Morphometric Analysis of Beas River Basin in Kullu District of Himachal Pradesh, India Using Geospatial Techniques

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Abstract

Analysing the morphologcal 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 Beas River basin. The DEM and SOI toposheet has been used to delineate the basin and drainage network in the ArcGIS Software with the help of Spatial Analysis Tools. From this research, we have derived that the basin is having dendritic drainage pattern, and the average drainage density of the basin is 0.42 /km^2. The mean bifurcation ratio of the Beas River basin is 2.275 which mean there is minimum structure disturbance. 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

INTRODUCTION

A river basin is a key geomorphic and hydrological unit that develops as a result of the complex interplay of the earth's surface topography, climate, and hydrological processes. It is a strategic geographic unit that can be micro basin (Few Hectares) to macro basin (Millions of Hectors) [(1–3)] and its network depicts the entire three-dimensional geometry and evolutionary processes [(4, 5)]. The study of measuring and analyzing the size, shape, and configuration of the Earth's surface characteristics is known as morphometric analysis. It's a quantitative tool for estimating the many aspects of the drainage system, including the number and length of the streams, the drainage density, the ratio of bifurcations, the slope, the form, and the relief of the basin[(6–8)]. It offers important information on the geology and hydrology of the basin as well. Morphological factors are critical in mitigating a drainage basin's hydrological issue, environmental change, drainage characteristics, flood risk and unsustainable water consumption[(9–11)]. Traditional sources for the morphometric analysis include topographic maps and field surveys which were popular methods for drainage evaluation and numerous scholars have looked at various catchment aspects using traditional methods[(12–17)]. Nowadays rapidly developing spatial information technology, RS, and GIS provide excellent and widely tools for addressing the bulk of issues with water resource planning and management, compared to conventional data processing techniques. Assessing drainage morphometry benefits greatly from the synoptic image over a large region that satellite remote sensing can provide. Watershed analyses which rely on the digital elevation model (DEM) have seen a surge in popularity, accuracy, efficiency, and cost-effectiveness. Water shortage and surplus may be affected by geomorphological changes within a watershed. To thereby determine the effect of geomorphological processes on the hydrology of the catchment, a quantitative examination of the watershed geometry is essential (18–20).

Morphometric analysis of the basin plays crucial role in planning and development of the watershed as well as for achieving sustainable land and water resource use and provides platform for planners and policymakers to build management plans for catchment area (21).

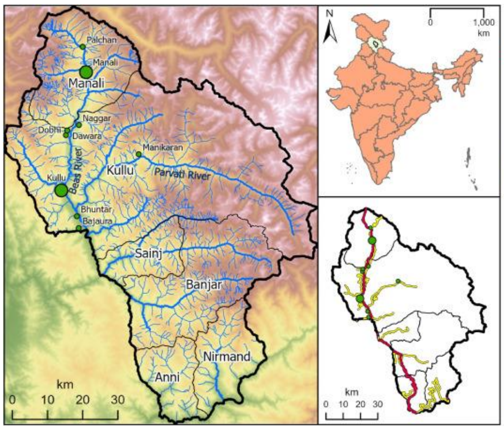
The present work deals with the morphometric analysis of the Beas River basin in Kullu valley.

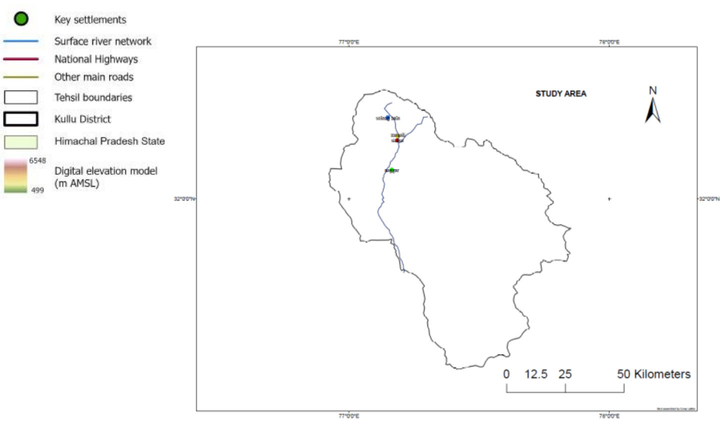
The geological setting of the area around the Kullu valley manifests some unique features which in turn have given rise to typical geomorphological characteristics of the area. The relief components of the Kullu valley are composed of highlands, lowlands and slope in between them. These slopes are under continuous modification by the erosional and depositional processes of the geomorphic agents like glacial and fluvio-glacial and also some mass movements like landslides, avalanches, creeps that are occasional. The aim of the present study is to determine morphometric parameters for the Beas River basin.

