A Quantitative Analysis of the Drainage Characteristics of Asan River Watershed, Uttarakhand

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Abstract- The present study identified the importance of quantitative analysis of the drainage characteristics of Asan River watershed for water resource management and development using geospatial approach. The study watershed has been classified into twelve sub-watersheds (namely W1, W2, W3…etc) with sixth order stream. The maximum and minimum elevations in the area were found to be 2200m and 381m respectively. The drainage density (D_d) of the study area varies from 2.43 to 4.14 km/km2. Toposheets (SoI), SRTM DEM and satellite image-based different hydrological evaluation such as drainage network, topographic parameters were evaluated and interpreted for the study area. All the extracted morphometric parameters (linear, areal and relief aspects) has been prepared through the use of Remote Sensing and GIS software's in order to compute watershed attributes which are useful for various applications of the hydrology of the Asan Watershed.

Keywords — Morphometric Parameters, Watershed Hydrology, Digital Elevation Model, Geospatial Approach, Asan River Watershed.

I. INTRODUCTION

The geospatial approach is confirmed to be a very scientific tool for the generation of precise and updated information for characterization of drainage basin parameters and also widely used for thematic mapping of natural resources for planning, development, management, monitoring in environmental studies. Many researchers from various parts of the world like,-Horton [24 & 25], Strahler [2-6], Miller [35] , Schumm [26&28], works with the morphometric parameters for the drainage basin characterization. Evaluation of morphometric parameters requires the analysis of various drainage parameters such as ordering of the various streams, measurement of basin area and perimeter, length of drainage channels, drainage density (D_d), bifurcation ratio (R_b), stream length ratio (R_L), and relief ratio (R_h).Rai (1989) works on hydrogeomorphological studies of Western Doon valley based on Remote Sensing techniques with selective field checks [39]. Magesh et al. (2013) evaluated various morphometric parameters from topographical maps and shuttle radar topography mission (SRTM) DEM in GIS environment [19]. Jasrotia et al. (2012) analyzed morphometry and hydrogeomorphology for delineating ground water potential zones of Western Doon valley [7]. Sreedevi et al. (2013) stated that the influence of morphometric variables on hydrology in a semi-arid watershed using GIS and SRTM data [21]. Morphometric characteristics provide a means for describing the hydrological behavior of basin (Bardossy et al 2002) [1].The geology and geomorphic characteristics of a drainage basin are important for hydrological investigations involving the water resource assessment of the study area.

II.STUDY AREA

Asan river watershed is located in the western part of the Doon Valley, and it is one of the largest intermontane valleys between the Mussoorie Ranges of the Lesser Himalaya to the north and the Siwalik Ranges to the south. The study area located between 77' 38º05" to 78º05'50" E Longitude and 30º14'15" N to 30º30' 51" N Latitudes. It covers an area of approximately 784.36 sq. km. The study area is an asymmetrical longitudinal synclinal valley which extends for about 34 km. in length and 20 km in width. The master streams Asan flows ward and join the Yamuna River. The study watershed enjoys a humid subtropical monsoon climate with the rhythm of weather with an annual rainfall of 2200 mm.

III. OBJECTIVES

The study aimed to compute the different morphometric parameters to portray and evaluate the hydrological behavior of the Asan river watershed. The main objectives of the present study are

1. To study the quantitative aspect of drainage system
2. To evaluate linear and areal and relief aspects of morphometric characteristics.

