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Morphometric Analysis of Suswa River Basin Using Geospatial Techniques †

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Abstract: Analysing the morphological features of the drainage basin helps to understand its hydrological characteristics and the association of water, with soil, topography, and vegetation of the catchment. Morphometric analysis reveals the linear, areal, and relief aspects of a drainage basin. In this study, morphometric analysis has been performed using geospatial techniques to evaluate the hydrological characteristics of the Suswa River basin. The SRTM (Shutter Radar Topography Mission) DEM at 30 m resolution has been used to delineate the basin and drainage network in the Arc GIS Software with the help of Spatial Analysis Tools. From this research, we have derived that the basin is having sub-dendritic to dendritic drainage pattern, and the average drainage density of the basin is 2.84 km/km^2. The elongation ratio of the Suswa River basin is 0.46 which implies that the basin is elongated in shape with moderate relief. This study concludes that morphometric analysis based on GIS & remote sensing techniques is a competent tool for hydrological studies. The present study would be beneficial to various managers and decision-makers for the organization working on watershed management and sustainable natural resources management.

Keywords: morphometric analysis; GIS; remote sensing; DEM; watershed management

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1. Introduction

Excessive and unsystematic use of available natural resources such as water and soil are happening at a rapid pace which deteriorates their quality needed for the future [1,2]. Due to degraded water quality, the vast majority of the accessible water is not safe for use and consumption [3]. These issues are increased due to faulty adoption of agricultural practices, over-exploitation of resources, and ignorance of watershed management [4]. The Watershed is an optimal unit for sustainable development and management of natural resources [5]. It is a geographical unit in which the hydrological cycle and its components such as condensation, precipitation, infiltration, runoff, and evapotranspiration can be analysed. Morphometric analysis is a quantitative description and mathematical analysis of the landforms that are applied to a drainage basin [6]. Morphometric analysis has been performed since the mid-nineties for linear, aerial, and relief aspects along with the explanation of their association with reference to vegetation, soil, and water management [7,8]. Integrating the latest techniques of Remote Sensing and GIS plays a key role in the delineation and analysis of drainage basins [9]. DEMs (Digital Elevation Models) are the necessary information utilized in the investigation of watershed topography [10,11]. The availability and flexibility of a DEM-based surface hydrological model have provided an appropriate method for watershed management and natural resource management [12]. The present work deals with the morphometric analysis of the Suswa River basin which provides its geo-hydrological behaviour using geospatial techniques. Suswa, a tributary of Song, is a historic river that runs along the northern border of the Rajaji National Park and is filled with historical inhabitations and settlements. Increased urbanisation and haphazard infrastructure have harmed the river's water quality and quantity. Massive amounts of untreated sewage constantly flowing through it have severely disrupted the surrounding environment and considerably impaired the minimum flow. River flow is lowered owing to diversion for agricultural land or trash discharge, magnified due to deforestation and encroachment of the riverbed causing flooding, or enhanced during monsoon and post-monsoon seasons. Both can occur in the same river at various times of the year, resulting in a general propensity for flow patterns to reverse. The preservation of natural biodiversity is critical to ecosystems' health and long-term utilisation [13]. This study would be beneficial for the policy makers/decision makers of various disciplines for a better understanding of natural resources.

2. Materials and Methods

2.1. Study Area

The Suswa River basin lies in the central part of Dehradun city, Uttarakhand, India. Basin's topmost stream originates from the lower Mussoorie ranges having two important drainage networks Rispana River & Bindal River, and the basin outlet is merges with Song River which further meets the Ganges in India. The coordinate of the study area falls between Latitude (from 30°24′53.0″ N to 30°06′28.2″ N) and Longitude (from 78°06′07.7″ E to 78°07′22.5″ E). The upper half of the basin is a part of the core city area, and the lower half is the outer city area. Maximum drainage of the city flows through the basin. The total area of our study is 310.98 km^2 with elevations ranging from 405 m to 2278 m. The annual rainfall in the area is 1945 mm. The summers are moderately hot and the winters are very cold. The yearly temperature varies from 2 °C in winters to 41 °C in summers. The study area map is shown below in Figure 1.

