Morphometric Analysis of Asan River Basin Using Geo-spatial Technique a Case study from Central Himalaya

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Abstract : A morphometric analysis of Asan basin, a part of Doon Valley, has been attempted using remote sensing and GIS. Watershed boundary and drainage map were prepared using 30m Cartosat DEM and SOI toposheets. A sub-dendritic pattern was observed for the basin. Highest stream order is sixth order, for main river Asan. A drainage density of 1.79 km /km^2 suggests resistant but permeable sub-surface Mean bifurcation ratio was estimated to be between 2 to 4.4 which signifies negligible control of surface by subsurface structures. An elongation ratio of 0.84 suggests an oval shape of basin. It is concluded that geospatial technologies provide a fairly reliable and speedy analysis of the basin for watershed prioritization.

Index Terms - Morphometry, Asan, Drainage, DEM, GIS.

I. Introduction

Geomorphological analysis of a region is increasingly becoming essential pre-requisite information for any sort of developmental program to be implemented in an area. Mapping the earth surface and phenomena has been one of the prime concerns of geographers. This study attempts geomorphological analysis of Asan drainage basin based on morphometric approach using remote sensing data in a GIS platform. Drainage basin morphometry aids in characterizing the drainage network, allows comparison of different drainage network associated characteristics and analyzing the impact of various variables like geology, precipitation etc. on the drainage network (Kale and Gupta, 2001). Before the advances of computer technology, doing morphometry was a difficult and tedious task. Morphometry as it stands today evolved with the advent of GIS. Initial GIS applications in geomorphometry were limited to basic DEM operations for topographic analysis and visualization (Evans, 1972). It was only 1980's that DEM started being increasingly used for automatic watershed and stream network delineation (Jenson and Domingue, 1988). Increasing use of GIS for geomorphometry came with contribution of Burrough (1986), Gardner (1990) and Dikau (1993). Major boost to morphometric analysis in geomorphology came only in 1990's, with improvements in Arc/ Info (Gregory and Goudie, 2011). With free availability of SRTM (90m or 30 m) and ASTER DEM and recently CartoDEM for India morphometric analysis become easier and faster.

Significance of this study is that it helps monitor the watershed characteristics keeping in view hazard studies, site suitability analysis for sustainable development and planning. In this study an attempt is made to carry out morphometric analysis of Asan river drainage basin with geospatial technique.

II. Study Area

Geographical extent of the study area is 30º14'22" N to 30º29'08" N latitude and 77º40'09" E to 78º05'46" E longitude (Fig.1.1). This covers an area of 691.27 km^2. It is bordered by Himachal Pradesh in the west, Dehradun city in the East. The accessibility to study area varies with terrain. Thus, major part of basin is well accessible through motored roads and railways, having a good road network. While uphill reaches around Mussoorie Hills are quiet lacking in rail development. The administrative blocks that make this region are Vikasnagar, Sahaspur and parts of Dehradun. The basin is an asymmetric synclinal valley (Kiriwongwattana & Aggarwal, 2012). Doon valley is broadly classified into three geomorphic units, namely structural hills, residual hill, flood plain, alluvial fan (Singh et al., 2001; Thakur et al., 2007).

