A GIS-Based Assessment of Asan River Basin for Watershed Management

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Abstract

Watershed prioritization, management, and development are crucial for conserving not only the water resources but also associated soil and vegetation. This furthermore depends on the hydrological assessment of a specific river basin. The present study aims to evaluate and understand various topographical as well as morphometric characteristics of the Asan River basin for sustainable watershed management. Spatial Analysis Tools of ArcGIS software has been used to delineate watershed and execute other geospatial operations. SRTM DEM data at 30m resolution has been utilized to perform the morphometric analysis of the watershed. Also, Sentinel-2B data at 10m resolution has been used to evaluate the Vegetation Index. Various maps related to Basin, Slope, Aspect, Elevation, Land use & Land cover, and NDVI (Normalized Differential Vegetation Index) have also been prepared. We found a positive correlation of NDVI with elevation & slope and a negative correlation with drainage density of the basin. The elevation ranging from 400m to 900m, and slope ranging from 0° to 20°, favoured the vegetation growth. The highest vegetation at drainage density ranging from 1.7 km/km^2 to 9.8 km/km^2. This study concludes that the Asan River basin is less elongated in shape with moderate relief, the DEM-based hydrological assessment at the watershed scale is more practical and precise compared to other available techniques and has a promising impact on basin vegetation. This study would be helpful to various decision-makers and managers for sustainable natural resource management and watershed management.

***Key words**: GIS, Remote Sensing, Morphometric Analysis, NDVI, DEM, Watershed Management.*

Introduction

The world is moving toward water scarcity crises due to higher water demand, climate change, and urbanization, (Boretti and Rosa, 2019). To protect the globe from water crises, water resource management and watershed characterization become necessary. Watershed management is a part of water resource management. It combines soil, vegetation, & water to conserves the precious natural resources and also enhances the land use productivity (Phansalkar and Verma, 2004). Since a watershed is part of the land that is used for farming, groundwater infiltration, industrialization, and other anthropogenic works, watershed management is become necessary for social, economic, and environmental point of view (Asgari, 2021; Schmidt & Morrison, 2012).

In several hydrologic and soil modelling methods many input parameters are required, also their equation can be a complicated depending on the environment and landscape variability. Manual extraction of these input parameters can be error-prone and tedious, particularly with macroscale watersheds. (Nangia et al., 2010). A GIS-based approach is more scientific, cost-effective, and accurate for the watershed basin assessment. DEM data, along with multispectral satellite imagery from various GIS-based platforms have a better impact on water and land resource management (Singh et al., 2012). Remote Sensing and GIS based watershed basin evaluation has been carried out by several scientists and researchers for the multiple terrains and it has been proved one of the eminent scientific techniques for the generation and characterization of drainage basin parameter (Singh et al., 2014; Hlaing et al., 2008; Grohmann, 2004; Korkalainen et al., 2007; Pankaj and Kumar, 2009; Javed et al., 2009).

The present work deals with the GIS-based assessment of the Asan River basin for the watershed management. This study would be beneficial for the policy makers/decision makers of various disciplines for a better understanding of natural resources.

Study Area

Asan River basin lies on the west of the Dehradun city of Uttarakhand, India. Basin's topmost stream originates from the lower Mussoorie ranges, but the origin of the Asan River is at Chandrabani in Dehradun near shiwalik hills (Ramsar Site report, 2020) and the basin outlet merges with the Yamuna River. The coordinate of the study area falls between Latitude (from 30°14'N to 30° 28'N) and Longitude (from 77°38'E to 78°05'E). The east part of the basin is the core city area and the west part is the outer city area. The total area of our study is 701.15 km^2 with elevations ranging from 390 m to 2218 m. The total annual rainfall in the area is 1945 mm. The summers are generally hot and the winters very cold. The yearly temperature varies from 41°C in summers to 2°C in winters. The map of the study area has been shown below in (Fig.1).