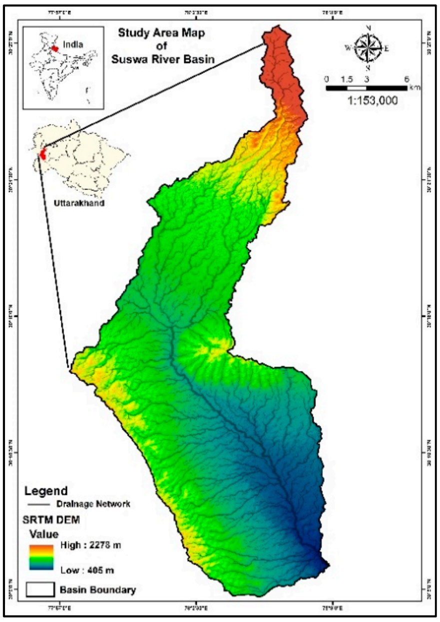

Figure 1. Study Area Map of Suswa River Basin.

2.2. Materials and Methods

The morphometric analysis provides methodical and accurate information about the drainage basin. There are several formulas for quantifying hydrological parameters which have been used in this study. These formulas are mentioned below in Table 1. SRTM (Shuttle Radar Topographic Mission) DEM at 30 m spatial resolution has been downloaded from the USGS (United States Geological Survey) Earth Explorer website (http://earthexplorer.usgs.gov/ (accessed on 5 July 2022)). For delineating the basin boundary and drainage network, the Hydrology tool inside the Spatial Analysis Tools of Arc GIS desktop software has been used. Additionally, the Slope map, Aspect map, Elevation map, and Drainage Density map of the Suswa River basin have been prepared.

Table 1. Formulas and Parameters for computation of morphometric analysis.

Sr. No.	Formulas	Parameters	Reference
1	Hierarchical rank	Stream order (w)	[14]
2	Length of the stream	Stream length (L_u)	[15]
3	$L_{sm} = L_u / N_u$	Mean stream length (L_{sm})	[14]
4	$R_L = L_{u/}(L_u - 1)$	Stream length ratio (R_L)	[15]
5	$(R_b) = \mathrm{Nu}/\mathrm{Nu} + 1$	Bifurcation ration (R_b)	[16]
6	R_{bm} = average of bifurcation ratios of all order	Mean bifurcation ratio (R_{bm})	[17]
7	$D_d = L_u / A$	Drainage density (D_d)	[15]
8	$T = D_d \cdot F_s$	Drainage texture (T)	[18]
9	$F_s = N_u / A$	Stream frequency (F_s)	[15]
10	$Re = 2\sqrt{(A/\pi)}/L_b$	Elongation ratio (R_e)	[16]
11	$R_c = 4\ \pi\ A / P^2$	Circularity ratio (R_c)	[14]
12	$F_f = A / L^2$	Form factor (F_f)	[15]
13	$R = H - h$	Relief	[19]
14	$R_r = R / L$	Relief Ratio	[20]

3. Results and Discussion

This study shows the morphometric analysis of the Suswa River basin in three different aspects (Linear, Areal, and Relief). The slope, aspect, and drainage density of the basin are also evaluated, laying the foundation for understanding watershed management. These aspects can be defined on the basis of different hydrological parameters which are given below:

3.1. Linear Aspects

The linear Aspect represents all the linear features inside a drainage basin such as Stream Order (w), Stream Number (Nu), Bifurcation Ratio (RbF), Stream length (km), and their mean. Suswa River basin follows Horton's first law [15]. The number of streams in each category falls in a geometric sequence, as represented by the graph in Figure 2. There is a total of six orders in the basin shown in Figure 3a. The total number of streams in the Suswa River basin is 1092 and the total length is 883.12 km (Table 2). The bifurcation ratio is the ratio of the number of stream segments of a given order to the number of stream segments of the next higher order. In this basin region, the range of bifurcation is between 1 to 4.97 which means there is minimum structure disturbance. The mean bifurcation ratio is 5.13. The bifurcation ratio is important in drainage basin examination as it helps in interpreting the basin shape and the runoff behaviour. The higher the values of the bifurcation ratio, the higher the flood risk.