Study Area

Situated in the North-western part of Himachal Pradesh, Kullu District is often referred to as the "Valley of Gods" Resting in the lap of the Himalayas. The study area is located in the middle Himalayas and is one of the most visited places in India. The district is located at 31°58’ N latitude and 77°06’ E longitude. It has a population of 4.38 lakh and an area of 5,503 square kilometers (22). It is bordered by Lahaul and Spiti in the north, Shimla district in the southeast, Mandi District in the south, and Kangra district in the west. A major tributary of the Indus River, Beas, flows through the district. Its major tributaries like Parbati, Tirthan, Bhuntar Khad, and Nogli Khad drain the whole district. Administrative headquarters are located in the main Kullu town. Kullu town has an average elevation of 1,278 m (4,193 ft). It lies on the bank of Beas River. The region experiences a warm and temperate type of climate. The summer season from April to June is very pleasant and winters in November to February experience snowfall (23).

Map 1: Location map of Study Area **Map 2: Location map of Beas River in Kullu District**





Source: USGS-ASTERDEM

Database and Methodology

In the Present study both field and laboratory based work was undertaken in order to generate the necessary data. The Beas River basin has been defined using the digital elevation model (DEM) at 30 m spatial resolution has been downloaded from the USGS (United States Geological Survey) and Survey of India toposheet (1:50000). The processing of the DEM and SOI toposheet (53e/11) was done using ArcGIS 10.5 software, and the watershed is classified based on morphometric analysis. The analysis of morphometric properties has led to the classification of these traits into three aspects: linear, relief, and areal. The morphometric parameters have been determined as per the standard methodology as shown in Table 1.

Table 1: Methods of calculating morphometric parameters

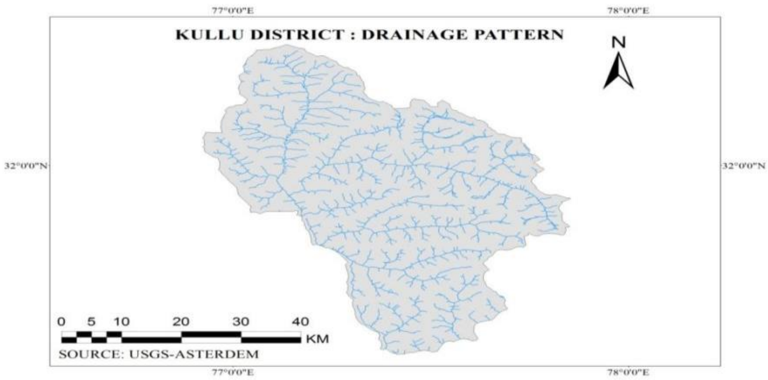
Parameters	Formulae	References
Stream order (u)	The smallest permanent streams are called "first order". Two first order streams join to form a larger, second order stream; two second order streams join to form a third order, and so on. Smaller streams entering a higher ordered stream do not change its order number.	Strahler (1964)
Bifurcation ratio (Rb)	$Rb=Nu/(Nu+1)$	Horton (1932)
Stream frequency (Fs)	$Fs=\sum Nu/A$	Horton (1945)
Drainage density (Dd)	$Dd=Lu/A$	Horton (1945)

Results and Discussion

This study shows the morphometric analysis of the Beas River basin in three different aspects. The drainage pattern, bifurcation ratio, stream ordering, stream frequency and drainage density of the basin are also evaluated, laying the foundation for understanding watershed management. The results of various parameters discussed as follows.