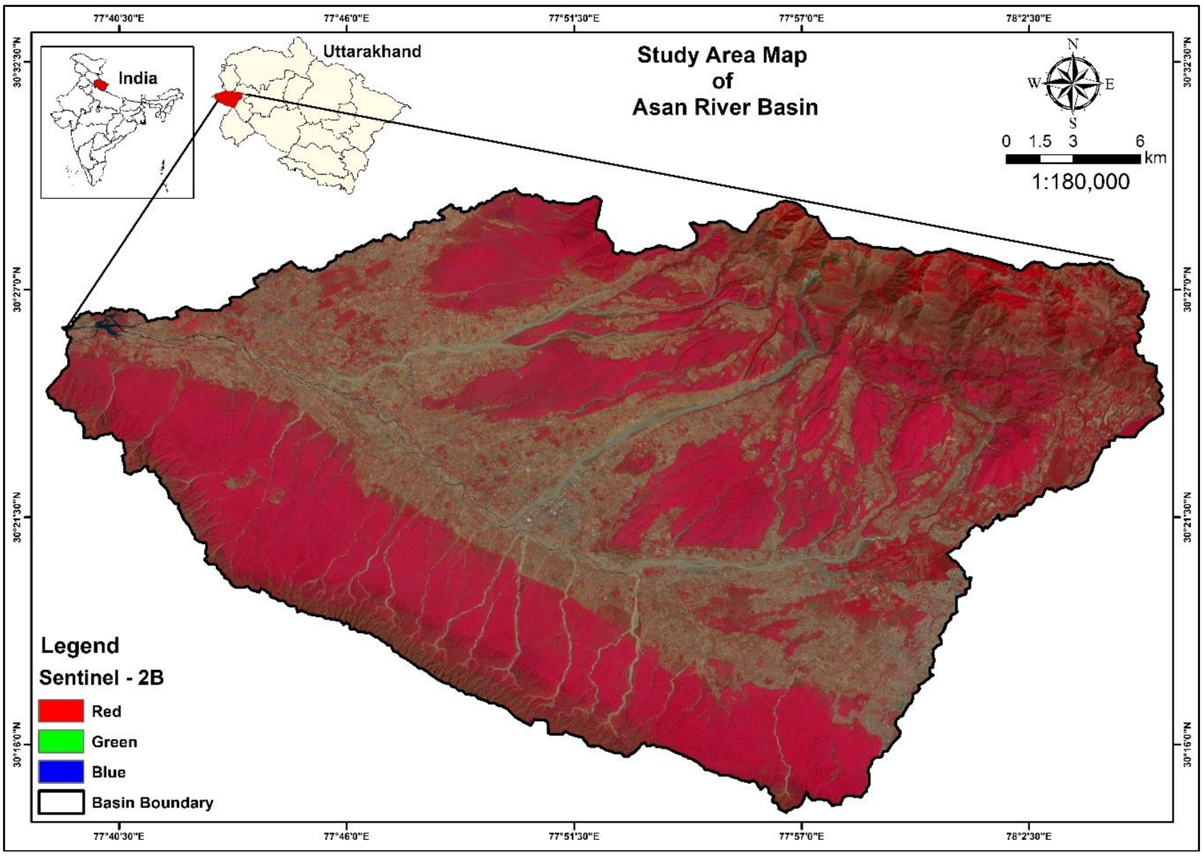

Fig.1 The Study Area Map

Materials & Methods

In this present work, the combined use of multispectral satellite images and DEM data has been utilized for the generation of a spatial data and evaluation of various hydrological parameters and vegetation analysis. For delineating the watershed basin boundary and stream network the Hydrology tool a sub-tool of the Spatial Analysis Tools in Arc GIS desktop software has been used. Also, the Aspect map, Elevation map, Drainage Density map, NDVI map, LULC map, and Slope map of the Asan River basin has been prepared.

Normalized Differential Vegetation Index (NDVI) Formula:

[NDVI = ((Nir) - (Red)) / ((Nir) + (Red))]

Where, Nir = Sentinel-2B (Band-8) and Red = Sentinel-2B (Band-4).

Range: (-1 to +1)

Table 1. Data type and date source used for present work

Sr. No.	Type of data	Date of data	Source
1.	Sentinel-2B satellite imagery	19/04/2022	https://scihub.copernicus.eu/dhus/#/home
2.	SRTM DEM	23/09/2014	https://earthexplorer.usgs.gov/

Table 2. Formulas and Parameters for computation of morphometric analysis.

Sr. No.	Formulas	Parameters	Reference
1	Hierarchical rank	Stream order (w)	(Strahler, 1964)
2	Length of the stream	Stream length (L_u)	(Horton, 1945)
3	$L_{sm} = L_u/N_u$	Mean stream length (L_{sm})	(Strahler, 1964)
4	$R_L = L_u / (L_u — 1)$	Stream length ratio (R_L)	(Horton, 1945)
5	(R_b) = Nu/Nu + 1	Bifurcation ration (R_b)	(Schumm, 1956)
6	R_{bm} = average of bifurcation ratios of all order	Mean bifurcation ratio (R_{bm})	(Strahler, 1957)
7	$D_d = L_u/A$	Drainage density (D_d)	(Horton, 1945)
8	$T = D_d \cdot F_s$	Drainage texture (T)	(Smith, 1950)
9	$F_s = N_u/A$	Stream frequency (F_s)	(Horton, 1945)
10	$Re=2\sqrt{(A/\pi)}/L_b$	Elongation ratio (R_e)	(Schumm, 1956)
11	$R_c = 4\ \pi\ A/P^2$	Circularity ratio (R_c)	(Strahler, 1964)
12	$F_f = A/L^2$	Form factor (F_f)	(Horton, 1945)
13	$R = H — h$	Relief	(Hadley and Schumm, 1961)
14	$R_r = R/L$	Relief Ratio	(Schumm, 1963)

Results and Discussion

4.1 Morphometric Analysis

The morphometric analysis explains the linear aspects, areal aspects, and relief aspects of the drainage basin which is useful to understand its hydrological characteristics.

4.1.1 Linear Aspects

In linear aspects, the basin's linear characteristics such as Stream Number (Nu), Stream Order (W), Bifurcation ratio (Rb), and Stream Length (km) are defined. The total number of streams in the basin is 2616. The basin follows Horton's first law wiz., the stream number (Nu) in each category falls in a geometric sequence, as represented by the graph in (Fig.2). The stream orders are ranging from (1st order to 6th order) as shown in (Fig.3). The bifurcation ratio is ranging from 2 to 12 and the mean bifurcation ratio is 5.45. The bifurcation ratio defines the drainage pattern in the basin, where the pattern is dendritic in shape.

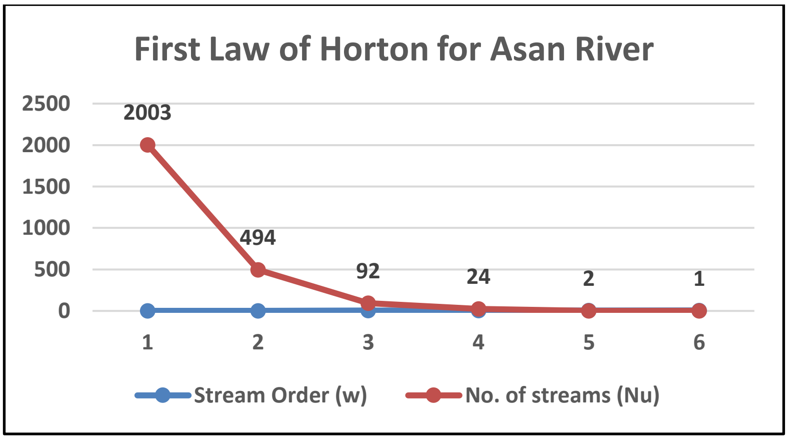

Fig. 2 First Law of Horton for Asan River

Table 3. Linear Aspects Table

Stream Order (w)	Number of streams (Nu)	Bifurcation ratio (RbF)	Mean bifurcation ratio (Rbm)	Total length of streams (km)	Mean length of streams (km)	Length ratio (RL)
1	2003		5.45	973.75	0.77	
2	494	4.05		511.67		0.53
3	92	5.37		303.09		0.59
4	24	3.83		155.62		0.51
5	2	12.00		29.31		0.19
6	1	2.00		32.41		1.11
Total	**2616**		**Total**	**2005.85**		