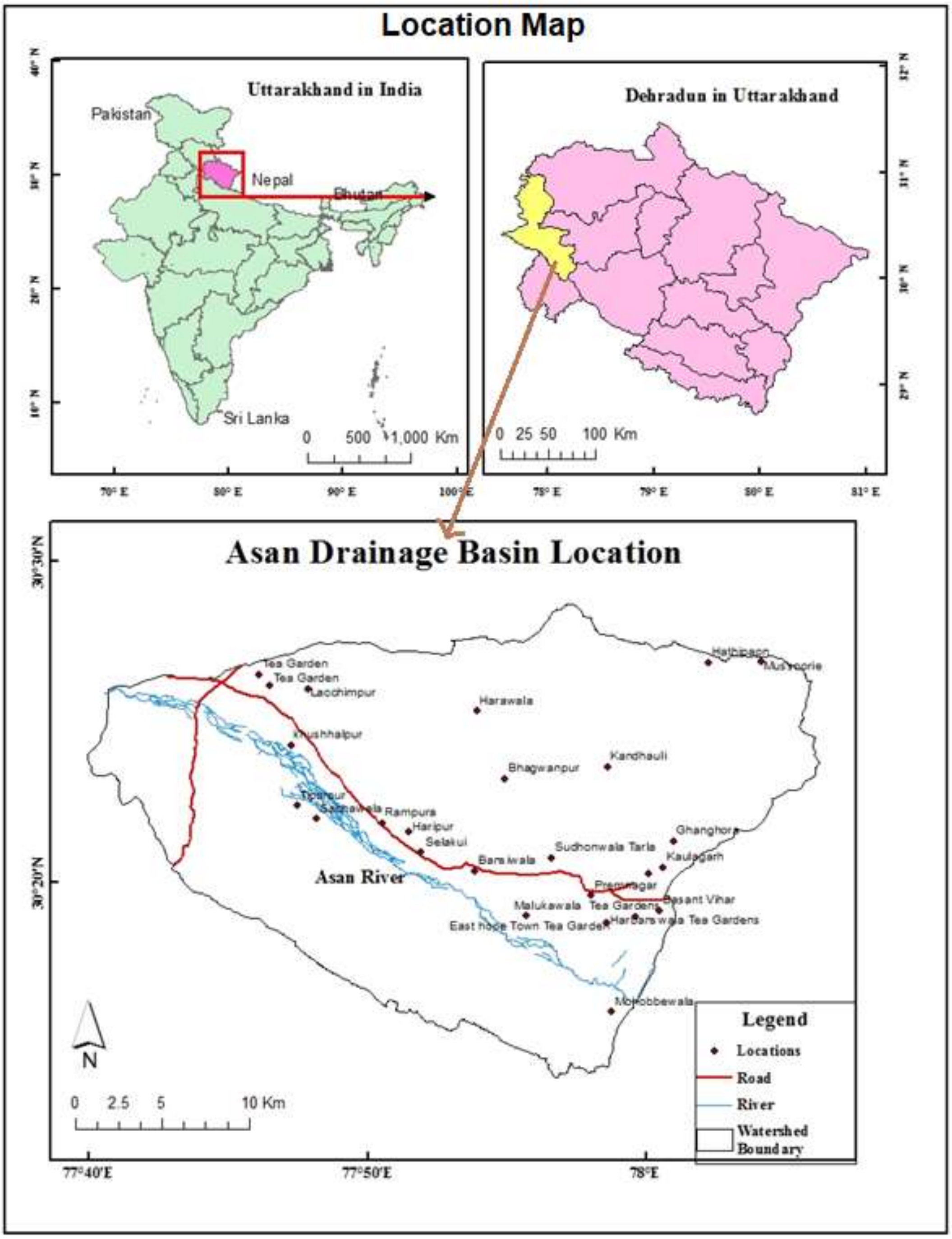


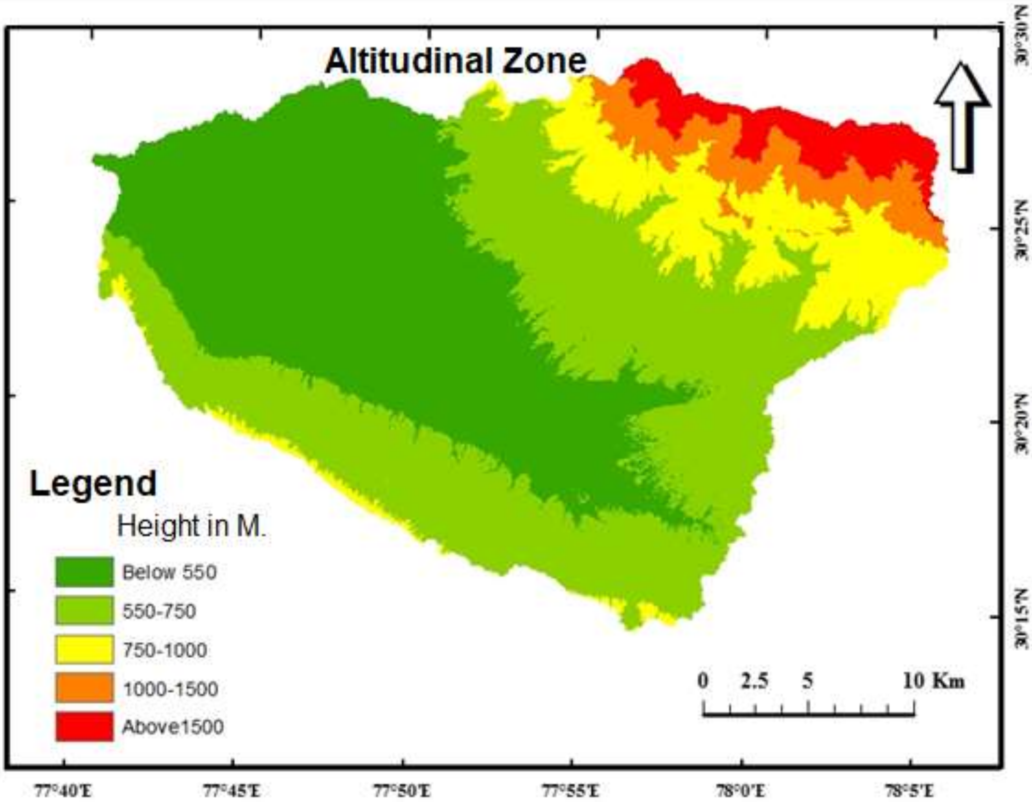
Fig.1 Location of Study Area

III. Database and Methodology

The study employs quantitative methodology and utilizes secondary data sources. Remote sensing data forms a significant secondary data type that has been used for the study. Cartosat DEM (30m) and SOI toposheets (53 J/3, 53 F/16, 53 F/15) were used for geomorphic analysis of the study area.

Data Analysis. Topographical maps were georeferenced in Arcmap 10.3 to sub-pixel accuracy and mosaic dataset was created. Manual delineation of watershed was done based on the principal that watershed boundary cuts the contours at right angles. It involved identification of highest points around rivers and its tributaries, using contours and connecting them (through digitization). Automatic delineation was achieved in ArcMap using 'hydrology' tools in spatial