Salud, Ciencia y Tecnología. 2022; 2(S2):189
doi: 10.56294/saludcyt2022189

ORIGINAL ARTICLE

Morphometric Analysis of Gandak River Drainage Basin Using Geographic Information System (GIS) And SRTM-DEM

Análisis morfométrico de la cuenca de drenaje del río Gandak mediante el Sistema de Información Geográfica (SIG) y SRTM-DEM

Arushi Jha[1], Naresh Chandra Gupta[1], Bratati Dey[2]

[1]University School Of Environment Mangement (USEM). GGS Indraprastha University, Sec 16C, Dwarka. New Delhi, India.
[1]University School Of Environment Mangement (USEM). GGS Indraprastha University. New Delhi, India.
[2]Swastik Edustart. Vikaspuri. New Delhi, India.

Cite as: Jha A, Gupta NC, Dey B. Morphometric Analysis of Gandak River Drainage Basin Using Geographic Information System (GIS) And SRTM-DEM. Salud Cienc. Tecnol. 2022; 2(S2):189. https://doi.org/10.56294/saludcyt2022189

Submitted: 18-11-2022 **Revised:** 06-12-2022 **Accepted:** 20-12-2022 **Published:** 31-12-2022

Editor: Fasi Ahamad Shaik

ABSTRACT

Quantification of drainage networks in relation to geomorphology, lithology, climate, and tectonics gives important evidence of an area's hydro-geomorphic, denudation characteristics, and drainage development. The current research used the Shuttle Radar Topographic Mission (SRTM) DEM to investigate drainage morphometry and its impact upon the environment, as well as hydrological analysis of the Gandak river basin, which is a prominent tributary of the River Ganga in India. The morphometric characteristics of watersheds have been evaluated using avant-garde methods like those developed by Horton and Strahler. Their findings demonstrate that techniques for geographic information systems and remote sensing are more effective for computing and analysing morphometric parameters. Using the Arc GIS 10.5 programme, 17 morphometric parameters were determined. These parameters reflect the dendritic type of drainage pattern of Gandak watershed. Specifically, these watershed has a porous subsurface; hence, runoff is comparatively modest, as seen by the low drainage density, infiltration rate, and frequency of streams. The Gandak basin's low drainage density and coarse drainage pattern suggested an open opportunity for artificial recharge structures. The current morphological-based prioritisation is also supported by geological field verification. As a result, adequate soil erosion management techniques are required in this basin to protect the land from future erosion. This research will aid in the efficient use of water resources and the long-term development of the Gandak River basin.

Keywords: Watershed; Morphometry; Geographic Information System; Gandak River Basin.

RESUMEN

La cuantificación de las redes de drenaje en relación con la geomorfología, la litología, el clima y la tectónica aporta evidencia importante acerca de las características hidrogeomorfológicas, de denudación y de desarrollo del drenaje de una zona. La presente investigación utilizó el MDE de la Shuttle Radar Topographic Mission (SRTM) para investigar la morfometría del drenaje y su impacto en el medio ambiente, así como el análisis hidrológico de la cuenca del río Gandak, afluente destacado del río Ganges, India. Las características morfométricas de las cuencas hidrográficas se evaluaron con métodos vanguardistas como los desarrollados por Horton y Strahler, quienes demostraron que los sistemas de información geográfica y la teledetección son más eficaces para calcular y analizar dichos parámetros. Utilizando el programa Arc GIS 10.5, se determinaron 17 parámetros morfométricos, los cuales reflejan el patrón dendrítico de drenaje de la cuenca del Gandak. Concretamente, esta cuenca tiene un subsuelo poroso; por lo tanto, la escorrentía es modesta, como lo demuestran la baja densidad de drenaje, la tasa de infiltración y la frecuencia de arroyos. La baja densidad y el patrón de drenaje grueso sugieren una oportunidad para las estructuras artificiales de recarga.

La actual priorización basada en la morfología se verificó geológicamente. En consecuencia, se requieren técnicas adecuadas de gestión de la erosión del suelo para proteger la tierra de la futura erosión en esta cuenca. Esta investigación contribuirá al uso eficaz de los recursos hídricos y al desarrollo, a largo plazo, de la cuenca del río Gandak.

Palabras clave: Línea divisoria de aguas; Morfometría; Sistema de Información Geográfica; Cuenca del Río Gandak.

INTRODUCTION

The watershed is the key component of the water delivery system because it allows surface run-off to enter a specific route, drain, stream, or river.[6] It is possible to construct effective land and water resource management strategies by first gaining a good understanding of the behaviour of the watershed. The geology, height, and climate of every location are all directly correlated with the dynamic ecosystem of water.[20] Therefore, it becomes essential to accurately quantify the morphological, geomorphic, and topographic aspects of a watershed in order to assess its hydrologic response[1]

'Morphometry may be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its landforms'.[7] Drainage basins are the fundamental units of the fluvial landscape, and a large number of studies have focused on their geometric characteristics, which include the topology of the stream network and the quantitative description of drainage texture, pattern, shape, and relief characteristics.[2,13] Measurements of the linear, aerial, relief, gradient of the channel network, as well as the contributing ground slope of the basin enable a successful completion of the morphometric study.[19,25,26]

Numerous morphological investigations have demonstrated the widely-accepted morphological principle that watershed morphology reflects different geological and geomorphological processes across time.[5,8,9,10,11,12,14,22,23,24,27,29,43,45] Understanding topographic processes, soil physical attributes, and erosion features all benefit greatly from drainage morphometry. The drainage analysis appears to be insufficient in the absence of a methodical approach to the development of watersheds in the area. Drainage lines in an area aid in describing the evolution of the area as well as its current three-dimensional geometry.[36] Understanding drainage lays the groundwork for comprehending the initial gradient of the drainage basin or watershed, variations amongst rock resistance, structural response, and geology and geomorphologic chronology. A watershed evaluation is required to determine the health of the watershed and categorise it. Therefore, morphometric analysis can be used to describe a drainage basin numerically. Morphometric estimation can also be used to evaluate hydrological parameters such as the evolution of a watershed, its terrain, surface characteristics, aquifers, and beneath geology.[4,18,31]

Furthermore, quantitative examination of drainage systems is a vital piece of watershed characterization.[44] It becomes essential in all hydrological surveys, including those that evaluate the environment, manage watersheds, administer groundwater, and analyze the potential for groundwater. Within the watershed, hydrological and geomorphological processes take place, and watershed-scale morphological traits provide insight into the emergence and evolution of surface processes.[15,30,37,38,46]

Using traditional techniques, the drainage features of several river basins and sub-basins in various parts of the world have been examined.[12,18,43,44] As per Strahler's classification, a section devoid of tributaries is referred to as a first-order stream. A secondary flow segment is created when two primary flow segments converge, et cetera. Surface runoff and flow intensities in drainage systems can be calculated using geomorphological features in association with morphometric parameters.[47] The morphometric study aims to collect precise data on quantifiable elements of the drainage basin's stream network. Numerous hydrological phenomena can be related to the physiographic characteristics of a drainage basin, including its shape, slope, drainage density, size, and length in contributories, among others.[19,41]

Water management research is important to protect limited water resources, as surface water resources are not only scarce in most places but completely absent in others.[39,40] Watershed management needs geographic information such as: watershed slope, channel network arrangement, location of drainage watersheds, channel length and geomorphological parameters –i.e. Basin priority and relative topography, shape factor, circulation ratio, bifurcation ratio and drainage density– in order to take action on soil and water conservation.[41]