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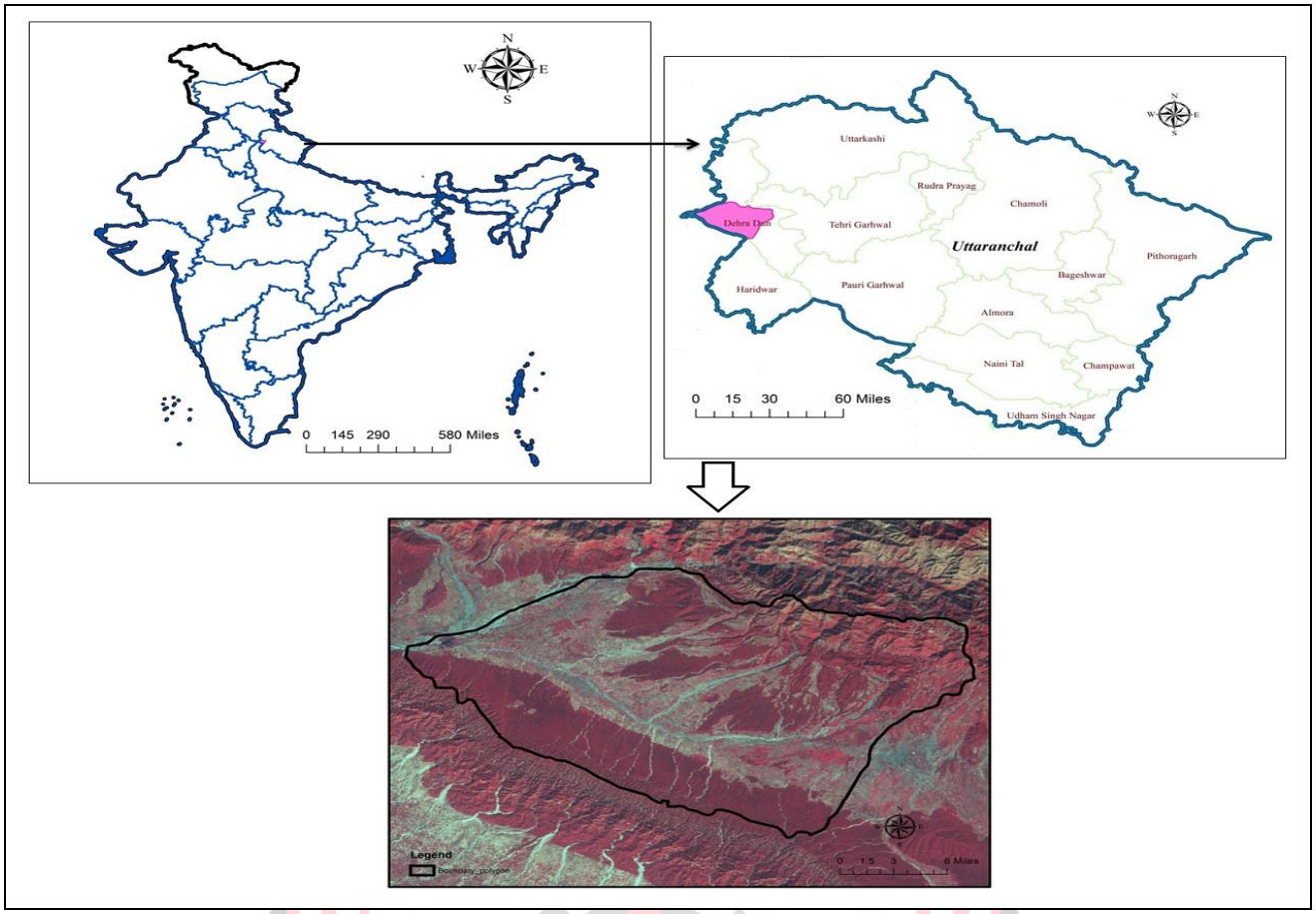

Figure 1: Location Map of Asan River Watershed

IV. DATA AND METHODOLOGY

Drainage characteristics of Asan river watershed have been studied through the use of remote sensing and GIS software's (ArcGIS 9.3, ERDAS Imagine 9.1), SRTM DEM, Topographical Sheets and Satellite images (LANDSAT 8) analysis for the development of water and soil conservation measures. It is covered in the Survey of India toposheet numbers 53f/11, 53f/14, 53f/15, 53f/16, 53J/3 on 1:50,000 scale (Table 1). Asan river watershed is extracted from the SRTM DEM data with a spatial resolution of 90 m using the georeferenced SOI toposheets(figure2). The contributing basin area was extracted with the help of various geoprocessing techniques (SRTM DEM > Filled DEM > Flow Direction > Flow Accumulation > Stream Network > Watershed Extracted) in ArcGIS 9.3.The following procedure was followed to carry out the work.

a) The SOI toposheets were geometrically rectified and georeferenced by taking ground control points (GCPs) by using UTM projection and WGS 84 datum. Further, all geocoded toposheets were mosaic using ERDAS Imagine 9.1 image processing software.