analyst. This involved first a mosaic of DEM tiles and further subset of the mosaic. A one-kilometer buffer was made using the boundary from manual digitization to derive a mask for extracting DEM subset to reduce the processing time. The process gives a smaller DEM including the area of interest. Thereafter, following steps were performed in ArcMap:

i. The DEM is filled so as to prevent any inland drainage, which might hamper river drainage modeling.
ii. Flow direction is calculated for the AOI. This gives the direction of surface runoff.



Attitudinal zone (height in meter)	Area(km^2)	Percentage of total area
Below 550	268.67	38.86
550-750	276.62	40.01
750-1000	81.18	11.74
1000-1500	36.29	5.25
1500 above	28.46	4.11
Total	691.22	100.00

Fig. 1 Altitudinal Zones

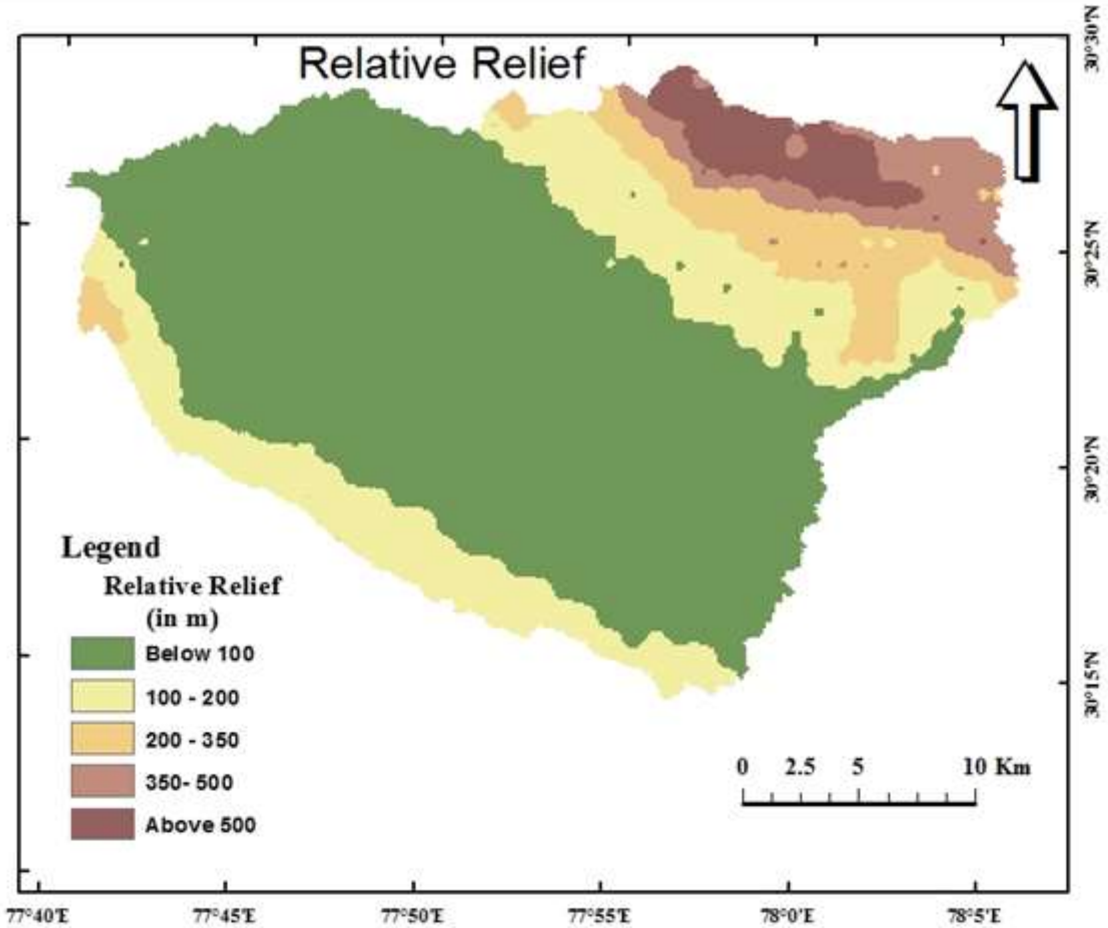
iii. Flow accumulation is derived to calculate total flow accumulating in each pixel.