Remote sensing technology is a convenient method for morphometric analysis, as satellite images provide a large-area weather view and are thus extremely useful in watershed morphometric analysis. Fast emerging spatial information technology such as GPS, remote sensing, and GIS, in comparison to traditional data processing approaches, have excellent instruments to overcome most of the problems of water and land resource planning and management.[21] GIS-based assessment using Shuttle Radar Topography Mission (SRTM) and Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) data provides an accurate, fast, and inexpensive method to calculate hydrological systems.[3,34] The processed DEM was successfully used to generate the river network and other support layers. Specifically, using a GIS environment to generate a digital elevation model (DEM) of the area and derive morphological parameters such as watershed sequence, watershed area, watershed density, topography, and pipe network diameter.[16,48,28]

For geomorphological research, researchers have applied automatic terrain assessments based on an SRTM-DEM in the current scenario. SRTM-DEM resolution is becoming increasingly relevant in topography, landscape, and soil research, according to a growing number of recent studies.[4] The use of SRTM-DEM for delineating watersheds and drainage networks using automated means is made easier with the use of a geographic information system (GIS). For evaluating morphometric analysis, these procedures are accurate and provide both qualitative and quantitative benefits.[31]

For hydrological studies involving the estimation of groundwater potential, among other parameters, the geographic and geomorphic features of a drainage basin are significant. The current work attempts to calculate several morphometric aspects of the Gandak River watershed by using remote sensing and GIS technology. This is consistent with the most current developments and studies that were previously discussed.

METHODS

Study area

The Gandak Basin is bordered to the north by the Himalayas, to the south by the Ganges River, the Burhi Gandak Basin to the east, and the Ghagra River to the west. Near the Tibet-Nepal border, southeast of Dhaulagiri, in north latitude 29°18" and east longitude 83°85, the upper stages of the river Gandak, also known locally as Kalie or Krishna Gandaki, originate in the southern Tibetan glacier at an elevation of 7 620 m. The Gandak river receives a number of tributaries, including the Mayangadi, Trisuli and Bari, before emptying into the plains of the West Champaran district of Bihar at Triveni (Valmikinagar). At this point, the river is joined by the Panchand and Sarhad tributaries. The river then runs southward for another 45 kilometers, forming the border between Uttar Pradesh and Bihar. After passing through Bihar, it eventually merges with the Ganga across from Patna.

Up until Triveni, the catchment region of the Gandak River is trapezoidal in shape. Out of its 45.731 sq km total catchment area, 5.687 sq km are in Tibet, 30.882 sq km are in Nepal, 1874 sq km are in the U.P., and 7.288 sq km are in Bihar. It runs for 250 km across India and 380 km via Tibet and Nepal (42).

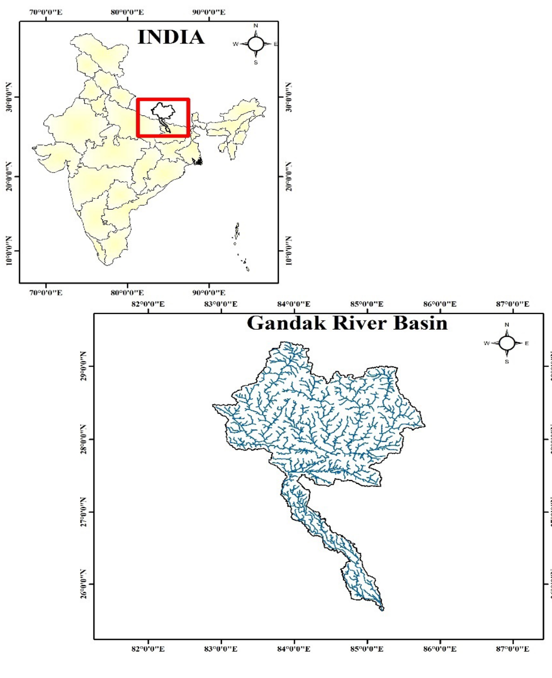


Figure. 1 Location map of lower Gandak Basin in Bihar (India)

Methodology

The Gandak watershed Digital Elevation Model was generated using scale 1:50,000 Survey of India toposheets and ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) elevation data from the USGS (United states Geological Survey) website. The SOI (Survey of India) topographic map was georeferenced in ArcGIS desktop 10.5 using the WGS 84 datum, Universal Coordinate System, and the World Mercator projection. Unmatched and freely accessible global elevation data sets have been produced by the SRTM (Shuttle Radar

Topography Mission) for computational and environmental applications.[40] The morphometric parameters were evaluated using a geoprocessing model. The Gandak River Basin boundary was drawn using ArcGIS' spatial analyst tool and ASTER DEM data. Using the Strahler system (1953) the length of the streams and the size of the basin were analyzed in the Arc hydro tool, and the stream order was generated.

Strahler and Horton's approach for flow orders was used to calculate the drain sequence. The retrieved drainage network was used to build the morphological parameters. The estimated parameters for the Gandak watershed were divided into three categories: linear, aerial, and relief aspects. Formulas in table 1 were used to calculate the morphological traits listed above. Figure 1 also depicts the procedure used to compute selected morphometric parameters in the form of a flowchart.

SRTM-DEM and ArcGIS 10.5 software were also used to create a drainage density map, a slope map, a stream order map, and a relief map. In morphometric research, slope examination is a necessary limitation.[40] The local lithological settings often define the slope variation in the research area.

Table 1. Method of Calculating Morphometric Parameters of Drainage basin

Morphometric Parameters	Formula/Definition	References
	LINEAR	
Stream order (U)	Hierarchical order	(44)
Stream Length (L_U)	Length of the stream	(12)
Mean stream length (Lsm)	$L_{sm}=L_u/N_u$; Where, L_u= Total stream length of a given order (km), N_u=Number of stream segment of that order	(12)
Stream length ratio (R_L)	$R_L= L_{sm}$ / $_{L-1}$ Where, L_u= Mean stream length of order (u),	(12)
	L_{u-1}= mean stream length of its next lower order.	
Bifurcation Ratio (R_b)	$R_b = N_u / N_{u+1}$ Where, Nu= Total number of stream segments present in the given order, N_{u+1}= Number of stream segments of the next higher order	(32)
Mean bifurcation ratio (R_{bm})	Average of bifurcation ratios of all orders	(44)
Basin length(L_b)	$L_b = 1{,}312 \times A^{0{,}568}$	(39)
Basin perimeter	P = Outer boundary of drainage basin measured in kilometers	(39)
	RELIEF	
Basin relief (B_h)	Vertical distance of the lowest and highest points in drainage basin.	(32)
Ruggedness Number (R_n)	$Rn=B_h \times D_d$ Where,B_h= Basin relief, D_d=Drainage density	(32)
Relief Ratio (R_h)	$R_h= B_h/ L_b$	(32)
	AERIAL	
Drainage density (D_d)	D_d=L/A, Where, L=Total length of stream of all orders, A= Area of basin. (km^2)	(12)
Stream frequency (F_s)	$F_s=N_u/A$ Where N_u= Total no. of streams of all orders,	(12)
	A = Area of the basin (km^2)	
Drainage Texture (R_t)	$R_t = N_u/P$ Where, N_u=Total number of stream of all orders, P=Perimeter of basin	(12)
Form factor (R_f)	$R_f=A/(Lb)^2$ Where, A=Area of basin(km^2), L_b= Square of Basin length	(12)
Circulatory ratio (R_c)	$R_c = 4\pi A/P^2$ Where A= Area of basin, π =3,14,	(22)
	P = Square of perimeter of basin(km)	
Elongation ratio (R_e)	$R_e= 2/L_b \times (A/\pi)^{0{,}5}$ Where, A=Area of basin, π=3,14, L_b=Basin length	(32)
Infiltration number	$D_d \times F_s$	(12)
Length of overland flow (L_g)	$L_g=1/2D_d$ Where, Drainage density	(12)
Constant channel maintenance(C)	$C=1/D_d$ Where, D_d= Drainage density	(12)
Drainage Frequency (F_s)	N/A, Where N=Total number of streams; A =Area of watershed	(39)

Ethics approval of research

This article does not contain any studies with human participants or animals performed by any authors.