4.1.2 Areal Aspects

Areal aspects include the areal elements such as Area (km^2), Elongation Ratio (Re), Form factor (Ff), Stream Frequency (Fs), Parameter (km), Drainage Density (Dd), Drainage Texture (T), and Circularity Ratio (Rc). The total area of the Asan River basin is 701.15 km^2 and the parameter is 137.35 km. As per Schumm, the elongation ratio has been classified into three classes; (i) (>0.9) = circular, (ii) (0.9–0.8) = oval, (iii) (0.8–0.7) = less elongated and (iv) (<0.7) = elongated. Here, 0.7 is the value of the elongation ratio which implies that the basin is less elongated in shape with moderate relief. The circulatory ratio value is 0.47 which explains that the basin is less circular or less elongated in shape. The form factor is the flow intensity of the basin. The 0.38 value of the form factor indicates that flow intensity inside the basin is very low. As per Horton, the stream frequency is directly related to drainage density. Hence, the value of stream frequency is 3.73, and the Mean drainage density is 2.86 km/km^2 which implies that both are directly related to each other. The drainage texture value is 10.67 implies that the drainage texture is coarse with highly resistant permeable material.

Table 4. Areal Aspects Table

Basin area (km^2)	Perimeter (km)	Length (km)	Form factor (Ff)	Elongation ratio (Re)	Circularity ratio (Rc)	Drainage density (km/km^2)	Stream Frequency (Fs)	Drainage Texture (T)
701.15	137.35	43	0.38	0.70	0.47	2.86	3.73	10.67

4.1.3 Relief Aspects

Relief Aspects defines the 3D elements of the basin. The total basin relief is 1828m which indicates the basin is having moderate relief. The value of the relief ratio is 42.51. The low value of the relief ratio implies that the maximum area of the basin is having a very gentle slope.

Table 5. Relief Aspects Table

Height of basin mouth (z) m	Maximum height of the basin (Z) m	Total basin relief (R) m	Relief ratio
390	2218	1828	42.51