iv. Stream ordering is done first manually and then using DEM. Stream ordering was followed by giving river outlet or pour point. This gave Watershed boundary. Using stream order and other basin parameters like area, linear and areal parameters were calculated.

IV. RESULTS AND DISCUSSION

A. RELIEF AND SLOPE CHARACTERISTICS

An attempt is made to assess altitude, relative relief and slope.



Relative Relief in meter	Area (Km^2)	Percentage	Remark
17-100	439.38	63.58	Very Low
100-200	139.23	20.14	Low
200-350	49.68	7.18	Moderate
350-500	34.25	4.95	High
500-734	28.52	4.12	Very High
Total	**691.06**	**100.00**	

Fig. 2 Relative Relief

1) **Relative Relief**

It gives the relief range (highest elevation values minus lowest elevation values) for a unit area and provides better approximation of topographic variation within a unit area. To create a relative relief map the basin area was first divided into equal sized grids of 1 kilometer square, using fishnet tool (in data management tools) with geometry type as polygon. Using DEM 'Zonal Statistics by Table' was calculated for fishnet polygon file. The statistical parameter to be calculated is given 'range'. This will give relative relief values to unit sized grids. To create a raster surface of relief, these values are transferred to fishnet label (point file) by joining the attribute table of file to table to zonal statistics table by the common field 'ID'. These values are now interpolated using Inverse Distance Weighted Interpolation on basis of 'range' field to produce a raster surface, which is then reclassified to 5 classes.

2) **SLOPE ANALYSIS**

2.1 Flat area (0-2). This zone has negligible slope lesser than two degrees due to which it can be regarded as flat. It is mostly along the river stream (Asan River) and along its tributaries in the direction of Dharamwala Reserved Forest and Darawat Reserved Forest. Most of the river beds in western and central part of study area are in this category. SitlaRao tributary flood plain also comes in this zone.

2.2 Almost flat (2-4). This zone having a slope of 2 to 4 degrees is categorised as almost flat. The central and western part of study area near to Asan river basin and the urban area like Harbatpur, Rambagh, Asanbhagh, Haripur, Rampura comes under this zone. Dharamwala and Darawat reserved forest area also show a slope of 2 to 4 degrees.