Clinical Trial Registration

No clinical trial registration was required in this research work.

RESULT AND DISCUSSION

The Gandak watershed has a dendritic drainage pattern (figure 4). When tributary streams enter the main river, they unevenly branch out in different directions, giving it its distinctive appearance.[40] Linear, aerial, and relief aspects are involved in the morphometric analysis (table 2 and 3).

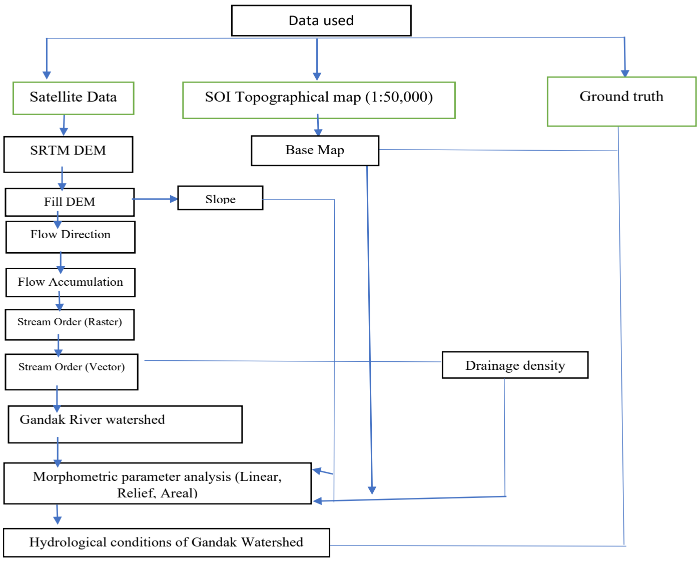


Figure 2. Methodology

Table 2. Result of morphometric analysis

Stream order	Number of stream N_u	Total length of stream L_u (Km)	Bifurcation ratio (R_b)	Mean stream length (L_{sm})	Stream length ratio (R_L)	Mean of Bifurcation ratio
I	988	4566,59	3,71	4,62	-	
II	266	2151,99	3,8	8,09	1,75	
III	70	1090,64	10	15,58	1,93	6,13
IV	7	873,44	7	124,78	8,01	
V	1	527,55	-	527,553	4,23	

Table 3. Result of morphometric analysis

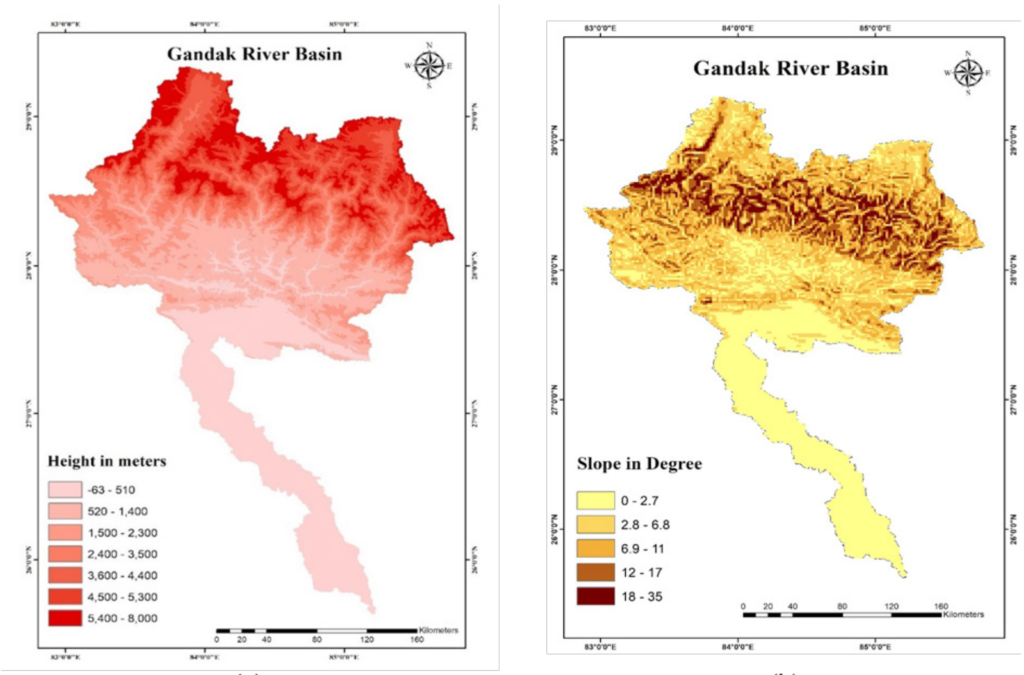
Sr. no	Parameter	Value
1	Basin Area $(Km)^2$	54470,4
2	Perimeter (Km)	2417,457
3	Basin order	5
4	Drainage density(D_d) (Km/Km^2)	0,169
5	Stream frequency (F_s) (Km^2)	0,024
6	Relief Ratio (R_h)	12,40
7	Drainage texture(R_t) (Km)	0,55
8	Basin Length(L_b) (Km)	642,796
9	Basin Relief (B_h) (m)	7,976
10	Ruggedness number (R_n)	1348
11	Mean Bifurcation ratio (R_b)	6,13
12	Form Factor (R_f)	0,132
13	Infiltration Number	1,55
14	Circulatory ratio (Rc)	0,117
15	Elongation Ratio (Re)	0,409
16	Length of overland flow (L_g) (Km)	2,96
17	Constant channel maintenance (C) (Km)	5,92
18	Drainage frequency(F_s)	9,18

Relative relief

The morphometric variable relative relief is used to examine the morphological properties of any topography.[11] The highest relief of the area was 8011 m, and the lowest relief was estimated at 35 m (figure 3a). A flat to mild slope type is indicated by the low terrain in the southern Gandak basin. Because of its flat nature and proximity to water, the area could be primarily allocated for agricultural operations and access to water as a resource.

Slope

The slope map was created using ArcGIS 10.5 software spatial analyst tool and SRTM DEM (Figure 3b). The slope findings were divided into seven groups with natural breaks. Lower slopes were dominant in the study area's lower section, whereas steeper slopes could be noted in the study area's northern region. Slope analysis is a vital part of geomorphological study for both morphometric analysis and the formation of watersheds. The climato-morphogenic forces, in turn, control the slope components in areas with rocks of varying resistance (19,47). Higher slope degrees result in faster runoff, more erosion (potential soil loss), and less ability for ground water recharge. The research area's south sector has the lowest slope (>2°), indicating flat topography, while the hilly region's northern portion has the highest slopes (>3°) resulting in faster sedimentation in the low-lying areas. In order to plan and develop engineering structures, build systems for collecting water, mechanise agriculture, and implement many other resource conservation strategies, slope data can be employed.