Table 1: Details data information used in the present work

Types of data/software	Details of data	Sources
Surveyof India, toposheets	Toposheet numbers 53f/11, 53f/14, 53f/15, 53f/16, 53J/3 on 1:50,000scale.	Survey of India (SOI), Dehradun, India
LANDSAT 8 satellite imagery	Path/row: 145/43 dated 16/12/2016	https://landsat.usgs.gov
SRTM DEM	Resolution-90 m , 2000	USGS website

b) The Catchment area of the Asan river watershed delineated both from SRTM DEM (pour point based) and Survey of India topographical sheets through making AOI (Area of Interest) of the basin and same AOI were used to cut the satellite Image of the study area. All twelve sub-watersheds are delineated from Survey of India, toposheets by manual methods.

c) The measurements of basin geometric characteristics (e.g., area, perimeter of the basin, length of the basin) are obtained from GIS software (table5).

d) The drainage network of the Asan river watershed is extracted from a series of geoprocessing tools in ArcGIS 9.3 by assign threshold value 100.

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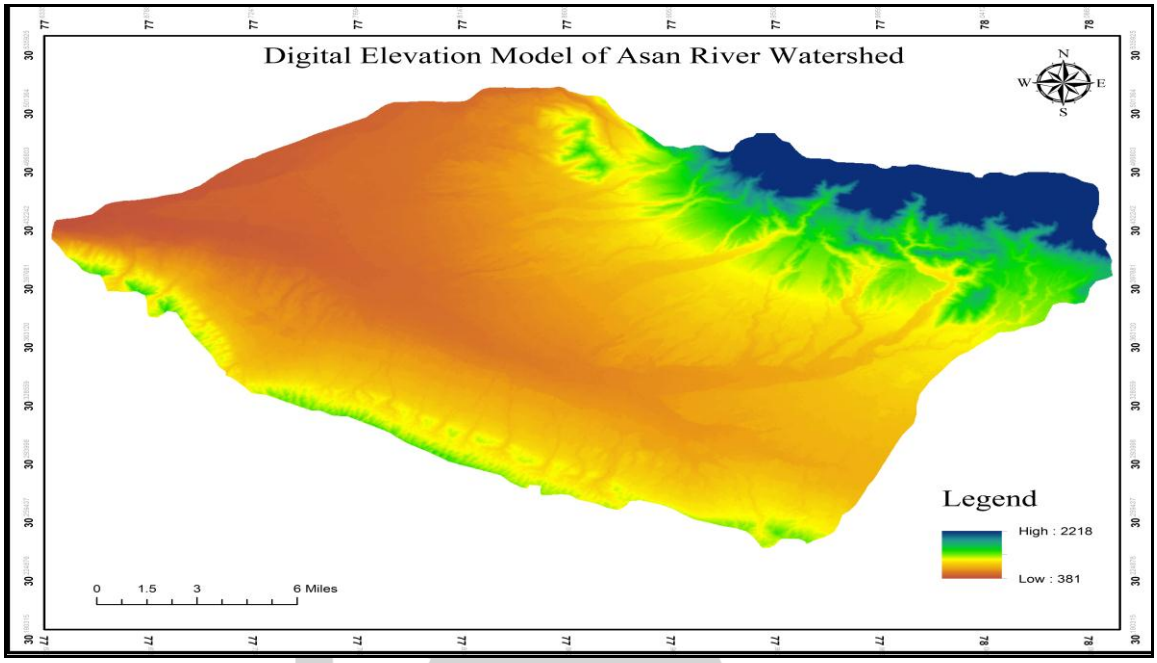

Figure 2: Digital Elevation Model of Asan River Watershed

e) Quantitative morphometric parameters have been calculated from SRTM DEM to assess the drainage characteristics of Asan river watershed. Many important parameters (like,- linear, areal and relief) were computed such as perimeter(P), basin area(A), basin length(L_b) , drainage density (D_d), stream frequency (F_s), elongation ratios (R_e), bifurcation ratio (R_b), circulatory ratio (R_c) etc. using the standard mathematical formulae given in Table 2.

f) Asan watershed has been ranked Sixth Order Stream (figure3). According to Strahler (1964) stream ordering method to designates a segment with no tributaries as a first-order stream. Where two first-order stream segments join, they form a second-order stream segment and so on [24].

Table 2: Methodology adopted for computations of morphometric parameters.