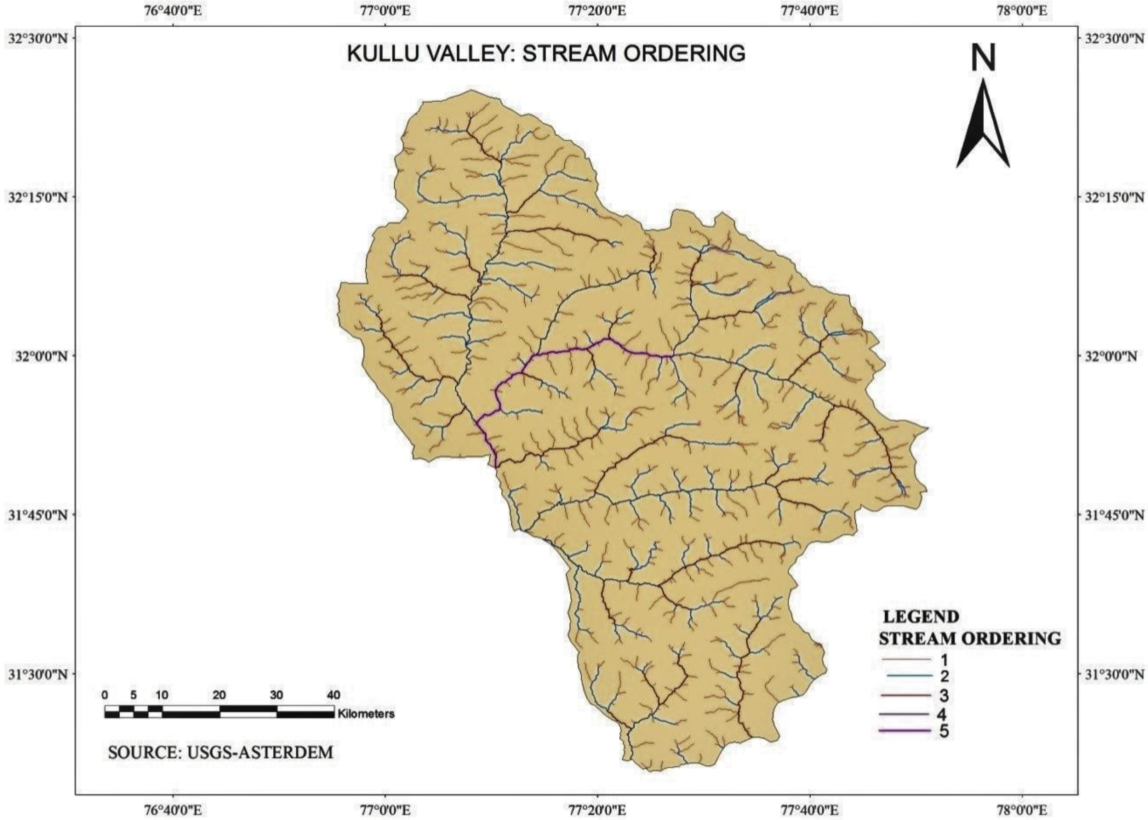
Drainage Pattern: Drainage pattern means spatial arrangement and form of drainage system in terms o f geometrical shapes in the areas of different rock types, geological structure, climatic conditions and denudational history.

Map 3: Kullu District: Drainage Pattern



The pattern shown is called herringbone drainage pattern. It is also called as the rib pattern and it is developed in mountainous area where broad valleys are flanked by parallel ridges having steep hillside slopes. The longitudinal consequent streams, as master streams, are developed in the longitudinal parallel valley, as lateral consequents after originating from the hill slopes of the bordering parallel ridges join the longitudinal consequents almost at right angle.

Map 4: Kullu district: Stream Ordering



Bifurcation Ratio: The bifurcation ratio is the ratio of number of stream segments of given order to the number of segments of higher orders. It is a dimensionless property and shows the degree of integr ation prevailing between streams of various orders in a drainage basin. It refers to the determination of th e hierarchical position of a stream within a drainage basin. A river basin consists of its several branches having different position in the basin area and they have their own morphometric characteristics.

Table 2: Bifurcation ratio of drainage basin

Stream Order (μ)	Number of streams(Nμ)	Length of streams(km)	Bifurcation Ratio (Rb= Nμ/Nμ+1)
1	743	1211.72	2.43
2	305	564.23	1.48
3	206	325.29	1.38
4	149	209.33	3.82
5	39	52.04	-
Total	1442	2362.61	Mean= 2.275

Where, N_u= No. of streams of a given order.

$N_{\mu+1}$ = No. of streams of the next higher level.

Mean bifurcation ratio=2.275

Mean Bifurcation ratio of the drainage basin is 2.275 which suggests that the river flows through flat or rolling plains and over small mountainous area and the geology is reasonable homogeneous and there is no structural disturbance. Since this value lies in the average value of bifurcation ratio i.e 2-4 which shows that the area is not more prone to flood.