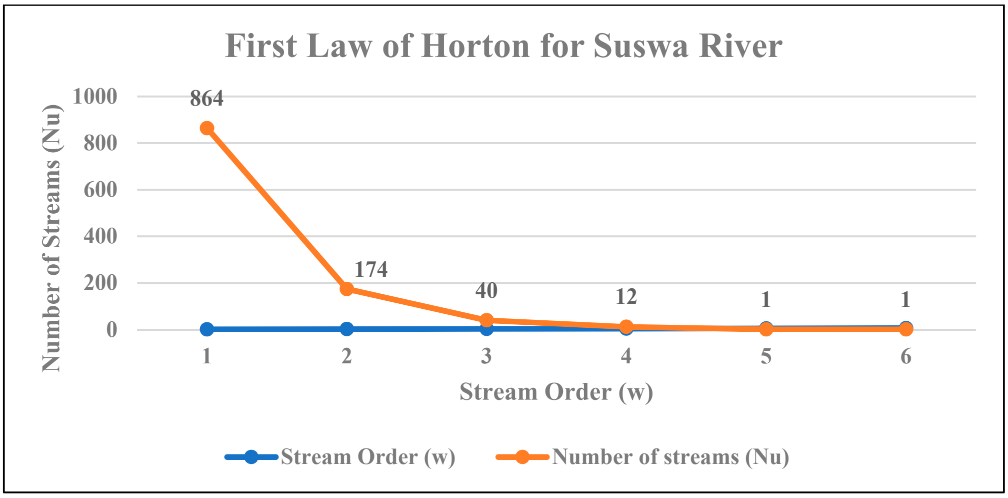

Figure 2. First Law of Horton for Suswa River basin.

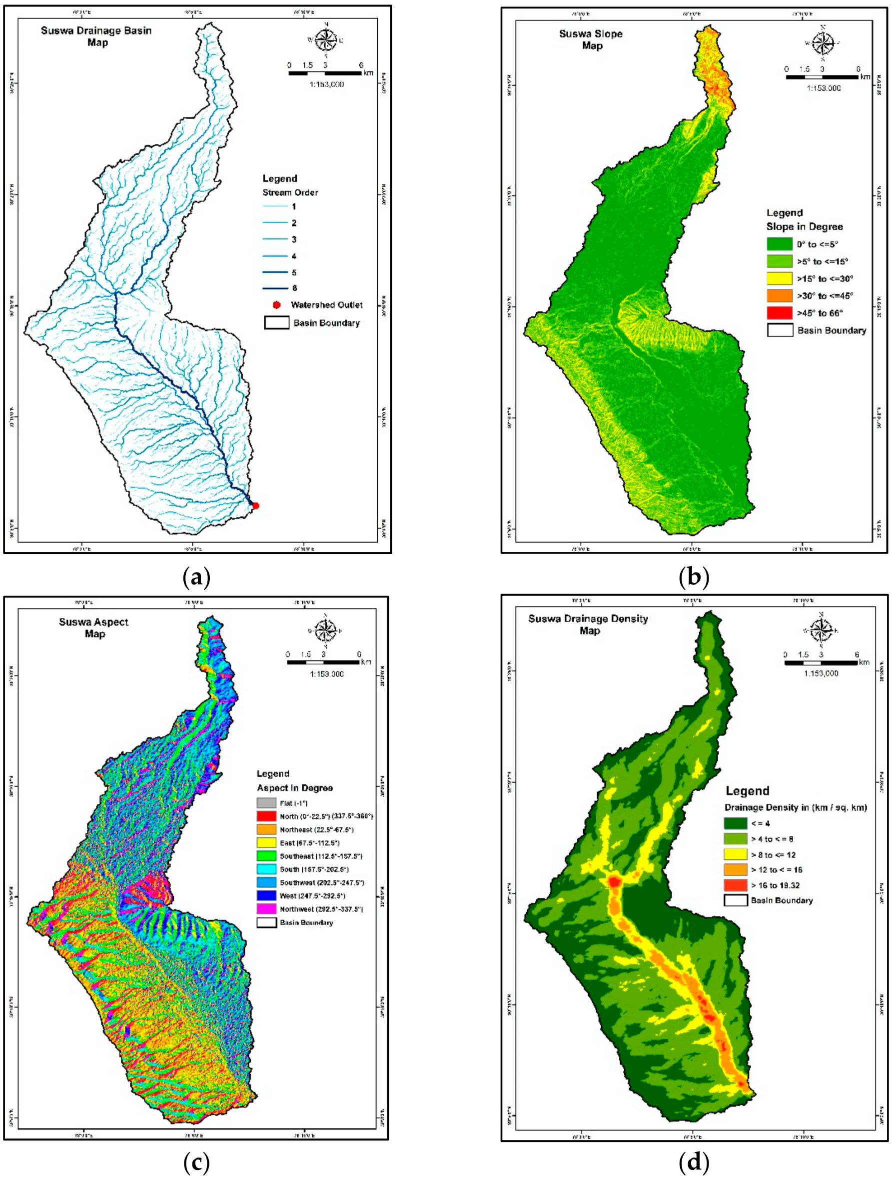

Figure 3. (**a**) Drainage Basin Map; (**b**) Slope Map; (**c**) Aspect Map; (**d**) Drainage Density Map.

Table 2. Linear Aspects of Suswa River Basin.