SL.No.	Parameters	Formulae	References
1.	Stream order (U)	Hierarchical rank	Strahler (1964)
2.	Stream length (L_u)	Length of the stream	Horton (1945)
3.	Mean stream length (L_{sm})	$L_{sm}= L_u/N_u$	Strahler (1964)
4.	Stream length ratio (R_L)	$R_L =L_u/(L_u -1)$	Horton (1945)
5.	Bifurcation ration (R_b)	$R_b =N_u/N_u+1$	Schumm (1956)
6.	Mean bifurcation ratio (R_{bm})	R_{bm} = average of bifurcation ratios of all order	Strahler (1957)
7.	Drainage density (D_d)	$D_d =L_u/A$	Horton (1945)
8.	Drainage texture (T)	$T= D_d$ x F_s	Smith (1950)
9.	Stream frequency (F_s)	$Fs =N_u/A$	Horton (1945)
10.	Elongation ratio (R_e)	$R_e =D/L$	Schumm (1956)
11.	Circularity ratio (R_c)	$R_c =4p\pi A/P^2$	Strahler (1964)
12.	Form factor (F_f)	$F_f =A/L^2$	Horton (1945)
13.	Length of overland flow (L_g)	$L_g = 1/DX2$	Horton (1945)
14.	Total Relief or Basin Relief (R)	$R=H – h$	Hadley and Schumm (1961)
15.	Relief ratio (R_r)	$Rr =R/L$	Schumm (1963)

V. GEOLOGY

According to Thakur (1981) Doon Valley has distinct geological attributes with a wide spectrum of rock types ranging in age from Proterozoic to Quaternary [36]. The study area broadly classified into six geological or stratigraphic successions. The details description of geological or stratigraphic successions has been given in the following table3.

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Table 3: Geological /Stratigraphic Succession of Asan River Watershed

Age	Geologic Unit			Lithology
Holocene to Recent	Alluvium			Loose unconsolidated, unstratified material of sand,silt,and clay
	Doon Gravel	Sub-recent Fan Terrace Material (SFT)		Small pebbles and cobbles of sandstone, quartzite and phylite.
Late Pleistocene to Early Holocene		Doon Fan Gravel (DFG)		Sub-rounded boulder sand gravels of quartzite and sandstone
Early Pleistocene		Older Doon Gravel (ODG)		Big boulder of quartzite and sandstone embeded in clay
Late Pleistocene to Early Pleistocene	Siwalik Group	Upper Siwalik Formation		Boulder, conglomerate bed
Late Miocene to Early Pleistocene		Middle Siwalik Formation		Micaceous sandstone with clay and shale pockets
Late Palaeocene to Middle Eocene	Subathu Formation			Red shale and limestone
Neo-Proterozoic	Krol Group	Krol Formation	Krol-C	Granulary grey limestone with calcite veins
			Krol-B	Pink Ferruginous limestone with olive green and dark violet shale
			Krol-A	Grey siliceous limestone with dolomite
		Infra Krol Formation		Grey to black state and shale
Meso-Proterozoic	Jaunsar Group	Nagathat Formation		Grey,violet,fine,grained quartzite with slaty intercalation
		Chandpur Formation		Greyish green folded phyllite and massive, greyish white, coarse grained quartzite
		Madhali Bhadraj Formation		Pele white to greyish white ,coarse grained quartzite with slate intercalation

Source: Modified after Auden (1934), Valdiya (1980) and Rai (1989).

VI. GEOMORPHOLOGY

According to Guha (2005) Asan river watersheds have been identified into six geomorphological units [29]. The details description of geomorphological units has been given in the following table.

Table 4: Major Geomorphic Units of Asan River Watershed

SL.No	Major units	Sub-Units		Origin	Height(m)	Extent
1	Denodo-Structural Hill	-		Denudation dominate on structure	900-2229	In the north of area from Hathiari to Jharipani
2	Structural Hill	More dissected		Denudation with structure dominating	500-900	In the south of the area from Karaundi - wala Rao to Laldhang Rao
		Less dissected			550-1264	In the north of the area from Kata Patthar to Rajpur Reserve Forest.
3	Residual Hill	-		Denudation of colluvial/fluvial	600-1100	In the north of the area viz Ambari, Horawala, Kandholi and Majhaun block reserve forest.
4	Piedmont Zone	Northern	Up	Colluvial / fluvial deposits	540-950	Chillion to Sinaula.
			Md		520-650	Ambari to Birpur.
			Lr		400-500	Harbatpur to Kolhupani
		Southern	Up		500-700	Langra - wala Khala to Laldhang Rao.
			Md		450-650	Yamuna colony to Mohabbe - wala.
			Lr		400-500	Matak majri to Herbhanj - wala.
5	River Terrace	-		Fluvial deposits	420-500	Terraces of Suarna, Asan and Yamuna rivers.
6	Flood Plain	-		Fluvial deposits	<420	Flood Plain of Asan, Suarna, Sitla Rao and Yamuna rivers.