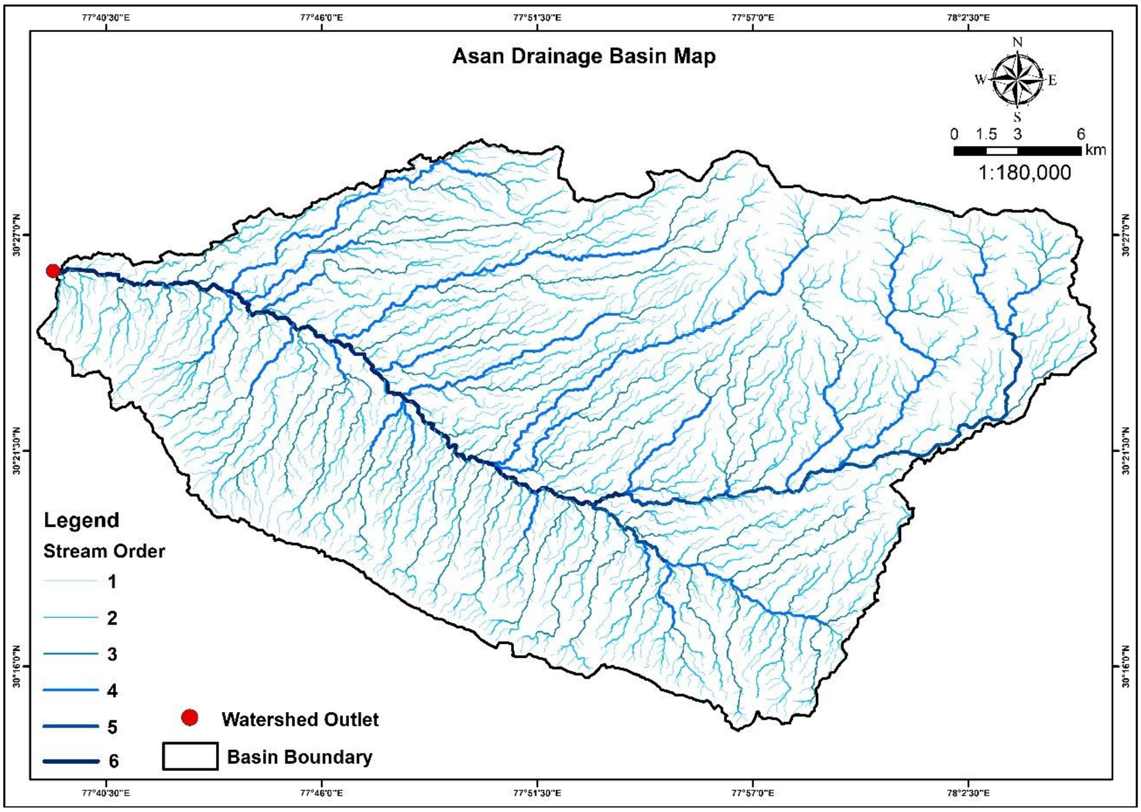

Fig.3 Drainage Basin Map

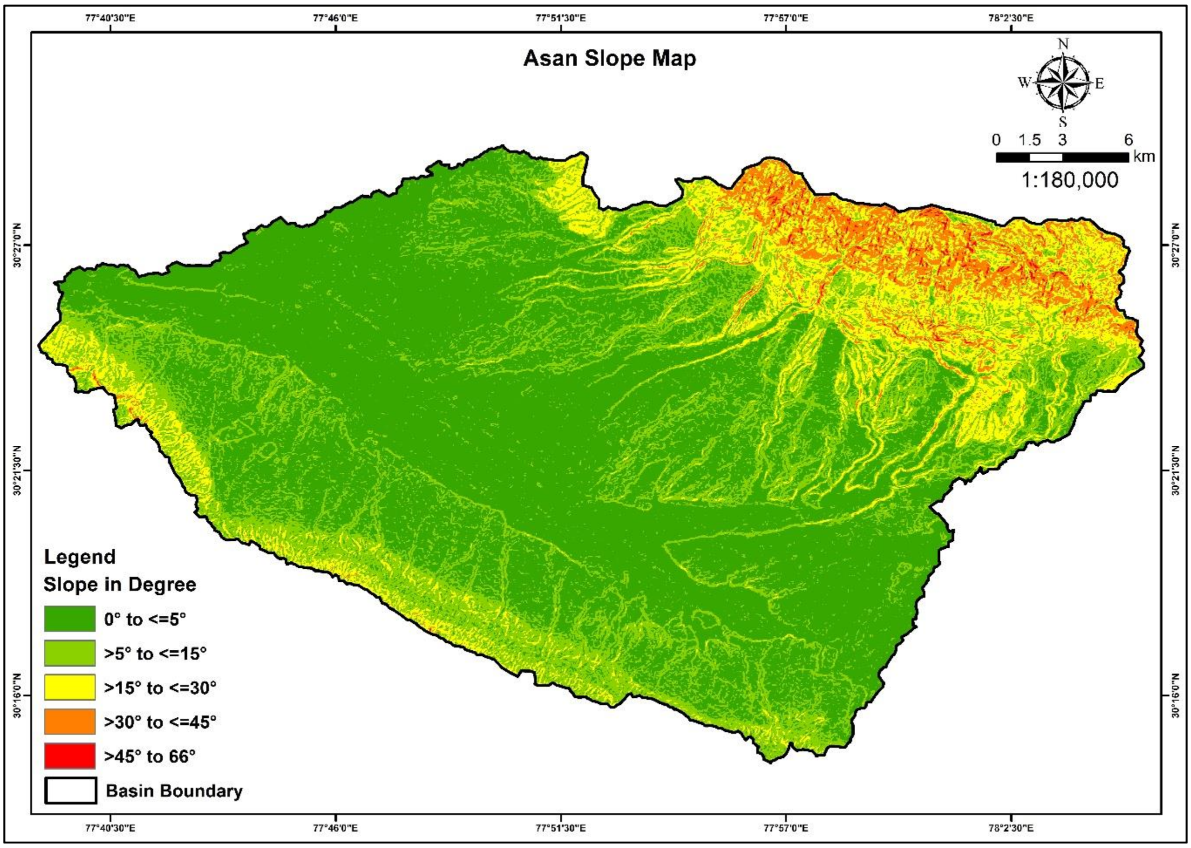

Fig.4 Slope Map

4.2 Slope

Slope defines the steepness of the area. The Asan River basin slope is divided into 5 classes as shown in (Fig.4): (0° to <=5°) is very gentle having 57.52% of the total area, (>5° to <=15°) is gentle having 25.36% of the total area, (>15° to <=30°) is Moderate having 12.14% of the total area, (>30° to <=45°) is steep having 4.62% of total area and (>45° to 66°) is very steep having 0.36% of total area. It is visible from the table and map that most of the basin area is very gentle to gentle. A gentle slope implies that the basin is good for groundwater infiltration having less runoff.

Table 6. Slope Table

Sr. No.	**Slope Classes**	**Area in km^2**	**Area in %**
1	0° to <=5°	403.3	57.52
2	>5° to <=15°	177.82	25.36
3	>15° to <=30°	85.13	12.14
4	>30° to <=45°	32.37	4.62
5	>45° to 66°	2.53	0.36
Total Area		**701.15**	**100**

4.3 Aspect

The aspect shows the direction of the slope. The Aspect at (0°-22.5°) is north, at Northeast (22.5°-67.5°) it is east, and so on. For this study, the direction of the slope is west-facing as shown in (Fig.5). This indicates that the slope has higher moisture content and higher vegetation cover as compared with the east-facing slope.

Table 7. Aspect Table

Sr. No.	**Aspect Classes**	**Area in km^2**	**Area in %**
1	Flat (-1°)	2.58	0.37
2	North (0°-22.5°) (337.5°-360°)	91.39	13.03
3	Northeast (22.5°-67.5°)	79.93	11.4
4	East (67.5°-112.5°)	70.67	10.08
5	Southeast (112.5°-157.5°)	75.09	10.71
6	South (157.5°-202.5°)	91.35	13.03
7	Southwest (202.5°-247.5°)	95.09	13.56
8	West (247.5°-292.5°)	97.75	13.94
9	Northwest (292.5°-337.5°)	97.3	13.88
Total Area		**701.15**	**100**

4.4 Elevation

The Elevation of Asan River Basin is classified in 5 classes shown in (Fig.6): (<= 600m) is very low having 43.62% of the total area, (> 600m to <= 900m) is low having 43.15% of the total area, (> 900m to <=1,200m) is moderate having 6.48% of the total area, > 1,200m to <= 1,600m) is high having 3.36% of the total area and > 1,600m to 2,218m) is very high having 3.39% of the total area. The maximum area of the basin is having very low to low elevation value which implies that elevation has a direct relation with slope and indirect relation with drainage density.