(a) (b)

Figure 3. Relief map (a) and Slope map (b) of the study area

Linear aspect

The linear aspects parameters taken were stream order (U), stream length ratio (R_l), stream length (L_u), mean stream length (L_{sm}), stream numbers (N_u), and bifurcation ratio (R_b).

Stream Order(U)

Horton in 1932 was the first to establish the concept of stream order. The stream ordering method is used to determine a river basin's stream classification. In this study, the Strahler (1964) method of stream classification was used. "A channel segment of order two is produced when two first-order streams combine, an order three channel segment is produced when two second-order streams come together, and so on."[44]

The basin's trunk stream is the highest order of stream. The drainage basin's first phase of analysis is the stream ordering, which is based on a hierarchical framework. It ranks the streams and determines their order. According to Strahler (1964), the watershed was identified as the fifth-order basin (figure 4). In the steep region of the Gandak watershed, there are more first-order streams, which indicates the density of the terrain and compactness of the underlying lithology. In this study area, the first-order streams exhibit the highest frequency. Additionally, the existence of several streams in the basin suggests that the terrain is still eroding, while the lower number of streams denotes mature topography.[30]

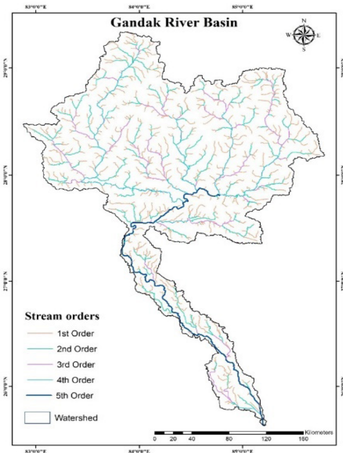


Figure 4. Stream order map of the study area

Stream length (L_U)

Horton's law was used to determine the length of the streams using a GIS tool. Stream length is an important feature of the basin's hydrology because it exhibits surface runoff characteristics. The entire length of stream channels often increases in first-order streams, but it decreases as stream order rises.[47] The total stream length of the research area is 9210.21 kilometres, with total stream lengths in the I, II, III, IV and V orders of 4566.59, 2151.99, 1090.64, 873.44 and 527.55 kilometres, respectively. Longer streams are typically a sign of gentle gradients, but comparatively small streams are a sign of regions with steep topography and a finer texture.[44]

Mean stream length (L_{sm})

The mean stream lengths were determined by dividing the total stream length of the order by the total number of stream segments in the order. According to Strahler (1964), the L_{sm} is a parameter associated with the size of a drainage network as well as its surrounding surfaces. Since they are proportional to the basin's size and topography, the L_{sm} values vary among basins.

Stream Number

A watershed's number of streams depends on variables such as the soil type, vegetation, geology, rainfall, and slope. A watershed's number of streams is also an indication of significant runoff conditions. Furthermore, the frequency of first-order streams suggests the prospect of flash flood in the event of high rainfall in the area downstream.[21] The overall number of streams in Gandak river basin watershed is 1332. Whereas I, II, III, IV and V-order total stream is 988, 266, 70, 7 and 1 respectively. The aforementioned remarks show that the studied area has a higher prevalence of first-order streams.

Stream Length Ratio (R_L)

The stream length ratio is linked to the basin's surface flow, discharge, and erosion stage. The ratio of the mean length of one order to the next lower order of stream segments is known as the stream length ratio defined by Horton (1945). In the study area, the calculated stream length ratio reveals variation within streams of different orders, ranging from 0,47 to 0,60 (Table 2). As late youth streams exhibit a reduction, an upward trajectory in value from low to high order streams suggests that the catchment has matured. According to this study, the topography is tectonically active, which affects the fluvial pattern of the Gandak river watershed and affects discharge and sediment deposition. The variation in stream length ratio illustrates the relationship between topography and slope (R_L). It is vital to the basin's discharge regulation and different erosional stages.[39]

Bifurcation ratio/ mean bifurcation ratio (R_b)

R_b is the ratio of the number of streams in any given order to the number of streams in the next higher order in a drainage basin.[12] It is associated with the branching pattern of a drainage network. A drainage basin's ability to incorporate streams of various orders is shown by this dimensionless property. R_b is influenced by the slope, weather, and physiography. R_b exhibits mild variation among locations or ecosystems, with the exception of those where strong geological control predominates. According to Strahler (1957), variation in the ratio at different orders shows geological and lithological developments in the basin. The R_b for the Gandak watershed ranged from 3,7 to 10 (table 22), with a mean bifurcation ratio R_{bm} of 6,13. Minimum Rb values are seen in basin regions with fewer structural disturbances, however, a maximum value denotes a significant difference between sequential orders brought on by developed topography. A circular basin is more likely to have a low Rb, whereas an elongated basin has a high Rb. The total bifurcation ratio was 24,5 and mean was 6,13 in the current study region.

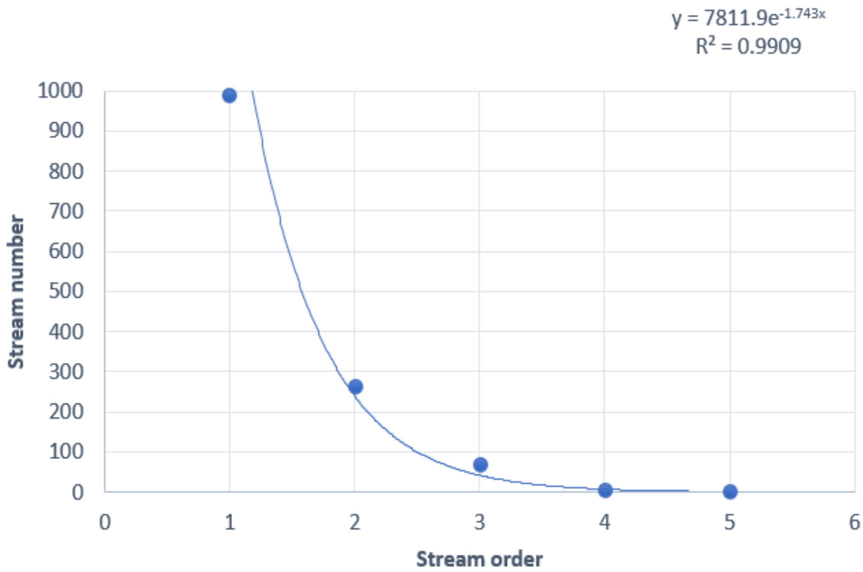


Figure. 5 Correlation between stream number and stream order

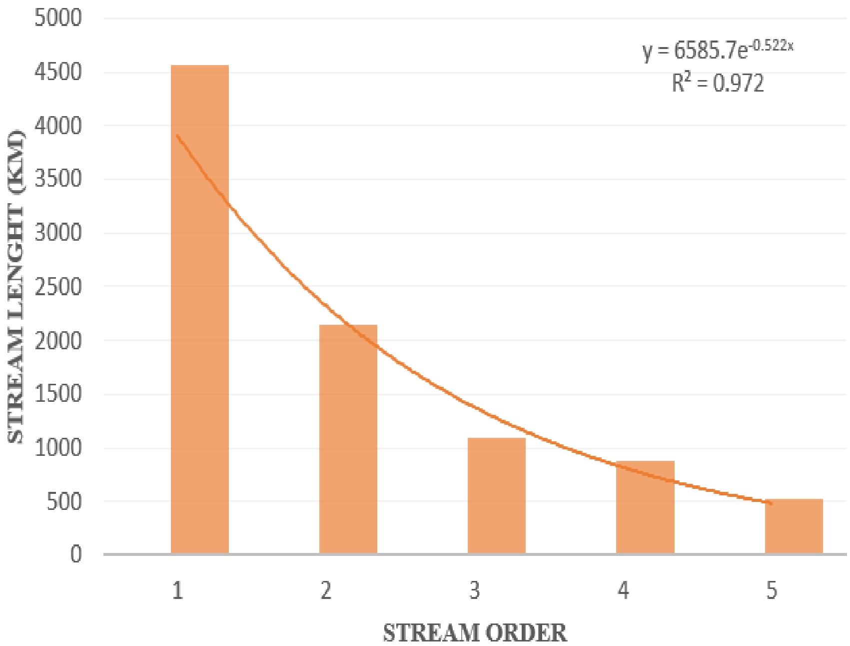


Figure 6. Stream order and stream length relations

Aerial aspect

Infiltration number, Circularity ratio, Stream frequency, Drainage texture, length of overland flow, Drainage density, form factor ratio, and elongation ratio were the aerial aspect metrics used in this study. The basin area and perimeter are the primary determinants in quantitative morphology.