Source: Guha (2005).

VII. RESULT AND DISCUSSION

Basin Area *(A)*, Basin Perimeter *(P)* and Basin Length *(L_b)* are the three most significant morphometric parameters which determine the shape, size and genetic aspect of relief and drainage network. The total basin area of Asan River

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watershed is 784.36, basin perimeter is 487.51 and total basin length is 170.45.

Table 5: Basin Parameters of Asan River Watershed

SW. Name	Basin Area (*A*) in sq. km	Perimeter (*P*) in km	Basin Length (L_b) in km
W1	176.12927	59.30770	23.84
W2	55.063228	30.94856	9.04
W3	111.72035	53.63180	20.73
W4	65.617625	59.58768	22.72
W5	66.148776	40.64574	14.84
W6	54.845319	48.11552	20.10
W7	54.851385	39.64433	13.84
W8	67.719004	49.36823	17.97
W9	39.622628	27.26405	7.65
W10	44.903301	36.07708	7.20
W11	26.977872	24.02394	6.34
W12	20.761358	18.89647	6.18
Total	784.36	487.51	170.45

Source: Computed by Author

LINEAR ASPECT

Stream order (***U)*** refers to the hierarchical rank of stream segments in the drainage network. The drainage map of the Asan watershed has been ranked (Sixth Order Stream) according to Strahler (1964) stream ordering method [6].

Horton (1945), formulated a law of **Stream number (N_u)** that the total number of stream segments of each order [25]. In the study basin *Nu* of first to sixth order streams are 2066, 412,106, 24, 2, and 1 respectively (Table 6).

Table 6: Showing Stream Order of Asan River Watershed

Sub-watershed	Stream Order(*U*)						Total
	I	II	III	IV	V	VI	
W1	444	96	19	6	1	0	566
W2	146	26	7	2	0	0	181
W3	321	62	18	3	1	0	405
W4	200	41	9	1	0	0	251
W5	167	33	10	3	0	0	213
W6	131	18	4	1	0	0	154
W7	134	28	7	2	0	0	171
W8	167	28	7	2	0	0	204
W9	107	21	8	1	0	0	137
W10	118	28	7	2	0	0	155
W11	70	17	6	1	0	0	94
W12	61	14	4	0	0	1	80
TOTAL	2066	412	106	24	2	1	**2611**

Source: Computed by Author

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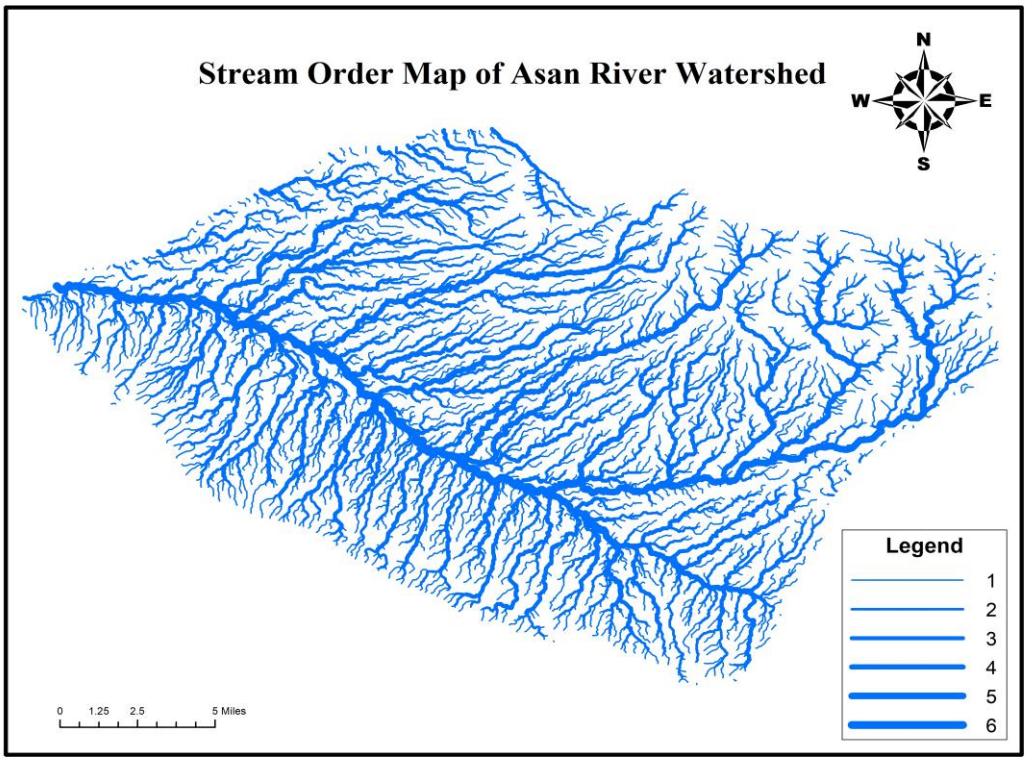