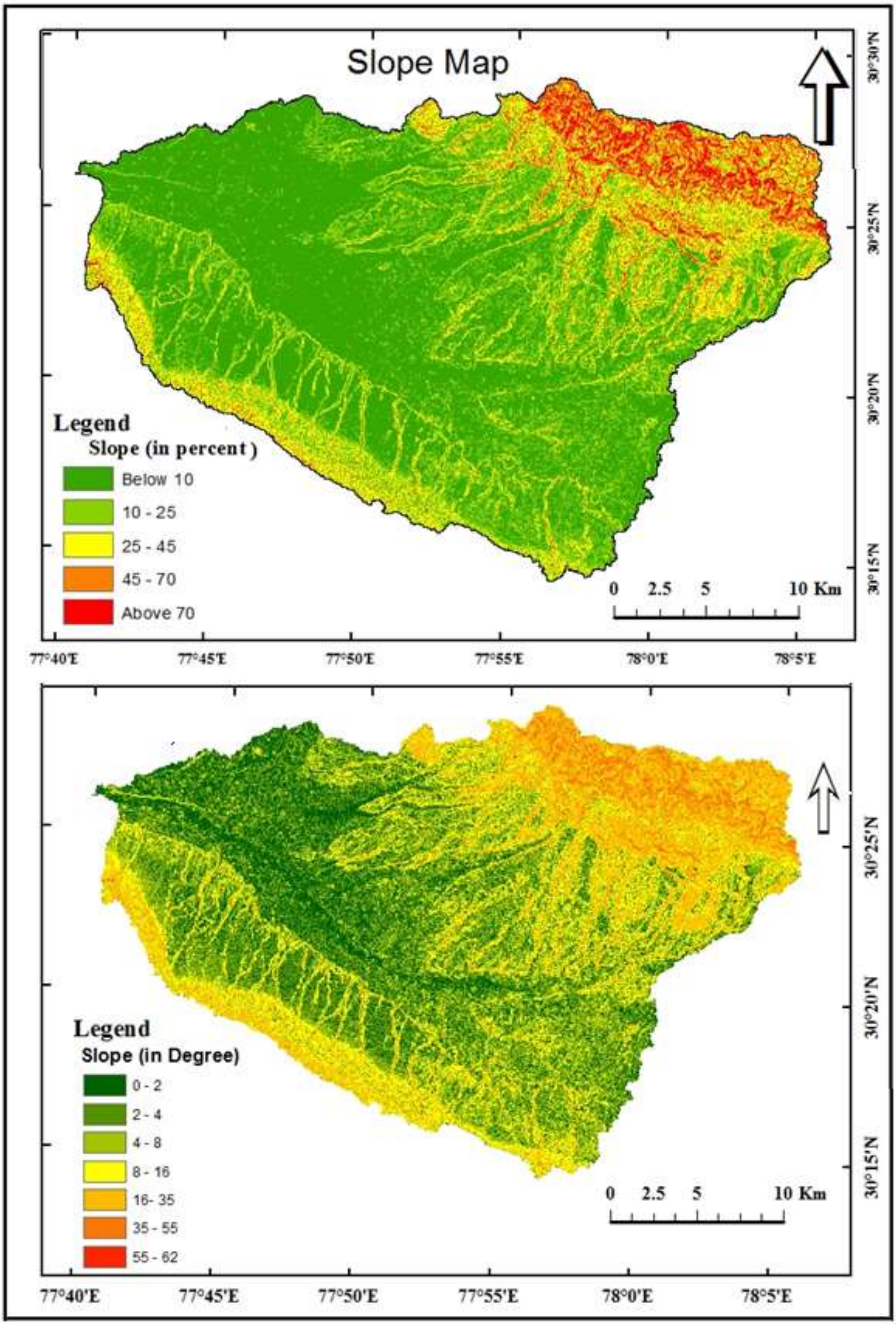


Fig. 3 Slope Map

2.3 Gentle slope (4-8). This zone having a slope of 4 to 8 degrees is categorised as gentle sloping. Area in Dharamwala Forest and Darawat reserved forest comes under this zone. The tributaries or stream along with the boundaries of different forest like Dudhai, Horawala, Majhaun, Kandholi, Bain Khala Bit, Jhaira Reserved Forest, Karwapani, Batoli Reserved forests comes under this zone. Area near Salangaon, Niharwala comes under this zone.

2.4 Moderate slope (8-16). Area near to Shivalik range in Dharamwala Forest and Darawat reserved forest comes under this zone. The area having tributaries of Asan i.e. SitlaRao, DarawatRao, DhangaRao, KauntronwalaRao, ChamarwalaRao, KasumriRao, SakumbraRao, Sikh Rao, BirasRao, BhulRao, Bain Khala, PaundiKhala, ChorKhala, SuarnaNadi comes under this zone.Different forest like Dudhai, Horawala, Majhaun, Kandholi, Bain Khala Bit, Jhaira Reserved Forest, Karwapani, Batoli Reserved forests comes under this zone.

2.5 Steep Slope (16-35). With a steep slope from 16 to 35 degrees, area under Shivalik range in extreme South and some parts of terraces comes under this zone. Bakarna, Rikhauli, Batoli reserved forest areas and Mussoorie hills come under this zone.

2.6 Very Steep Slope (35-55). This zone has very steep slope ranging from 35 to 55 degrees. Most of the area in lesser Himalayas region comes under this category. KotiDhar, Hathipaon, Nelson Point are few sites falling under this zone.

2.7 Extremely Steep Slope (55-62). Area under this zone is very less. No single broad stretch can be identified but is strewn along the slopes of lesser Himalayas.