Area and perimeter (P)

"Area of the basin is calculated as total area projected upon a horizontal plane contributing to accumulate of all order of basins. Perimeter is the length of the basin boundary".[1,3] Basin area has a direct influence on the size of a storm hydrograph as well as the orders of magnitude of peak and mean runoff, which as mentioned is a hydrologically significant parameter.[29] The area of the Basin and mean annual runoff have a strong association. The Gandak watershed has a perimeter of 2417.457 kilometres and covers an area of 54470.4 kilometres (table 3).

Drainage density (D_d)

Drainage density was made known by Horton (1945) in American hydrologic literature, "Which is an expression to indicate the closeness of spacing of channels" .[3] The drainage density is computed as the total

https://doi.org/10.56294/saludcyt2022189

length of all streams in the drainage region divided by the total basic area. The drainage density of a landform feature, which provides a numerical assessment of the environment and runoff potential, is one of its most crucial features. Climate, infiltration capacity, rock type, surface roughness, relief, run-off intensity index, and vegetation cover all influence drainage density. Low drainage density points to low topography, high resistance or permeability of subsoil material, and dense vegetation. High drainage density points to high terrain, sparse vegetation, and weak or impervious subsurface material.[3,9] In the current research, low values for drainage density (0,169 km/km^2) suggest a very permeable sub-soil (table 3). Given that the low value of drainage density has a greater impact on infiltration, the region's wells will have good water potential and better specific capacities.[21] Infiltration is lower and surface runoff is higher in locations with greater drainage density. Due to the area's permeability and surface runoff, the drainage density can also serve as an indirect indicator of its groundwater potential.[30]

Table 4 Classification based on D_d by Smith

D_d (km/km^2)	Texture
< 1,24	Very Coarse
1,24-2,49	Coarse
2,49-3,73	Moderate
3,73-4,97	Fine
> 4,97	Very Fine

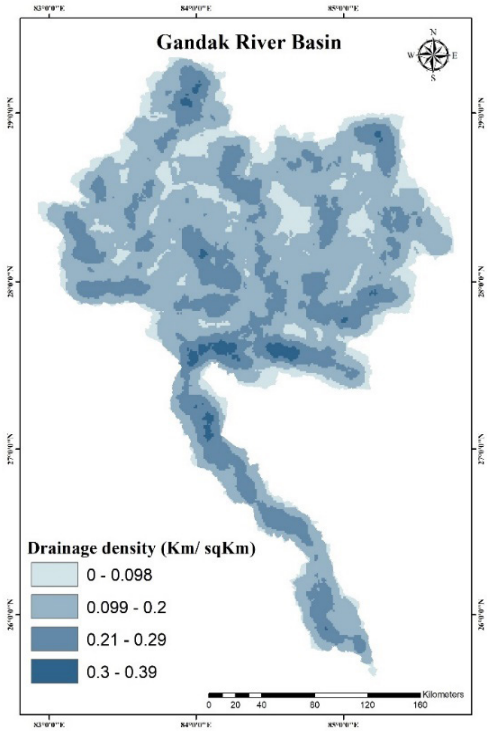


Fig. 7 Drainage density map of the study area.

Drainage Texture (D_t)

The rainfall, temperature, infiltration capacity, underlying lithology, relief features, and vegetation of the terrain all influence the drainage texture.[41] The total number of stream segments per perimeter of an area is used to calculate drainage texture. Smith (1950) [33] divided drainage texture into five separate types based on drainage density. Drainage density below 2 indicates very coarse drainage texture, between 2 and 4 shows coarse drainage texture, between 4 and 6 indicates moderate drainage texture, between 6 and 8 indicates fine drainage texture, and greater than 8 indicates very fine drainage texture. The research area drainage texture is 0,55 km^{-1}. The study region has an extremely coarse drainage texture, as stated by Smith's categorization (1950) and low infiltration capacity (table 4).

Stream frequency (F_s)

"The stream frequency is calculated as the total number of stream segments of all owithand drainage density; the watershed exhibits a rise in stream population in response to an increase in drainage density.[10,47] The frequency value in the research region was 0,024. The drainage density and stream frequency were positively correlated. Because of the slower runoff in basins with low to moderate drainage density as well as stream frequency, flooding is less likely.[41] Specifically, stream frequency in relation to stream orders as well as their characteristics provides details that may shed light on patterns in relief changes and degree of ruggedness in the Gandak watershed. It is a useful tool for determining the erosional process that is active in a given area. Higher frequencies indicate early fluvial cycle stages or revived erosional activity over steep slopes.[36]

Elongation Ratio (R_e)

"The elongation ratio is the ratio of the diameter of a circle with the same area as the drainage basin to the basin maximum length".[32] Re values close to 1 show minimal relief, whereas values between 0,6 and 0,8 indicate considerable relief besides a moderate to steep ground slope.[44] An index of elongation ratio can be used to classify watershed slopes as circular (>0,9), oval (0,9-0,8), or elongated (0,7). The research region had a R_e value of 0,41, reflecting its elongated shape. High relief and moderate to steep land slopes frequently have values between 0,6 and 0,8. With an elongation ratio about less than 0,7, elongated catchments offer significant relief preceded by steep slopes vulnerable to headward erosion. The hydrological impact of the elongation ratio is significant because, in contrast to catchments that are more circular, precipitation brought during a storm in highly elongated catchments must travel farther to reach the catchment outlet.

Circulatory Ratio (R_c)

The frequency and length of streams, basin slope, land use/land cover, climate, geological formations, and relief are all factors in the circulatory ratio.[11] "The circulatory ratio is the ratio of he basin surface area to the surface area of a circle with the same diameter as the basin perimeter".[44] R_c values nearing 1 imply that the basin is circular.[41] It is an important ratio that exemplifies a watershed dendritic stage. The low, medium, and high values of the circularity ratio correspond to the young, adult, and elderly phases of the river watershed life cycle, respectively[29, 48] Circularity ratios in the basin range from 0,40 to 0,50, indicating very permeable uniform geologic materials, whereas its shape is substantially elongated.[22] The circulatory ratio of the studied region was 0,117, which shows a less extended watershed, modest runoff flow, and permeability of the subsoil, indicating that the basin is elongated and in the early stages of its lifecycle.

Form factor (R_f)

"The form factor is defined as the ratio of basin area to the square of the basin length".[12] The form factor represents the intensity of a basin flow. Peak flows are greater and last for a shorter time in the high form factor, while peak flows are smaller and last for a longer time in the low form factor.[47] The form factor for this watershed area was 0,132, resulting in lower peaks for longer durations. The lower value of form factor <0,25 specifies an elongated basin shape.