With respect to the study area the bifurcation ratio of stream order 1 is 2.43 and while coming down to the 2nd stream order the bifurcation reduces to 1.48 which shows that the area which comes under the stream order 1 are more likely to develop flood like situations than the second stream order. The area of first and the second stream order consists of flat or rolling drainage basin. This may be due to the variation in topography. The bifurcation ratio of third stream order is 1.38 which shows that the area comes under this stream order are devoid of flood like situations where as the bifurcation ratio of fourth stream order is 3.82 which is the highest among all hence it shows that the areas which are drained by this stream are more prone to flood than all the other streams. The area comprised of mountainous and highly dissected drainage basin.

Stream Frequency: Stream frequency or drainage frequency is the measure of number of streams per u nit area. Forthe computation of stream frequency (SF), the basin is divided into grid squares depending u pon map scale and actual coverage of the basin and the number of streams in each grid are connected, ta bulated, quantified.

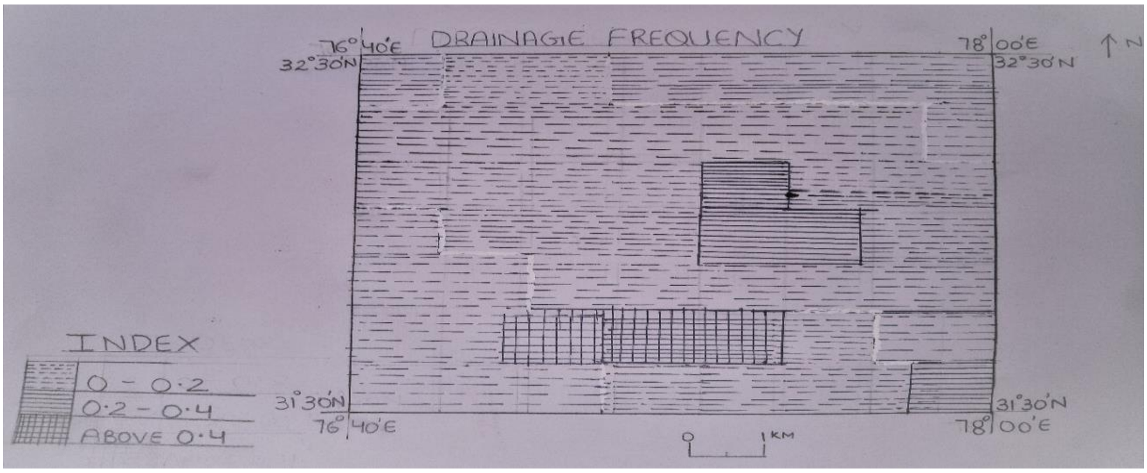
The general categories of stream frequency are:

1) Poor (0-0.2) 2) Moderate (0.2-0.4) 3) High (Above 0.4)

Total area of basin = 5513.458 km^2

Stream Frequency = Total number of streams / Total area of basin = 1442/5513.45km^2 = 0.26km^2 The str eam frequency value of the part of drainage basin in study area is 0.26 km^2 as calculated above. It mainl y depends on the lithology of the basin and reflects the texture of the drainage network. The moderate va lue of stream frequency 0.26km^2 pertains to less number of streams per unit area in the area of drainage basin. This is due to the mountainous soil there which cause high flow of water and the other reason is th e low vegetation cover.