B. Drainage Morphometry

Morphometry refers to quantitative analysis and measurement of different aspects of earth's surface, including landforms (Clarke, 1994; Zavoianu, 2011). Morphometric analysis is helpful for estimating shape and form of basin and predicating other properties of basin. For morphometric analysis of a river network a classification system to be followed thereafter has to be made. Stream ordering is done following this classification system. Two major such systems were those given by Horton (1945) and Strahler (1964). In Horton order system every stream in the network is assigned an order. Horton's method was modified by Strahler. First to give a drainage basin morphometry system was R.E Horton in 1945, which included precise or quantitative description of the drainage network and characteristics of the drainage basin (Kale and Gupta, 2001).

Strahler et al., 1957 regard stream ordering as the first step in quantitative analysis of drainage basin. For this Horton was the person who gave the technique in 1945. Here the method given by Strahler which has slight modification over Horton has been adopted. In this system, fingertip streams which do not have any tributaries are classified as order 1.

1) **Drainage network extraction**

With wide and free of cost availability of accurate DEMs, it has become possible to minimize the time involved in conventional methods to negligible by automatically extracting the drainage network from digital elevation models (Jenson and Domingue, 1988). Here the Cartosat DEM has been used.

2) Morphometry of Asan Basin

The unit of the analysis here is Asan drainage Basin and the important aspects to be measured can be broadly categorized into linear, areal and relief.

3) **Linear Aspects of the basin**. As the name suggests these are the length-based measurements or their derivatives for a particular watershed. This includes defining basin perimeter, stream network, Interaction of streams to therein establish the stream order or hierarchy, geometric properties of network components: the streams. For estimating the linear aspects of the river network first of all choice of stream ordering system has to be made. Following the chosen system, the entire stream is classified in different hierarchical orders.

3.1 Stream order

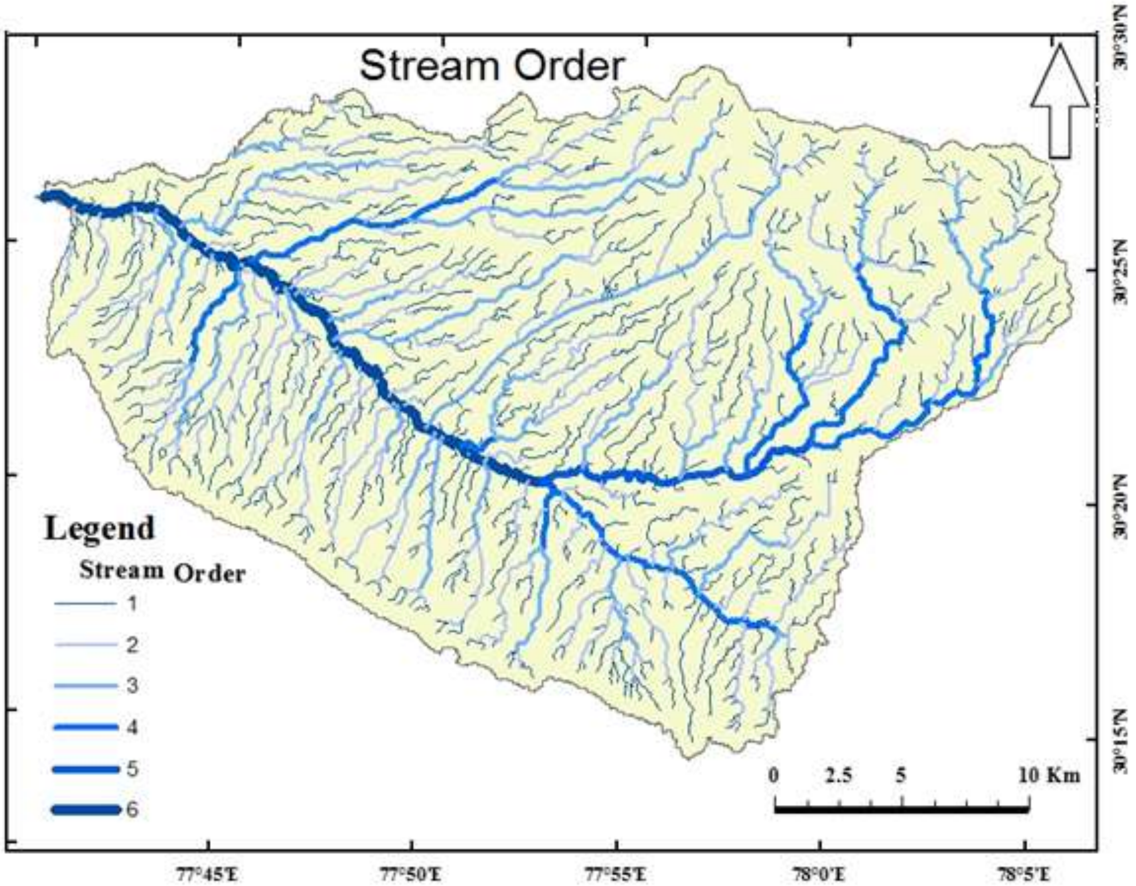
Stream ordering is crucial as order number is directly proportional to "relative watershed dimension, channel size and stream discharge" in that area or basin. Order being a dimensionless number also helps comparing geometry of two streams.

