61	**3**	**0.977**	**3.225**	**2.67**	**2.30**

4. CONCLUSION

DEMs generated from freely available SRTM and ASTER data are of coarser resolution, whereas the Cartosat1 data gives DEM with 2.5 m resolution. Cartosat 1 DEMs can generate more accurate topographic and morphometric parameters specially in hilly regions and steep slopes.

The quantitative analysis of morphometric parameters is found to be of immense utility in river basin evaluation, watershed prioritization for soil and water conservation and natural resources management at micro level. The morphometric analysis carried out in the subwatershed shows that the basin is having low relief of the terrain and is oval tending towards elongated shape.

Subwatershed assumes pear shaped characteristics, high degree of integration, high infiltration, flatter peak of flow for longer duration and easy to flood control

The morphometric parameters evaluated using GIS helped in understanding various terrain parameters such as nature of the bedrock, infiltration capacity, runoff, etc. Similar studies in conjunction with high resolution satellite data will help in better understanding of the landforms and their processes and drainage pattern demarcations for basin area planning and management.

Watershed prioritization is one of the most important aspects of planning for implementation of its development and management programmes.

The present study demonstrates the usefulness of GIS for morphometric analysis and prioritization of the subwatershed. The morphometric characteristics of the subwatershed show its characteristics with respect to hydrologic response of the watershed. Morphometric parameters can help in decision making process for water resources management. By understanding the morphological parameters, appropriate attention can be paid towards soil conservation and flood control measures in the subwatershed to preserve the land from further erosion and to alleviate natural hazards.

REFERENCES

1. Jacobsen K., 2006: ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) Technical report - test areas Mausanne and Warsaw, ISPRS Com IV, Goa 2006, IAPRS Vol. 36 Part 4, pp. 1052-1056
2. Baudoin,A,, Schroeder,M., Valorge,C., Bernard,M., Rudowski, V., 2004: The HRS-SAP initiative: A scientific assessment of the High Resolution Stereoscopic instrument on board of SPOT 5 by ISPRS investigators, , ISPRS Congress, Istanbul 2004, Int. Archive of the ISPRS, Vol XXXV, B1, Com1, pp 372 – 378
3. Jacobsen, K., 2004: DEM Generation by SPOT HRS, ISPRS Congress, Istanbul 2004, Int. Archive of the ISPRS, Vol XXXV, B1, Com1, pp 439-444
4. Ofomata, M. and J.E. Umeuduji, 2000. Topological Indices of Morphological Transformation in the Aboine Basin. Nigeria Environ. Revolution J., Vol. 1.
5. Horton, R.E., 1945. Erosional Development of Streams and their Drainage Basin. Approach to Quantitative Morphology. Geological Society of America Bulletine, 56: 275-320.
6. Shreve, R.L., 1966. Statistical Law of Stream Numbers, J. Geol., 74: 19-38.
7. Martinez, C., Hancock, G. R., Kalma, J. D., Wells, T., Boland, L. An assessment of digital elevation models and their ability to capture geomorphic and hydrologic properties at the catchment scale, International Journal of Remote Sensing, Vol. 31, No. 23. (2010), pp. 6239-6257
8. Strahler, A.H., 1964. Quantitative Geomorphology of Drainage Basins and Channel Networks In. Handbook of Applied Hydrology, McGraw Hill Book Company, New York, Section 4.II.
9. Schumn, S.A., 1956. "Evaluation of drainage systems and slopes in badlands at Perth Amboy, New Jersy", Bull. Geol. Soc. Amer., 67: 597-646.
10. Miller, V.C., 1953. "A quantitative geomorphic study of drainage basin characteristics in the Clinch 389042, Tech. Rept. 3., Columbia University, Department of Geology, ONR, Geography Branch, New York.
11. Strahler, A.N. and A.H. Strahler, 2002. A Textbook of Physical Geography, John Wiley and Sons, New York.
12. Chorley, R.J., E.G. Donald Malm and H.A. Pogorzelski, 1957. "A new standard for estimating drainage basin shape", Amer. Jour. Sci.,255: 138141.
13. Nag, S.K., 1998. "Morphometric analysis using remote sensing techniques in the Chaka subbasin Purulia district, West Bengal", J. Indian Soc. Remote Sensing, 26: 6976.
14. Singh, S., 1998. Physical Geography, Prayag Pustak Bhawan, Allahabad, India.