Fig 1: Kullu District: Stream frequency



SOURCE: Survey of India toposheet

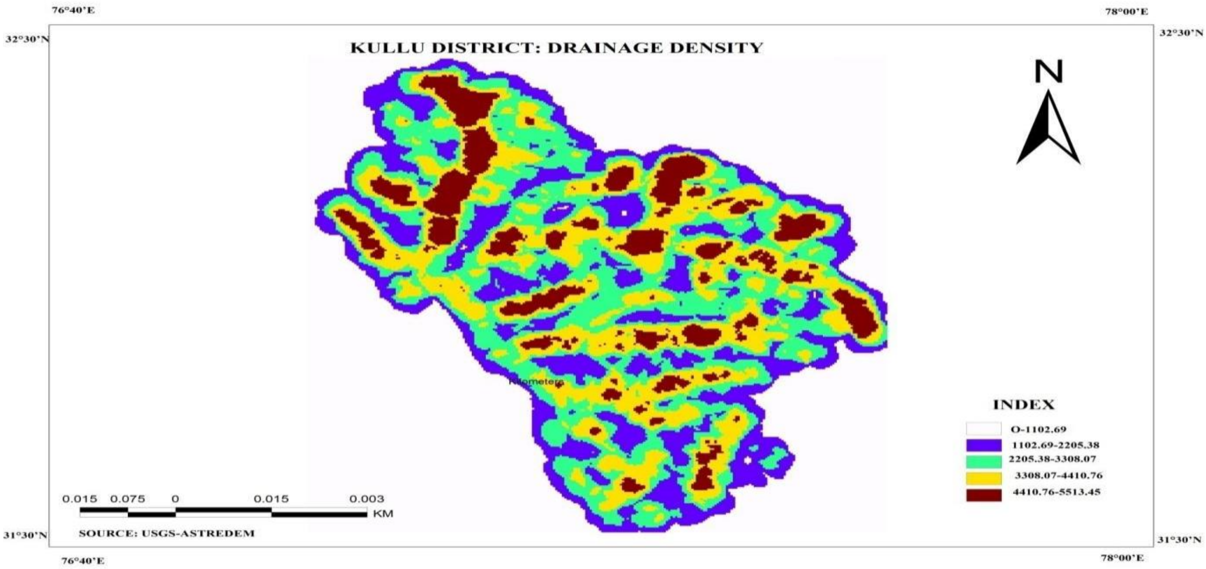
Drainage Density: It refers to the total stream length per unit area. Drainage density is defined as the rat io of total length of all the streams segments in a given drainage basin to the total area of that basin and t hus it can be derived as:

$D_d = L_K/A_K$ = Total length of all streams / Total area of basi = 2362.61/5513.45 = 0.42per km

where, L_K is the total length of all stream segments of a basin and A_K is the total area of the basin

The above calculated Drainage Density value corresponds to low density of stream in the study region. This is due to the low gradient of the study area. In the study area precipitation effectiveness is high as maximum proportion of rain water is absorbed by the vegetation directly leads to low value of drainage density in the lower areas as compared to high altitude areas which have high drainage density. Also, most of the precipitation occurs in rainy season in the form of rain and snow. The study area as a whole portrays a low to medium drainage density due to the presence of hard granitic, gneissic and quartzite rocks.

Map 5: Kullu District: Drainage Density



The given map shows the variations in the drainage density with respect to various areas of KulluDistrict The lowest class resembles the area having density of less than 1102.69 sq. km. This shows that the area is characterised by poor watershed and is less prone to flood like conditions. Similarly, the highest class resembling the area having density of more than 4410.76 sq. km. Is characterised by high watershe and is more prone to flood like conditions.

Conclusion

The measurement of linear, areal and relief aspects based on DEM generated from contour and spot height are really useful to identify physical and meteorological characteristics of the particular basin area. In this study, the value indicated by the drainage pattern, bifurcation ratio, stream ordering, stream frequency and drainage density of the basin are evaluated. The pattern of the drainage is dendritic in the study area. Many contributing streams joined together into the tributaries of the main river at acute angle and patterns mainly develop where the river channel follows the slope of the terrain. The basin with 5^{th} order stream has steep to very steep sloping mountainous terrain. Mean Bifurcation ratio of the drainage basin is 2.275 which suggests that the river flows through flat or rolling plains and over small mountainous area and the geology is reasonable homogeneous and there is no structural disturbance. The moderate value of stream frequency 0.26km^2 pertains to less number of streams per unit area in the area of drainage basin. The study area as a whole portrays a low to medium drainage density due to the presence of hard granitic, gneissic and quartzite rocks. So, GIS has proved to be an effective and efficient tool for computation and analysis of various morphometric parameters of the basin. The study suggests that in the near future, hydrological and geophysical investigations are crucial for effective and efficient watershed management.