From Strahler's (1964) hierarchical ordering scheme, Asan's comes up to be a sixth order stream, which is the highest order of the basin. It is after the confluence with SitlaRao that it becomes a sixth order stream. Stream ordering was first done manually on toposheet. This was done assuming a 1 cm long stream to be minimum criteria for stream ordering on a scale of 1:50,000. Therefore, length of such a stream on ground would be at 50,000x1 km = 0.5km. Assuming that at least 0.25km^2 of area is required to form a stream, while defining stream, a threshold of 287 cells was given which equal to an area of 0.25 Km^2 on ground (287x 30x 30= 0.25 km^2; where 30m x 30m is the resolution or pixel size of DEM).

The linear aspects discussed here include stream ordering, number of streams in each order, total length and mean length of stream in different orders and bifurcation ratio. Asan is the trunk stream and its important tributaries are of fifth, fourth and third order.

3.2 Stream Number

This denotes total stream segments in each order. Horton (1945) gave law of stream numbers, according to which number of streams in each order for a drainage basin form an inverse geometric series with the order number. The steam numbers in different orders is given in table with figure 4.



Order	Stream Number (N)	Bifurca-tion Ratio (Nu/Nu+1)	Mean Bifurca-tion Ratio	Length of Streams (Ls)(in m)	Stream length ratio (Lu/Lu-1)	Mean Length of Streams (Lms)	Maximum Length of Streams (in m)	Minimum Length of Streams (in m)
1	652	4.44	3.81	593204.07		909.82	6501.98	44.29
2	147	3.97		380437.99	0.64	2588.01	11187.068	41.75
3	37	4.63		159879.56	0.42	4321	18219	184.31
4	8	4		64359.41	0.40	8044.93	13489.72	1768.75
5	2	2		13226.29	0.21	6613.15	12616.16	610.13
6	1			26857.98	2.03			
	847			1237965.3				

Fig.4 Stream Order for Asan Basin

3.3 Length of streams

It refers to total length of all streams falling in a particular order. Mean length of stream is the average length of a stream under a particular order. Horton's law of stream length (1945) states that total length of stream segments in the successive orders tend to lie in a geometric sequence. Asan drainage basin follows Horton's first law and the number of streams in each category fall in geometric sequence, as shown by the graph. However, it doesn't follow second law, law of stream length. Regarding mean length of streams, Strahler (1971) says that cumulative mean stream length plotted against stream order (with the former being in log scale and latter in arithmetic scale), results in a straight-line regression of positive exponential forms. The mean length of streams generally increases with increase in order of the stream.

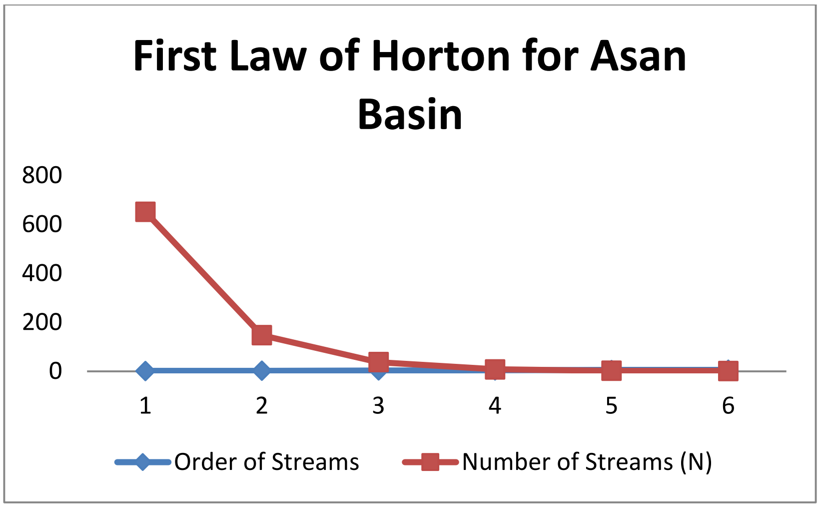


Fig. 5 First Law of Horton for Asan Basin

But this trend is broken down by the main stream, Asan which has a mean length of 6.61km, which is less than the mean length for 5th order stream (8.04km).