Infiltration number

The infiltration number, which describes regions of impermeable bedrock and high terrain in the watershed, is computed as the product of stream frequency and drainage density.[45,17] The low infiltration number calculated for the study was 1,55, which suggests that infiltration capacity will be extremely high and runoff will be extremely low.

Constant channel maintenance (C)

The inverse of drainage density is referred to as a channel maintenance constant.[32] C was calculated to be 5,917 in the research area (table 3). A higher value of C denotes reasonable lithological supervision with a porous surface, denoting a watershed unaffected by structural characteristics, a watershed with significantly higher infiltration levels, and a watershed with mild surface discharge or runoff.[28,32]

Length of overland flow (L_g)

"The length of overland flow (L_g) is the distance runoff travels across land before being absorbed by the mainstream".[45] Horton had proposed that this length of overland flow was usually equal to half the reciprocal of the drainage density, despite the fact that it is frequently equal to around half the distance between the stream channels. Rainfall intensity, infiltration rate, soils, vegetation cover, and other factors influence the value of L_g. L_g is calculated to be 2,959 for the overall Gandak River basin. Less rainfall is sufficient in river basins with lower overland flow values to pay for a significant amount of surface runoff to stream discharge. Greater overland flow length shows an extended flow path and, hence, smoother slopes. As a result, the groundwater level of the research area will rise due to effective groundwater recharge processes.

Relief aspect

In order to analyse multiple geo-hydrological characteristics, the relief aspects of the drainage basin investigation are related to the study of three-dimensional features involving the vertical dimension of landforms, volume, and area.[4]. The parameters studied were basin relief and ruggedness number.

Basin relief

A better understanding of basin relief is essential to comprehend the geomorphic activity and landform features. The vertical distance between the basin's lowest and highest points was used to deduce the basin relief.(4) Relief is inextricably linked to other basin characteristics, and it affects some indicators of basin response more strongly than others, such as sediment delivery and peak run-off rates. The relief of a drainage basin is an indicator of its own potential energy; the higher the relief, the more powerful the erosional forces operating on the basin. Lower relief (35m) and higher relief (8011 m) were observed in this investigation. As a result, the watershed relief was 7976 meters. This indicates that erosional pressures and average denudational rates were higher in the examined area.

Relief Ratio (R_h)

Ratio between a basin's overall relief and its longest dimension measured parallel to its major drainage line is known as the relief ratio.[32,35] Schumm demonstrated the exact connection between sediments lost per unit area and relief ratios, opening the door to the possibility of a strong relation among relief ratio as well as hydrologic parameters of a basin.[30] Gandak basin's Relief ratio was estimated to be as high as 12,408, depicting higher runoff intensity as well as higher discharge.

Ruggedness number

According to Strahler, "Ruggedness number is the product of relief of the basin and drainage density", where both parameters are in the same unit. When the slope is steep and both components are large, the ruggedness number achieves an unusually high value.[45] The ruggedness value in this research was 1,348. The watershed basin has a high degree of structural sophistication in relation to relief, and its drainage density also makes it extremely susceptible to soil erosion.

Hypsometric integral (HI):

A river basin hysometric analysis (HA) is useful in studying the relationship of a drainage basin horizontal area with its elevation. A hysometric curve can be generated by plotting relative heights (h/H) with relative area (a/A).[49] The HA was first given by Langbein(1947)[50]. Many studies have been conducted in which a hysometric study for a drainage basin was carried out using GIS techniques[51,52,53,54,55], and the same has been done for this study area. HI was estimated using equation 1.

$$HI = (H_{mean} - H_{min}) / (H_{max} - H_{min}) \quad (1)$$

Where:

H_{mean} = the weighted mean elevation
H_{max} = maximum elevation
H_{min} = minimum elevation

The hypsometric integral is a form of quantitative expression for hypsometry. By examining a large number of drainage basins, Strahler interpreted the hypsometric curves' shapes and divided the basins into three classes, young (convex upward curves), mature (S-shaped curves that are concave upward at high elevations and convex downward at low elevations), and peneplain or distorted (concave upward curves).[43,44] According to Straler, Hypsometric integral above 0,6 implies a dynamic or youthful stage, values in between 0,35-0,6 indicate a mature or equilibrium stage, and values less than 0,35 imply a monadnock stage or old stage. In the present study area of Gandak river basin, the calculated hypsometric integral (HI) was 0,47 (figure 8) indicating mature stage.

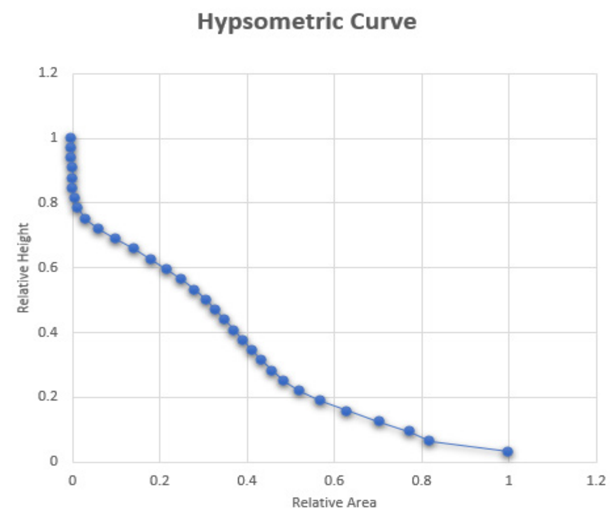


Figure 8. The Hypsometric curve of the study area

https://doi.org/10.56294/saludcyt2022189

The watershed delineation and obtained stream network were validated via Google Earth Pro (GEP) software. A similar map was created in Google Earth, showing numerous stream orders and sites to demonstrate stream validity. Figure 9 shows the Google Earth map of the study region that shows all stream orders and junction places.