Figure 3: Stream Order Map of Asan River Watershed

Stream length (L_u) is an important hydrological feature of the basin as it reveals surface runoff characteristics streams .Stream length (*Lu*) is the total length of streams of each order. The total length of all drainage networks in Asan river watershed is 2197.42 km. For the study watershed *Lu* observed first to sixth order are first (1078.75), second (581.07), third (324.62), fourth (158.74), fifth (29.84) and sixth (24.39).

Table 7: Showing Stream Length parameter with respect to stream order of Asan River Watershed

Sub-Watershed	Steam Order (N_u)	Steam Length in km(L_u)	Stream Length of Different Order in km (L_u)					
			I	II	III	IV	V	VI
W1	V	429.542	205.698	120.482	39.189	39.273	24.90	0
W2	IV	168.733	88.429	37.334	36.730	6.24	0	0
W3	V	316.670	156.054	88.642	53.349	13.685	4.94	0
W4	IV	163.104	83.117	52.266	27.727	0.833	0	0
W5	IV	187.400	90.820	43.698	26.297	26.585	0	0
W6	IV	142.899	67.636	31.405	25.838	18.020	0	0
W7	IV	163.104	79.019	48.424	20.280	15.381	0	0
W8	IV	189.234	93.351	46.963	22.640	26.280	0	0
W9	IV	121.936	65.915	25.939	27.503	2.579	0	0
W10	IV	141.825	65.985	40.098	30.183	5.559	0	0

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W11	IV	86.043	45.794	24.873	11.071	4.305	0	0
W12	VI	86.095	36.938	20.947	3.814	0	0	24.39
Total		2197.423	1078.756	581.071	324.621	158.74	29.845	24.39

Source: Computed by Author

Stream length ratio (R_L) is the ratio between mean stream length of a given order and its next lower order.In the study basin R_L value varied from 0.030 to 1.16 due to variation in slope and topographic condition. R_L of all sub basin (order wise) are shown in the Table 6.

Table 8: Showing Order wise Mean stream length and Stream length ratio of Asan River Watershed

Sub-Watershed	Mean stream Length (L_{sm})						Stream length Ratio (R_L)				
	I	II	III	IV	V	VI	II/I	III/II	IV/III	V/IV	VI/V
W1	0.46	1.25	2.06	6.54	24.90	0	0.58	0.32	1.00	0	0
W2	0.60	1.43	5.24	3.12	0	0	0.42	0.98	0.16	0	0
W3	0.48	1.42	2.96	4.56	4.94	0	0.56	0.60	0.25	0	0
W4	0.41	1.27	3.08	0.83	0	0	0.62	0.53	0.03	0	0
W5	0.54	1.32	2.62	8.86	0	0	0.48	0.60	1.01	0	0
W6	0.51	1.74	6.45	18.02	0	0	0.46	0.82	0.69	0	0
W7	0.58	1.72	2.53	7.69	0	0	0.61	0.41	0.75	0	0
W8	0.55	1.67	3.23	13.14	0	0	0.50	0.48	1.16	0	0
W9	0.61	1.23	3.92	2.57	0	0	0.39	1.06	0.09	0	0
W10	0.55	1.43	4.31	2.77	0	0	0.60	0.75	0.18	0	0
W11	0.65	1.46	1.84	4.30	0	0	0.54	0.44	0.38	0	0
W12	0.60	1.49	0.95	0	0	24.39	0.56	0.18	0	0	0