Table 8. Elevation Table

Sr. No.	**Elevation Classes**	**Area in km^2**	**Area in %**
1	<= 600m	305.84	43.62
2	> 600m to <= 900m	302.58	43.15
3	> 900m to <=1,200m	45.43	6.48
4	> 1,200 m to <= 1,600m	23.56	3.36
5	> 1,600m to 2,218m	23.74	3.39
Total Area		**701.15**	**100**

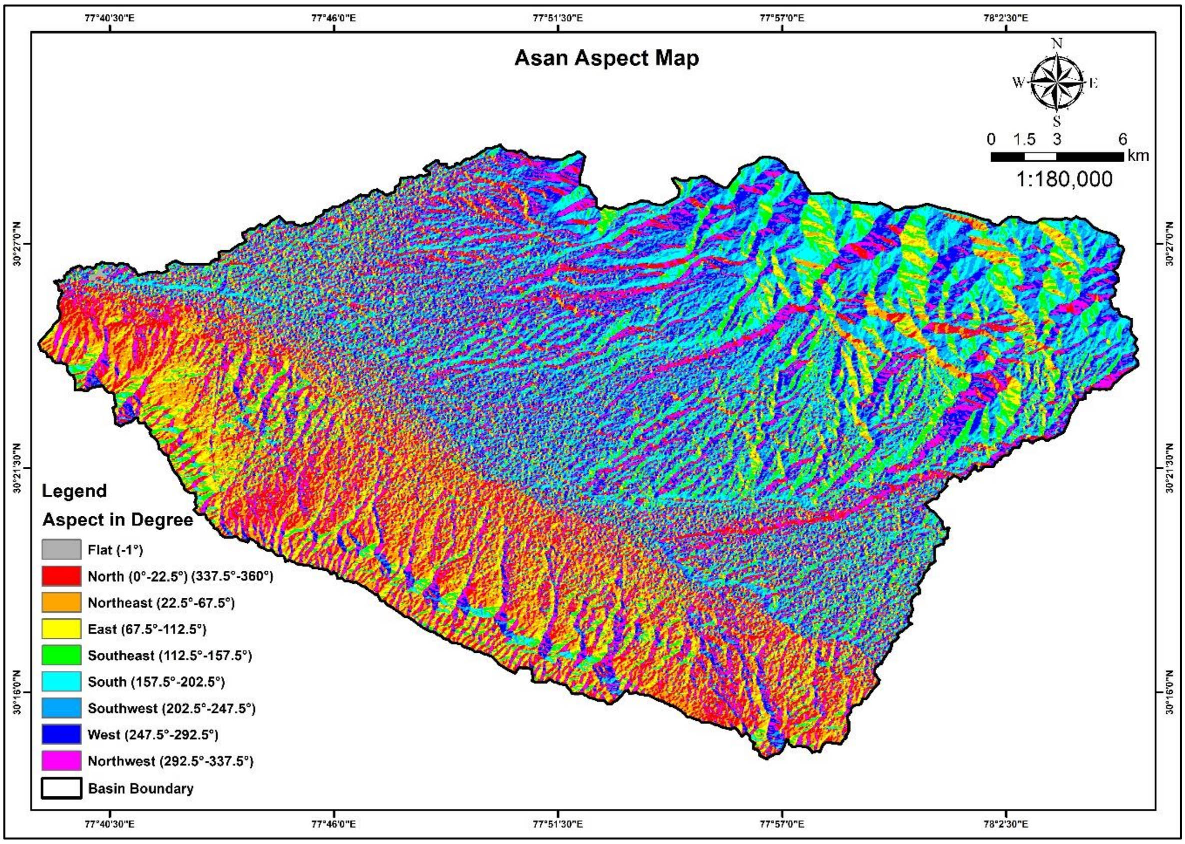

Fig.5 Aspect Map

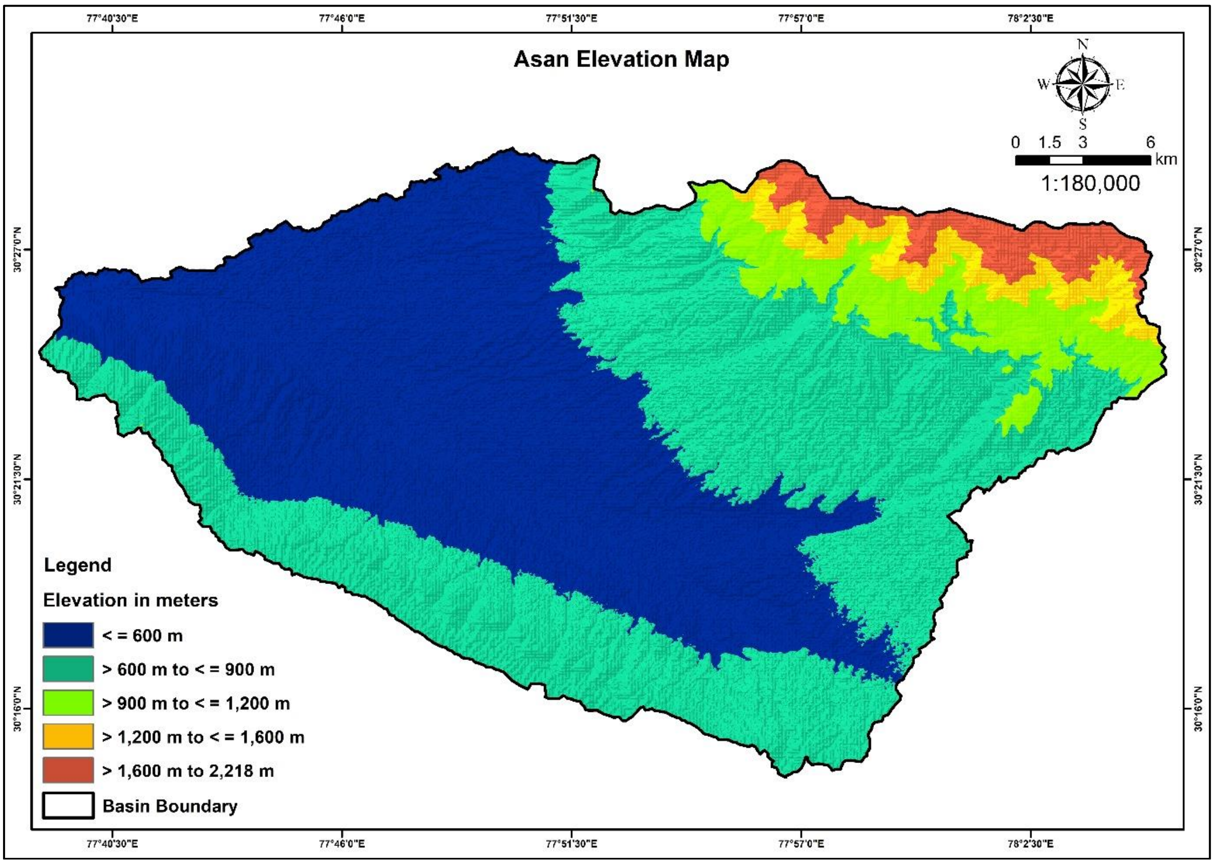

Fig.6 Elevation Map

4.5 Drainage Density

The drainage density of the basin is defined as the total length of streams per unit area. Here, the drainage density is divided into 5 classes as shown in (Fig.7): (<= 3 km/km^2) is very low having 12.1% of the total area, (> 3 km/km^2 to <= 6 km/km^2) is low having 54.35% of the total area, (> 6 km/km^2 to <=9 km/km^2) is moderate having 26.39% of the total area, (> 9 km/km^2 to <= 12 km/km^2) is high having 6.11% of the total area and (> 12 km/km^2 to 14.14 km/km^2) is very high having 1.05% of the total area. Most of the area in the basin is having low drainage density. The highest drainage density represents by the red colour on the map where Selaqui industrial drainage waste is flows into the Asan River which is a major concern on the issue of water quality and water infiltration.

Table 9. Drainage Density Table

Sr. No.	Drainage Density (km/km^2)	Area in km^2	Area in %
1	<= 3	84.85	12.1
2	> 3 to <= 6	381.05	54.35
3	> 6 to <=9	185.04	26.39
4	> 9 to <= 12	42.82	6.11
5	> 12 to 14.14	7.39	1.05
Total		**701.15**	**100**