3.4 Bifurcation Ratio

It is the ratio of number of streams in a particular order to that in next higher order (Schumm, 1956). Strahler (1957) states that significant difference in bifurcation ratio occurs only in cases where the surface form is controlled by underlying structures. The values of ratio generally range from 3 to 5 for networks found in homogeneous rock structure (Strahler, 1964). For Asan basin bifurcation ratio ranges from approximately 4 to 4.5, for Rb (1/2), (2/3), (3/4), (4/5), while a lower ratio of 2 is observed between streams of order 5 and 6 (Rb (5/6)). These values do not indicate any significant control of watershed by the geological structures.

4) Areal Aspects refer to shape and area of the basin and related parameters.

4.1 Drainage Density

It is the ratio of total stream length of all orders to the total area of basin or in other words stream length per unit area (Strahler, 1964). Drainage density for Asan basin is 1.79 km /km^2. This low value suggests that basin has a course drainage texture. The implication for subsurface materials is that the basin has resistant but permeable subsurface structure along with a low to moderate relief (Strahler, 1964).

4.2 Shape parameters

To examine the shape of the basin, few basic and few derivative parameters are very essential and hence have been discussed here.

4.2.1 **Basin area:** Refers to the total area of basin projected on a plane surface. The area of Asan Basin is 691.27 km^2.

4.2.2 **Basin Perimeter**: Refers to the total length of basin boundary, which in the present case stands to be 183.34 km.

4.2.3 **Length of Basin**: It is the longest dimension of basin parallel to main drainage line (Schumm, 1956). This is usually taken as the distance from outlet of river to farthest point in basin perimeter parallel to main drainage line. Basin length for Asan basin is 35.77 km.

4.2.4 **Elongation Ratio:** The ratio was devised by Schumm (1956) as a measure of basin shape. According to Schumm, it is the ratio of diameter of circle with same area as that of basin to the maximum basin length. Its values range between 0.6 to 1.0. High values represent low relief for basin while lower values mean basin has high relief and steep slopes (Strahler, 1964). It also hints towards the shape of basin, a value of 0.5 stands for more elongated basin, values between 0.5- 0.7 represent an elongated basin, values from 0.7- 0.8 mean a less elongated basin, 0.8 – 0.9 symbolize an oval basin while values between 0.9 to 1.00 signify a circular basin. The shape thus assessed though the value of elongation ratio reflects the hydrological character of a drainage basin predicting discharge of runoff, flood forecasting etc.

4.2.5 For Asan the value is 0.84, which means the basin has moderate to gentle slope and an oval shape. In reality for most part the slope is gentle, but in northern section it has high altitude with steep slopes, hence the value of 0.84.

4.2.6 **Circulatory Ratio**: It was proposed by Miller in 1953 to characterize basin shape. It is the ratio of basin area to the area of a circle having perimeter equal to that of the basin. The ratio is an indicative of stage of dissection of the basin (Singh, 1991). Low, medium and high values of the ratio represent youth, mature and old stage of the cycle of basin (Wilson et al., 2012). Asan basin has a low value of 0.28, which means youth stage of river cycle. Such anomalous value results from varied terrain and environment in the valley.

4.2.7 **Form factor**: Horton (1932) introduced form factor as the ratio of area of basin to square of length of the basin. Higher the form factor, circular is the basin; lesser the value, elongated the basin is. For Asan basin the form factor is 0.54, which suggest neither a perfect circular nor an elongated shape.

V. CONCLUSION

This work analyses the relief, linear and areal aspects of Asan basin. It was found that a large portion of study area has low relative relief which is in valley region also having very gentle slope. Relative relief is highest in regions where Lesser Himalayas rise from valley, though this region doesn't hall in highest altitude zone. Drainage pattern is sub-dendritic (to even sub-parallel in some regions) as the main river flows perpendicular to tributary stream but tributaries mostly are roughly parallel to each other. Most rivers are seasonal in nature. Asan the trunk stream comes to be a sixth order stream. Morphometric analysis reveals the basin shape to be oval. A moderately low value of bifurcation ratio (mean bifurcation ratio being 3.8) suggests a minimal impact of underlying structure on the surface. The stream numbers are true to Horton's first law i.e., they decrease in geometric series with the stream order, but it is not so for the second law. A single value of drainage density for a basin with such extensive area is insufficient to reveal clear picture. But a low value of 1.76 may be due to extensive vegetation cover on the surface.

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