Stream Order (w)	No. of Streams (Nu)	Bifurcation Ratio (RbF)	Mean Bifurcation Ratio (Rbm)	Total Length of Streams (Lu) (km)	Mean Length of Streams (km)	Length Ratio (R_L)
1	864			421.07		
2	174	4.97		253.43		0.60
3	40	4.35	5.13	127.3	0.81	0.50
4	12	3.33		48.56		0.38
5	1	12.00		8.54		0.18
6	1	1.00		24.22		2.84
Total	**1092**		**Total**	**883.12**		

3.2. *Areal Aspects*

Areal aspects of watershed covers various areal components, for example, Area (km^2), Perimeter (km), Elongation Ratio (Re), Drainage Density (Dd), Drainage Texture (T), Stream Frequency (Fs), Form Factor (Ff), and Circulatory Ratio (Rc). The result shows that the total area of the Suswa river basin 310.98 km^2 and the perimeter 122.45 km (Table 3). The elongation ratio has been classified by (Schumm, 1956) into three types; (a) circular (>0.9), (b) oval (0.9–0.8), and (c) elongated (<0.7). For the Suswa River basin, the value of the elongation ratio is 0.49 which means that the basin is elongated in shape with moderate relief. The circulatory ratio shows a lesser value of 0.26 which explains that the basin is less circular or more elongated in shape. The form factor shows the flow intensity of the basin. Here, the form factor value is 0.19 which indicates that flow intensity is very low. Since, stream frequency is directly related to drainage density [15]. Here, the value of stream frequency is 3.51 and drainage density 2.84 km/km^2 which implies that both are directly related to each other. The drainage texture value is 9.97, which implies that the drainage texture is coarse with presence of highly resistant permeable material & low relief.

Table 3. Areal Aspects of Suswa River Basin.

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)
310.98	122.45	40.5	0.19	0.49	0.26	2.84	3.51	9.97

3.3. *Relief Aspects*

Relief aspects are the three-dimensional properties of the drainage basin. It is related to the elevation difference between reference points in the watershed basin. Relief is the difference between the maximum and minimum height of the basin [16]. The relief ratio is the ratio of basin relief and basin length. Here, the total basin relief is 1873 m and the relief ratio is 46.25 (Table 4), which indicates that the basin has moderate relief, some areas have a steep slope and most of the region has a gentle slope.

Table 4. Relief Aspects of Suswa River Basin.

Height of Basin Mouth (m)	Maximum Height of the Basin (m)	Total Basin Relief (R) (m)	Relief Ratio
405	2278	1873	46.25

3.4. *Slope*

Slope defines the steepness of the area. In the Suswa River basin, the maximum height is 2278 m, whereas the minimum height is 405 m (Figure 1). Here, the slope is divided into five classes, as shown in Figure 3b: (0° to ≤5°) is very gentle, (>5° to ≤15°) is gentle, (>15° to ≤30°) is moderate, (>30° to ≤45°) is steep and (>45° to 66°) is very steep. It is visible from the map that most of the basin area has very gentle to moderate slopes. A gentle slope is good for groundwater infiltration having less runoff, whereas a steep slope or higher slope category has bad groundwater infiltration with more runoff.

3.5. Aspect

The aspect shows the direction of the slope. The direction of slope at (0–22.5°) is north, at Northeast (22.5–67.5°) it is east, and so on. For this study, the aspect is south facing, as shown in Figure 3c. This indicates that the south-facing slope has higher vegetation cover and higher moisture content as compared with the north-facing slope.

3.6. Drainage Density

The total length of streams per unit area is the drainage density of the basin. Here, the drainage density is divided into five classes, as shown in Figure 3d: (≤4 km/km^2) is very low, (>4 km/km^2 to ≤8 km/km^2) is low, (> 8 km/km^2 to ≤12 km/km^2) is moderate, (>12 km/km^2 to ≤16 km/km^2) is high and (>16 km/km^2 to 19.32 km/km^2) is very high. Most of the area in the basin has a very low to low drainage density. The highest drainage density represented by the red colour on the map, where the Bindal River and Rispana River are merging with the Suswa River.

4. Conclusions

The hydrological and morphological aspects of the watershed can be understood by its drainage morphometric parameters. The current study provides the precise data for topography, drainage system, stream length, water division, geomorphologic setup, and other factors crucial for the classification and management of watersheds. The basin's drainage system is primarily of the dendritic type, which aids in understanding a variety of topographical aspects, including infiltration rate and runoff, among others. The measured characteristics in this study highlight regions for surface-water accumulation and recharge-related actions that can be implemented for watershed management. Planners and decision-makers of sustainable watershed development programs will find this work greatly valuable for managing natural resources at the micro level on any terrain. The study suggests that in the near future, hydrogeological and geophysical investigations are crucial for effective and efficient watershed management.

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