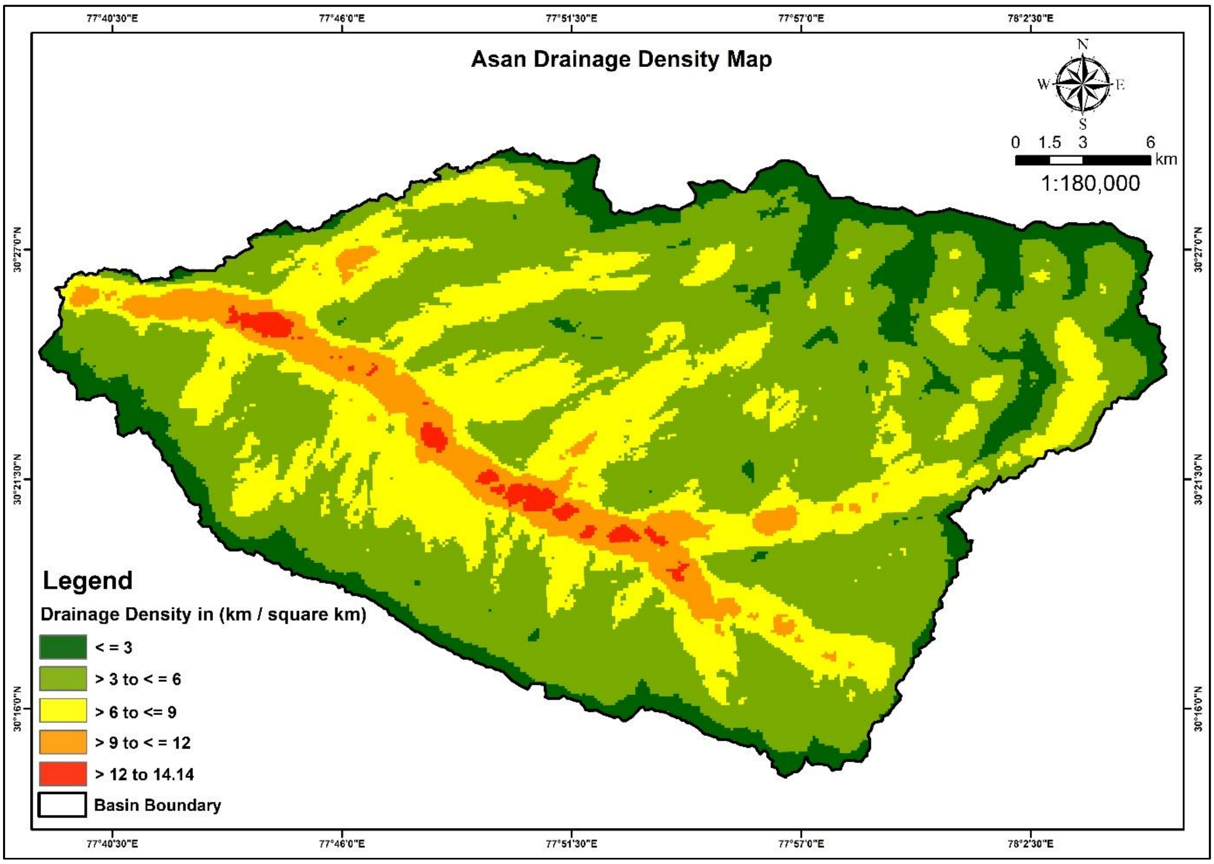

Fig.7 Drainage Density Map

4.6 Land Use and Land Cover (LULC)

LULC classification is another important factor for assessment of hydrological condition. of any area. It explains the usage of land resource by anthropogenic activities especially urbanization and agriculture (YanYun et al., 2014). Water resources are always under severe pressure due to climate change and land use practices. The LULC map has been prepared using the Sentinel-2B imagery. The method used for LULC classification is Supervised classification performed in ERDAS Imagine Software. There are 6 LULC Classes wiz.: Built-up, Agriculture Land, Forest Area, Wasteland, Dry Riverbed and Waterbodies as shown in (Fig.8). The result from the map depicts that more than half of the area in a basin is forest area (59.72%), followed by agricultural land (15.69%). The basin is surrounded by lesser Himalayas in the north & Shiwalik in the south and has a steep slope, while the central region of the basin is having a gentle slope which means more infiltration and less runoff. This implies that the central part is good for agriculture practices while only (8.23%) of the basin area is under wasteland category. The built-up is another dominating class of the basin