Source: Computed by Author

The **bifurcation ratio (R_b)** stated as the ratio of the number of stream segments of given order to the number of segments of the next higher order. The value of bifurcation ratio ranges from 2.83 to 9.00. Table 7 shows the bifurcation ratio between streams of different orders of the Asan river watershed. The bifurcation ratio is dependent upon the geological and lithological development of the drainage basin.

The **mean bifurcation ratio (R_{bm})** states that defined as the average of bifurcation ratios of all orders. In the present study the R_{bm} varies from 3.89 to 6.14 (Table 7) with small variation for different regions on different environment. High value of R_{bm} indicates complex structural control on drainage pattern and vice versa.

Table 9: Showing Bifurcation ratio and mean bifurcation ratio of Asan River Watershed

Sub-Watershed	Bifurcation Ratio (R_b)					Mean Bifurcation Ratio (R_{bm})
	I/II	II/III	III/IV	IV/V	V/VI	
W1	4.62	5.05	3.16	6.00	0	4.70
W2	5.61	3.71	3.50	0	0	4.27
W3	5.17	3.44	6.00	3.00	0	4.40
W4	4.87	4.55	9.00	0	0	6.14
W5	5.06	3.30	3.33	0	0	3.89
W6	7.27	4.50	4.00	0	0	5.25
W7	4.78	3.50	4.00	0	0	4.09

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W8	5.96	4.00	3.50	0	0	4.48
W9	5.09	3.00	7.00	0	0	5.03
W10	4.21	4.00	3.50	0	0	3.90
W11	4.11	2.83	6.00	0	0	4.31
W12	4.35	3.50	0	0	0	3.91

Source: Computed by Author

AREAL ASPECTS

The drainage density (D_d) [25] is defined as the total length of streams per unit area divided by the area of drainage basin (Horton 1945). The drainage density of the area varies between 2.43-4.14km/km2.High drainage density (>4.00) indicates the weak or impermeable subsurface material, thin vegetation and mountainous relief. Low drainage density of the watershed indicates the watersheds of highly permeable sub-soil and thick vegetation cover.

According to Horton (1932 and 1945), **Stream frequency or channel frequency (F_s)** defined as total number of stream segments of all orders per unit area [24 & 25]. The stream frequency of the Asan sub-watersheds varies from 2.80 to 3.87.The low stream frequencies value indicates sparse drainage network favoring groundwater recharge.

Drainage texture (R_t) means that the relative spacing of drainage line. According to Horton (1945), Rt is the total number of stream segments of all order per perimeter of that area [25]. Smith (1950) has been classified drainage density into five based on different textures: very coarse (<2), coarse (2-4), moderate (4-6), fine (6-8) and very fine (>8) [13].For the study basin drainage texture values ranges between 3.20-9.54.The computed values shows the drainage texture of the study area is very coarse to very fine.

According to Schumm (1956), **Elongation ratio (R_e)** stated that the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The elongation ratio classified into three categories namely (a) circular (>0.9), (b) oval (0.9 to 0.8), (c) elongated (<0.7) [28].The elongation ratio of the sub-watersheds varies from 0.35 to 0.69 with medium to high relief and elongated in shape basin category.

The circularity ratio(R_c) [35] defined as the ratio of the area of the basin to the area of the circle having the same circumference as the perimeter of the basin (Miller1953). In the present study, R_c ranges from 0.71 to 0.22. Low value indicates that the high to moderate relief and drainage system is structurally controlled.

The **form factor (F_f)** defined, as the ratio of basin area to square of basin length (Horton,1932**)**. The Rf Values for the study area varies from 0.12 to 0.86.

The length of overland flow (L_g) [25] is defined as approximately equal to half of the drainage density (Horton1945). The length of the overland flow for the study area varies from 0.15 to 0.50.The length of overland flow is mostly influenced by both hydrologic and physiographic structures of the area.