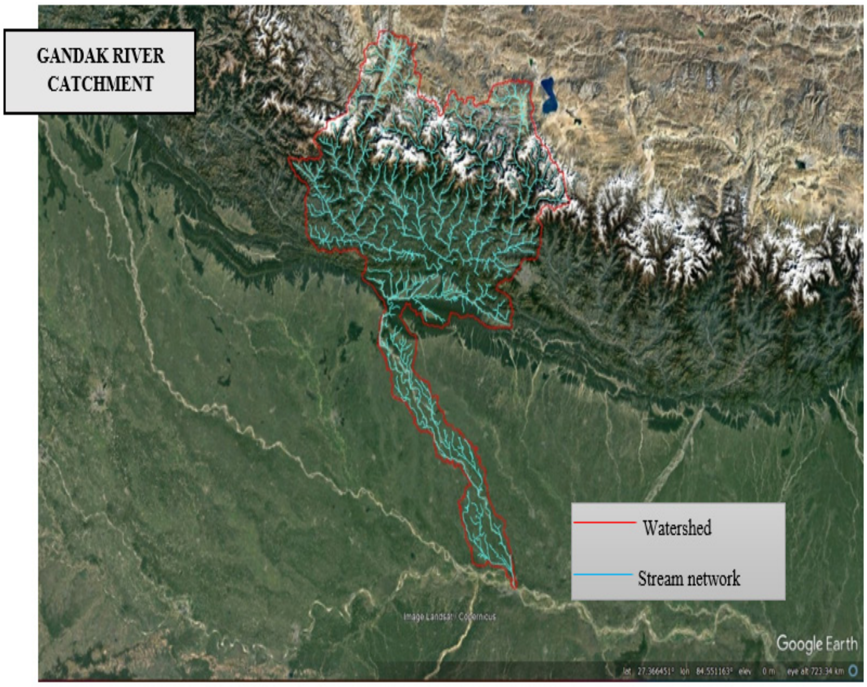


Figure 9. Study area map created in Google map for validation

CONCLUSION

Our findings demonstrate that techniques for geographic information systems and remote sensing are much more effective for processing and analysing morphometric parameters. Using Arc GIS 10.5 programme, 18 morphometric parameters were determined. These 18 parameters helped in elucidating the terrain characteristics of the study region, such as hydrological qualities, infiltration capacity, topography, surface runoff and lithology. According to Strahler classification, the studied region has a fifth-order watershed with a dendritic drainage pattern. The circulation ratio, form factor and elongation ratio data showed that the watershed has an elongated shape. The watershed bifurcation ratio implicates structural disturbances, higher values suggest that geological structure has an impact on drainage patterns and that more structural disruptions have occurred. According to the mean bifurcation ratio value, structural disturbances as well as geological factors influence the watershed drainage pattern. Due to the watershed permeable subsurface, runoff is comparatively modest, as seen by the low streams and low drainage density. Peak flow is expected to be higher, and sediment yield per unit area is higher due to the high basin relief and ruggedness number. The low drainage density suggests that water collection facilities in streams should be built at the proper scale. The low drainage density and coarse drainage pattern of the Gandak basin indicate that it has a lot of potential for artificial recharge structures. The presence of high Length of overland flow (Lg) 2,959 and Constant channel maintenance (C) values of 5,917 indicate that the area has been subjected to sheet erosion. The morphometric properties of the Gandak river basin can be applied to integrated watershed management, mapping of groundwater recharge zones, and rainfall harvesting. The first and second stream orders are high priority streams that are prone to greater erosion and soil loss than the others. The current morphological-based prioritising is also supported by geological field verification. As a result, in order to protect the land from future erosion, adequate soil erosion management techniques can also be adopted for the basin in the regions of high slope. To prioritise a watershed in order to take actions regarding soil and water conservation, the erosion status of the watershed can be estimated using the hypsometric integral value.

BIBLIOGRAPHIC REFERENCES

1. Abdulkareem JH, Pradhan B, Sulaiman WNA, Jamil NR. Quantification of runoff as influenced by morphometric characteristics in a rural complex catchment. Earth Syst Environ. 2018;2(1):145-162.

2. Abrahams AD. Channel networks: a geomorphological perspective. Water Resources Re-search.

1984;20(2):161-188.

3. Ahmed SA, Chandrashekarappa KN, Raj SK, Nischitha V, Kavitha G. Evaluation of morpho-metric parameters derived from ASTER and SRTM DEM—a study on Bandihole sub-watershed basin in Karnataka. Journal of the Indian Society of Remote Sensing. 2010;38(2):227-238.

4. Arulbalaji P, Gurugnanam B. Geospatial tool-based morphometric analysis using SRTM data in Sarabanga watershed, Cauvery River, Salem district, Tamil Nadu, India. Applied Water Sci-ence. 2017;7(7):3875-3883.

5. Burrough PA, McDonnell RA, Lloyd CD. Principles of Geographical Information Systems. Ox-ford University Press Inc; 2015.

6. Chopra R, Dhiman RD, Sharma PK. Morphometric analysis of sub-watersheds in Gurdaspur dis-trict, Punjab using remote sensing and GIS techniques. J Indian Soc Remote Sens. 2005;33(4):531-539.

7. Clarke JI. Morphometry from maps. Essays in Geomorphology. 1966;252:235-274. Elsevier Publ Co, New York.

8. Cox RT. Analysis of drainage-basin symmetry as a rapid technique to identify areas of possible Quaternary tilt-block tectonics: An example from the Mississippi Embayment. Geological So-ciety of America Bulletin. 1994;106(5):571-581.

9. Das S, Pardeshi SD. Morphometric analysis of Vaitarna and Ulhas river basins, Maharashtra, India: using geospatial techniques. Applied Water Science. 2018;8(6):1-11.

10. Dikpal RL, Renuka Prasad TJ, Satish K. Evaluation of morphometric parameters derived from Cartosat-1 DEM using remote sensing and GIS techniques for Budigere Amanikere watershed, Dakshina Pinakini Basin, Karnataka, India. Applied Water Science. 2017;7(8):4399-4414.

11. Gupta R, Misra AK, Sahu V. Identification of watershed preference management areas under water quality and scarcity constraints: case of Jhajjar district watershed, India. Applied Water Science. 2019;9(2):1-22.

12. Horton RE. Erosional development of streams and their drainage basins; hydrophysical ap-proach to quantitative morphology. Geological Society of America Bulletin. 1945;56(3):275-370.

13. Huggett R, Huggett RJ, Cheesman J. Topography and the Environment. Pearson Education; 2002.

14. Hurtrez JE, Sol C, Lucazeau F. Effect of drainage area on hypsometry from an analysis of small-scale drainage basins in the Siwalik Hills (Central Nepal). Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group. 1999;24(9):799-808.

15. Jasmin I, Mallikarjuna P. Morphometric analysis of Araniar river basin using remote sensing and geographical information system in the assessment of groundwater potential. Arab J Ge-osci. 2013;6(10):3683-3692.

16. Kannan R, Venkateswaran S, Prabhu MV, Sankar K. Drainage morphometric analysis of the Nagavathi watershed, Cauvery river basin in Dharmapuri district, Tamil Nadu, India using SRTM data and GIS. Data in brief. 2018;19:2420-2426.

17. Krishnamurthy J, Srinivas G. Role of geological and geomorphological factors in ground water exploration: a study using IRS LISS data. Int J Remote Sens. 1995;16(14):2595-2618.

18. Krishnamurthy J, Srinivas G, Jayaraman V, Candrasekhar MG. Influence of rock types and structures in the development of drainage networks in typical hardrock terrain. ITC Journal. 1996;3:252-259.

19. Magesh NS, Jitheshlal KV, Chandrasekar N, Jini KV. GIS based morphometric evaluation of Chimmini and Mupily watersheds, parts of Western Ghats, Thrissur District, Kerala, India. Earth Science Informatics. 2012;5(2):111-121.

20. Mesa LM. Morphometric analysis of a subtropical Andean basin (Tucuman, Argentina). Environ Geol.

2006;50(8):1235-1242.

21. Moharir KN, Pande CB. Analysis of morphometric parameters using remote-sensing and GIS techniques in the Lonar Nala in Akola district, Maharashtra, India. International Journal for Technological Research in Engineering. 2014;1(10):1034-1040.

22. Mueller JE. An introduction to the hydraulic and topographic sinuosity indexes. Annals of the Association of American Geographers. 1968;58(2):371-385.

23. Nag SK. Morphometric analysis using remote sensing techniques in the Chaka sub-basin, Pu-rulia district, West Bengal. Journal of the Indian Society of Remote Sensing. 1998;26(1):69-76.

24. Nag SK, Chakraborty S. Influence of rock types and structures in the development of drainage network in hard rock area. Journal of the Indian Society of Remote Sensing. 2003;31(1):25-35.

25. Nautiyal MD. Morphometric analysis of a drainage basin using aerial photographs: a case study of Khairkuli Basin, District Dehradun, UP. Journal of the Indian Society of Remote Sensing. 1994;22(4):251-261.