occupying (12.60%) of the area. This confirmed that the Asan River basin is having huge anthropogenic pressure which will directly affects the river health and its biodiversity. The waterbodies and dry riverbed are two categories occupying least percentage of area in the basin.

Table 10. LULC Table

Sr. No.	LULC Classes	Area in km^2	Area in %
1	Built-up	88.41	12.60
2	Agricultural Land	109.98	15.69
3	Forest Area	418.71	59.72
4	Wasteland	57.69	8.23
5	Dry Riverbed	24.97	3.56
6	Waterbodies	1.39	0.20
Total Area		**701.15**	**100**

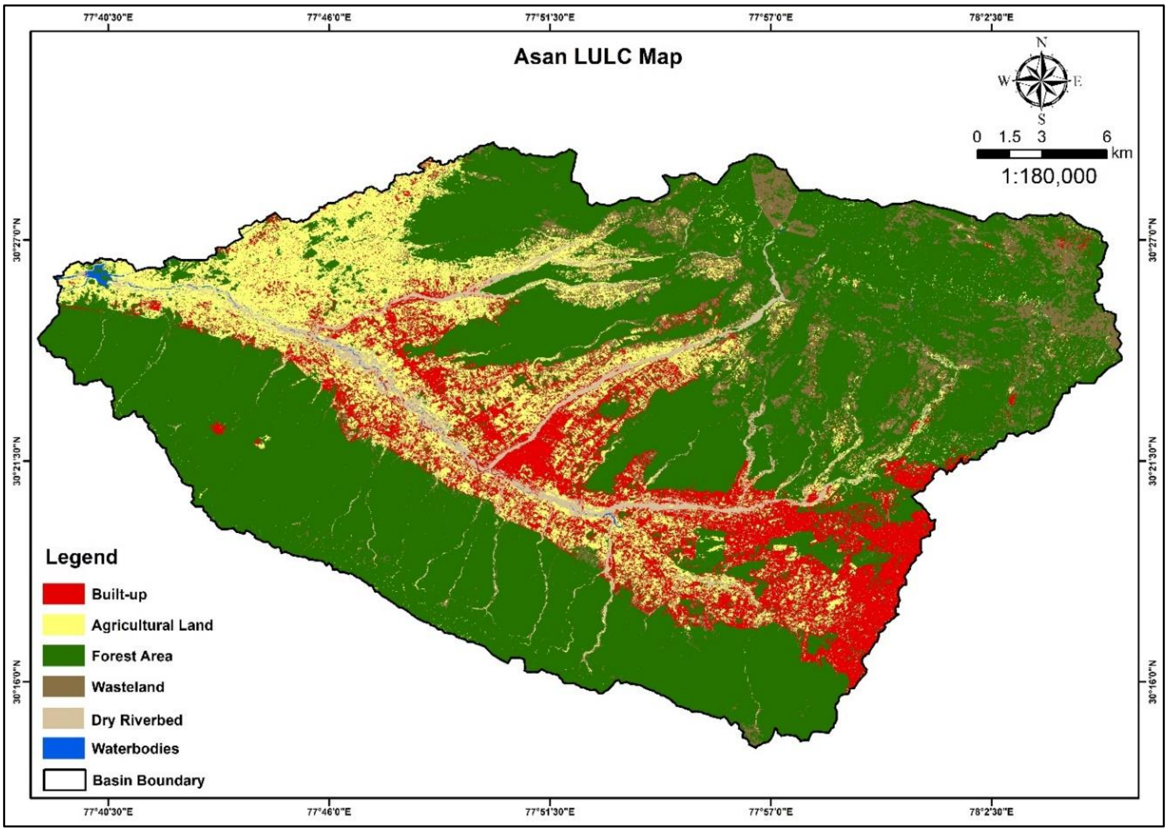

Fig.8 LULC MAP

4.7 Normalized Differential Vegetation Index (NDVI)

The NDVI measures the amount of vegetation covering a given area of land. The map in (Fig.9) shows that almost 45% of the area is having (Very High to High) NDVI value which shows that the basin is having a healthy green vegetation. Increasing the amount of green cover in an area is beneficial for carbon sinking, which in turn improves air quality. The NDVI value displayed on the map for the agricultural region of the basin is low.

Table 11. NDVI Table

Sr. No.	NDVI Classes	Area in km^2	Area in %
1	Very Low	36.65	5.23
2	Low	185.25	26.42
3	Medium	162.68	23.2
4	High	173.28	24.71
5	Very High	143.29	20.44
Total Area		**701.15**	**100**