Table 10: Areal Aspects of Asan River watershed

Sub-Watershed	Drainage Density (D_d)	Stream Frequency (F_s)	Drainage Texture(R_t)	Form Factor(F_f)	Circularity Ratio(R_c)	Elongation Ratio(R_e)	Length of Overland Flow(L_g)
W1	2.43	3.21	9.54	0.30	0.62	0.62	0.20
W2	3.06	3.28	5.85	0.67	0.72	0.92	0.16
W3	2.83	3.62	7.55	0.26	0.48	0.59	0.17
W4	2.48	3.87	4.26	0.12	0.23	0.40	0.20
W5	2.83	3.22	5.24	0.30	0.50	0.61	0.17
W6	2.60	2.80	3.20	0.13	0.29	0.41	0.19
W7	2.97	3.11	4.31	0.28	0.43	0.60	0.16
W8	2.79	3.01	4.13	0.20	0.34	0.51	0.17
W9	3.07	3.45	5.02	0.67	0.67	0.92	0.16

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W10	3.15	3.45	4.29	0.86	0.43	1.05	0.15
W11	3.19	3.48	3.91	0.67	0.58	0.92	0.15
W12	4.14	3.85	4.23	0.54	0.73	0.83	0.12

Source: Computed by Author

RELIEF ASPECTS

Basin relief (*R*) or Relative relief or Total relief is an important morphometric parameters to evaluate the morphological characteristics of basin topography .**Total relief *(H)*** refers to the elevation difference between the highest and lowest points in the basin. The total relief of the study area are ranges 350m - 1775m. The low relief indicates that the central part, around stream sides of the Asan basin is flat to gentle slope type, generally used for agricultural activities.

According to Schumm (1956), **The Relief ratio (R_h)** is the maximum relief to horizontal distance along the longest dimension of the basin parallel to the principal drainage line[28]. Highest R_h found in the sub basin W6 (0.0883) and Low value of R_h found in the sub basin W3 (0.0169) signify that the basin control under resistant basement rock and low degree of slope. Hadley (1961) also define as a dimensionless height-length ratio equal to the tangent of angle formed by two planes intersecting at the mouth of the basin, one representing the horizontal and other passing through the highest point of the basin[26].

Table 11: Relief characteristics of the Asan watershed.

Sub-Watershed	Max. Height (m)	Min. Height (m)	Basin Relief (*R*) in meters	Relief Ratio (R_h)
W1	2185	517	1668	0.0700
W2	862	424	438	0.0458
W3	869	519	350	0.0169
W4	1002	389	613	0.0270
W5	912	418	494	0.0333
W6	2218	443	1775	0.0883
W7	961	449	512	0.0370
W8	2068	486	1582	0.0324
W9	866	489	377	0.0493
W10	904	448	456	0.0633
W11	935	408	527	0.0831
W12	912	381	531	0.0859

Source: Computed by Author

VIII.CONCLUSIONS

Quantitative analysis of the morphometric parameters of the watershed indicate the greater efficiency and accuracy of using Geospatial approach compared to manual methods. The drainage network computations give us clue to understand about the hydrological conditions (like, - permeability capacity, storage capacity, surface run off and sediment yield) and nature of rock formation exposed within the watershed. The study reveals that the drainage basin mostly dominated by first order streams (2066). Drainage density is high in sub watershed W2, W9, W10, W11, and W12 while stream frequency is high in all sub watersheds except sub watershed 6 (2.80).The Asan watershed have moderate to high relief of the terrain and elongated in shape. The high value of drainage density indicates that the sub-basin is impermeable subsoil and sparse vegetation cover. The compute high elongation ratio values indicate high infiltration capacity and low runoff, whereas lower R_e values exhibits high susceptibility to erosion and sediment load. The variation of stream length ratio might be due to changes in slope and topographic conditions of the study area. High value of the mean bifurcation ratio indicates complex structural control on drainage pattern and vice versa. The study area has coarse to very fine drainage texture. High drainage texture falls under the sub watershed W1, W2, W3, W5 and W9. The drainage morphometry exhibits the basin mainly dendritic to sub dendritic due to topographic and slope control. The computation of basin relief parameters reveals that sub

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watershed W1, W4, W6 and W8 are characterized by high basin relief and steep slope, while sub watershed W2,W3,W5,W7,W9,W10,W11and W12 are characterized by relatively low basin relief. This study will be immense helpful for the utility in river basin evaluation, basin prioritization for soil and water conservation, flood management and other natural resource management.

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