26. Oguchi T. Drainage density and relative relief in humid steep mountains with frequent slope failure. Earth Surface Processes and Landforms: The Journal of the British Geomorphological Group. 1997;22(2):107-120.

27. Pande CB, Moharir K. GIS-based quantitative morphometric analysis and its consequences: a case study from Shanur River Basin, Maharashtra, India. Applied Water Science. 2017;7(2):861-871.

28. Pirasteh S, Safari HO, Pradhan B, Attarzadeh I. Lithomorphotectonics analysis using Landsat ETM data and GIS techniques: Zagros Fold Belt (ZFB), SW Iran. International Journal of Geoinformatics Research and Development. 2010;1(2):28-36.

29. Rai PK, Mohan K, Mishra S, Ahmad A, Mishra VN. A GIS-based approach in drainage morpho-metric analysis of Kanhar River Basin, India. Applied Water Science. 2017;7(1):217-232.

30. Rai PK, Chandel RS, Mishra VN, Singh P. Hydrological inferences through morphometric anal-ysis of lower Kosi river basin of India for water resource management based on remote sens-ing data. Applied Water Science. 2018;8(1):1-16.

31. Rawat PK, Tiwari PC, Pant CC, Sharama AK, Pant PD. Morphometric analysis of third order river basins using high resolution satellite imagery and GIS technology: special reference to natural hazard vulnerability assessment. E-Int Sci Res J. 2011;3(2):70-87.

32. Schumm SA. Evolution of drainage systems and slopes in badlands at Perth Amboy, New Jer-sey. Geological society of America bulletin. 1956;67(5):597-646.

33. Smith KG. Standards for grading texture of erosional topography. American journal of Sci-ence. 1950;248(9):655-668.

34. Singh AP, Arya AK, Singh DS. Morphometric analysis of Ghaghara River Basin, India, using SRTM data and GIS. Journal of the Geological Society of India. 2020;95(2):169-178.

35. Singh DS, Tiwari AK, Gautam PK. The Burhi Gandak: Most Sinuous River. In: The Indian Riv-ers. Springer, Singapore; 2018. p. 209-219.

36. Singh KN. Quantitative Analysis of Landform and Settlement Distribution in Southern Uplands of Eastern Uttar Pradesh, India. Vimal Prakashan; 1980.

37. Singh S. Quantitative geomorphology of the drainage basin. In: Readings on remote sensing applications. TS Chouhan and KN Joshi, Eds. 1992.

38. Singh S. Quantitative analysis of watershed geomorphology using remote sensing techniques. Annals of

Arid Zone. 1995;34:243-252.

39. Sreedevi PD, Subrahmanyam K, Ahmed S. The significance of morphometric analysis for ob-taining groundwater potential zones in a structurally controlled terrain. Environmental Geolo-gy. 2005;47(3):412-420.

40. Sreedevi PD, Owais SHHK, Khan HH, Ahmed S. Morphometric analysis of a watershed of South India using SRTM data and GIS. Journal of the Geological Society of India. 2009;73(4):543-552.

41. Sreedevi PD, Sreekanth PD, Khan HH, Ahmed S. Drainage morphometry and its influence on hydrology in an semi arid region: using SRTM data and GIS. Environmental Earth Sciences. 2013;70(2):839-848.

42. State Water Resources Agency (SWaRA). Government of Uttar Pradesh. Development of River Basin Assessment and Plans For All Major River Basins In Uttar Pradesh, Gandak Basin Plan Vol-II. February, 2020.

43. Strahler AN. Quantitative analysis of watershed geomorphology. Eos Transactions American Geophysical Union. 1957;38(6):913-920.

44. Strahler AN. Part II. Quantitative geomorphology of drainage basins and channel networks. In: Handbook of Applied Hydrology. McGraw-Hill, New York; 1964. p. 4-39.

45. Umrikar BN. Morphometric analysis of Andhale watershed, Taluka Mulshi, District Pune, India. Applied Water Science. 2017;7(5):2231-2243.

46. Vittala SS, Govindaiah S, Gowda HH. Morphometric analysis of sub-watersheds in the Pav-agada area of Tumkur district, South India using remote sensing and GIS techniques. Journal of Indian Society of Remote Sensing. 2004;32(4):351-362.

47. Waikar ML, Nilawar AP. Morphometric analysis of a drainage basin using geographical infor-mation system: a case study. Int J Multidiscip Curr Res. 2014;2(2):179-184.

48. Wilson JJ, Ch N. Morphometric analysis of major sub-watersheds in Aiyar & Karai Pottanar Ba-sin, Central Tamil Nadu, India using remote sensing & GIS techniques. Bonfring International Journal of Industrial Engineering and Management Science. 2012;2(Special Issue Special Issue on Geospatial Technology Development in Natural Resource and Disaster Management):8-15.

49. Miller VC. Quantitative Geomorphic Study of Drainage Basin Characteristic in the Clinch Moun-tain Area. Technical Report 3. Department of Geology, Columbia University; 1953.

50. Langbein WB. Topographic characteristics of drainage basins. U.S. Geol. Soc. Water-Supply Pap. 1947;968:125-158.

51. Obeidat M, Awawdeh M, Al-Hantouli F. Morphometric analysis and prioritisation of watersheds for flood risk management in Wadi Easal Basin (WEB), Jordan, using geospatial technologies. Journal of Flood Risk Management. 2021;14(2):e12711.

52. Shivaswamy M, Ravikumar AS, Shivakumar BL. Quantitative morphometric and hypsometric analysis using remote sensing and GIS techniques. International Journal of Advanced Research in Engineering and Technology. 2019;10(4).

53. Kumari P, Kumari R, Kumar D. Geospatial approach to evaluate the morphometry of Sabarmati River Basin, India. Arabian Journal of Geosciences. 2021;14(3):1-13.

54. Odiji CA, Aderoju OM, Eta JB, Shehu I, Mai-Bukar A, Onuoha H. Morphometric analysis and prioritization of upper Benue River watershed, Northern Nigeria. Applied Water Science. 2021;11(2):1-28.

55. Prasannakumar V, Vijith H, Geetha N. Terrain evaluation through the assessment of geomor-phometric parameters using DEM and GIS: case study of two major sub-watersheds in Attapa-dy, South India. Arabian Journal of Geosciences. 2013;6(4):1141-1151.

ACKNOWLEDGMENT

I would like to express my special thanks of gratitude to my teachers, Prof. N.C. Gupta, who gave me the golden opportunity to do this wonderful research, and also Dr. Bratati Dey who helped me in completing my research study. I will be eternally grateful for all of the knowledge I gained from my mentors as well as from this particular investigation.

Secondly I would also like to thank my University, Guru Gobind Singh Indraprastha University, for its constant financial support, represented by my monthly fellowship under the award letter GGSIPU/DRC/2021/681. I would also like to thank the reviewers for their time, effort, and helpful suggestions.

CONFLICT OF INTEREST

The authors declared that there are no competing or conflicting interests.

FUNDING

Short Term Research Fellowhip (STRF) under the award letter GGSIPU/DRC/2021/681 is being received per month.

AUTHORSHIP CONTRIBUTION

Conceptualization: Arushi Jha, Naresh Chandra Gupta, Bratati Dey.
Methodology: Arushi Jha, Naresh Chandra Gupta, Bratati Dey.
Writing - Original Draft: Arushi Jha, Naresh Chandra Gupta, Bratati Dey.
Writing - Review & Editing: Arushi Jha, Naresh Chandra Gupta, Bratati Dey.

https://doi.org/10.56294/saludcyt2022189