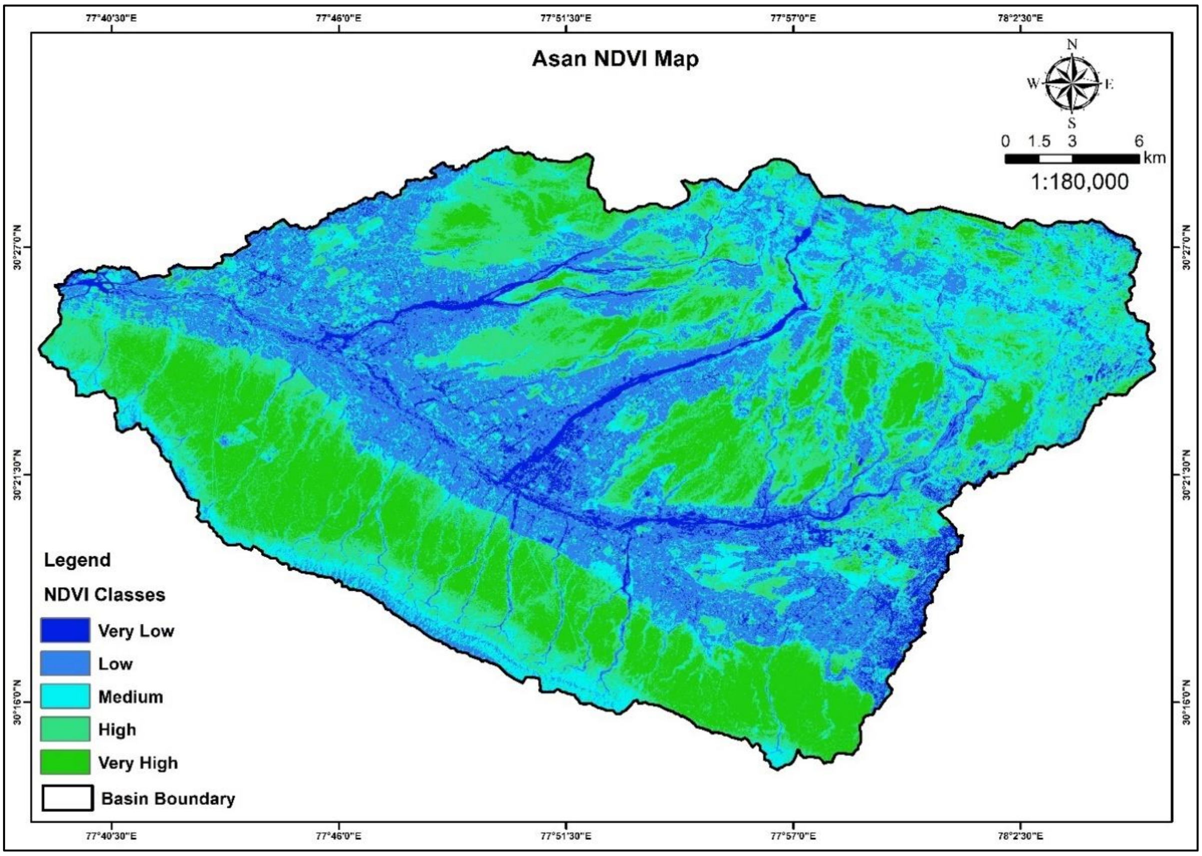

Fig.9 NDVI Map

NDVI relation with Elevation, Slope, and Drainage Density

We found a positive correlation of NDVI with elevation & slope and a negative correlation with drainage density of the basin as shown in (Fig.10). Here, we have taken (+0.3) as the NDVI threshold value. The elevation ranging from 400m to 900m, and slope ranging from 0° to 20°, favoured the vegetation growth. The highest vegetation at drainage density ranging from 1.7 km/km^2 to 9.8 km/km^2.

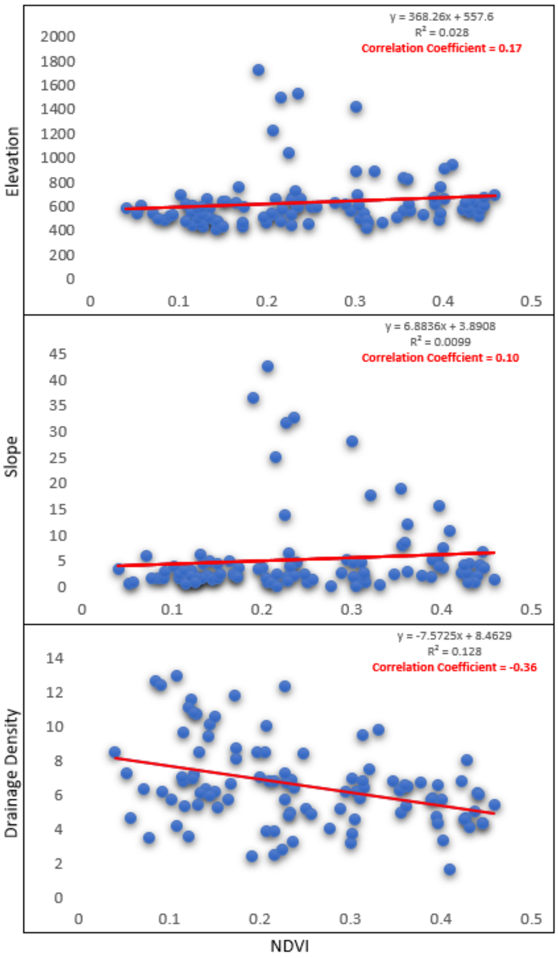

Fig.10 NDVI Correlation with Elevation, Slope and Drainage Density

Conclusions

From this study, we have concluded that the Asan River basin is less elongated in shape with moderate relief. It has been observed that stream segments of the 1st and 2nd order are present in the high altitudinal areas characterized by moderate to steep slopes, while the 3rd to 6th order stream segments occur in relatively gentle to very gentle slope areas wherein maximum infiltration caused by precipitation. Further, the NDVI shows a positive correlation with elevation & slope and a negative correlation with drainage density. The Selaqui industrial area and the households lives on both the banks of the river is having a negative impact on the river water quality. A large amount of dumped industrial waste and polluted urban runoff flows into the Asan River which ultimately merges with the Yamuna River, which is a major concern. Hence, this study demonstrated that GIS and Remote Sensing techniques are competent tools for understanding the hydrological characteristics of drainage basins. The integration of DEM and multispectral satellite data is the solution to the real-world problem. The result from such studies can provide baseline information for city planners especially related to disaster mitigation, watershed management, and urban river management.

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