References

1. Shekar PR, Mathew A. Morphometric analysis for prioritizing sub-watersheds of Murredu River basin, Telangana State, India, using a geographical information system. Journal of Engineering and Applied Science. 2022;69(1):44–44.
2. Pawan C, Arnab K, Mall R. A geo-spatial inter-relationship with drainage morphometry, landscapes and NDVI in the context of climate change: a case study over the Varuna River basin (India). Spatial Information Research. 2019.
3. Das S, Pardeshi SD. Comparative analysis of lineaments extracted from Cartosat, SRTM and ASTER DEM: a study based on four watersheds in Konkan region, India. Spatial Information Research. 2018;26(1):47–57.
4. Alemsha B. Morphometric analysis of a drainage basin using geographical information system in Gilgel Abay watershed. Ethiopia Applied Water Science. 2021;11:122.
5. Karabulut MS, Özdemir H. Comparison of basin morphometry analyses derived from different DEMs on two drainage basins in Turkey. Environmental Earth Sciences. 2019;78(18).
6. Sutradhar H. Assessment of Drainage Morphometry and Watersheds Prioritization of Siddheswari River Basin, Eastern India. Journal of the Indian Society of Remote Sensing. 2020;48(4):627–644.
7. Choudhari PP, Nigam GK, Singh SK, Thakur S. Morphometric based prioritization of watershed for groundwater potential of Mula river basin, Maharashtra, India. Geology, Ecology, and Landscapes. 2018;2(4):256–267.
8. Khan I, Bali R, Agarwal KK, Kumar D, Singh SK. Morphometric Analysis of Parvati Basin, NW Himalaya: A Remote Sensing and GIS Based Approach. Journal of the Geological Society of India. 2021;97(2):165–172.
9. Kumar D, Singh DS, Prajapati SK, Khan I, Gautam PK, Vishawakarma B. Morphometric Parameters and Neotectonics of Kalyani River Basin, Ganga Plain: A Remote Sensing and GIS Approach. Journal of the Geological Society of India. 2018;91(6):679–686.
10. Sharma S, Mahajan AK. GIS-based sub-watershed prioritization through morphometric analysis in the outer Himalayan region of India. Applied Water Science. 2020;10(7):1–11.
11. Mahala A. The significance of morphometric analysis to understand the hydrological and morphological characteristics in two different morpho-climatic settings. Applied Water Science. 2020;10(1):1–16.
12. Bera A, Mukhopadhyay BP, Das D. Morphometric Analysis of Adula River Basin in Maharashtra, India using GIS and Remote Sensing techniques. Geo-spatial Data in Natural Resources. 2018;p. 13–35.
13. Rai PK, Chandel RS, Mishra VN, Singh P. Hydrological inferences through morphometric analysis of lower Kosi river basin of India for water resource management based on remote sensing data. Ap-

plied Water Science. 2018;8(1):1–16.
14. Yang G, Chen Z, Jiang J. Drainage morphometry of the Lishui catchment in the middle Yangtze basin, China: morphologic and tectonic implications. Arabian Journal of Geosciences. 2020;13(13):561.
15. Venkatesh M, Anshumali. A GIS-based assessment of recent changes in drainage and morphometry of Betwa River basin and sub-basins, Central India. Applied Water Science. 2019;9(7):157.
16. Akhil R, Prasad TK, Vineethkumar V. Analyzing the significance of morphometric parameters in runoff efficiency: a case study in Valakkayi Tode tropical watershed, Valapattanam River, Kerala, India. Journal of Sedimentary Environments. 2022;7(1):67–78.
17. Tukura NG, Akalu MM, Hussein M, Befekadu A. Morphometric analysis and sub-watershed prioritization of Welmal watershed, Ganale-Dawa River Basin, Ethiopia: implications for sediment erosion. Journal of Sedimentary Environments. 2021;6(1):121–130.
18. Parvez M, Inayathulla D. Morphometry, hypsometry analysis and runoff estimation of Aam Talab Watershed Raichur. International Journal of Advance Research and Innovative Ideas in Education. 2019;5:1713–1727.
19. Nitheshnirmal S, Thilagaraj P, Rahaman SA, Jegankumar R. Erosion risk assessment through morphometric indices for prioritisation of Arjuna watershed using ALOS-PALSAR DEM. Modeling Earth Systems and Environment. 2019;5(3):907–924.
20. Godif G, Manjunatha BR. Prioritizing sub-watersheds for soil and water conservation via morphometric analysis and the weighted sum approach: A case study of the Geba river basin in Tigray, Ethiopia. Heliyon. 2022;8(12):e12261.
21. Salunke K, Wayal A. Morphometric Analysis of Panjhara River Basin With Use of GIS for Development of Watershed Plan. Indian Journal of Science and Technology. 2023; 16(12):894–902.
22. R.M. Johnson et al. ‘HiFlo-DAT’: A flood hazard event-disaster database for the Kullu District, Himachal Pradesh, Indian Himalaya. International Journal of Disaster Risk Reduction. 2025 (120) 105336.
23. Arora V. Temporal Study of Trend Analysis of Tourism Flow in Kullu District, Himachal Pradesh from 2008-2022 and it’s Seasonality for Tourism Forecasting. International Journal for Multidisciplinary Research. 2023; 5(6): 1-18.