

Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-Spatial Technology – A Case Study of Vishav Drainage Basin

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Abstract

The morphometric analysis of the drainage basin and channel network play an important role in understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural antecedents of the catchment. Morphometric analysis of a drainage basin expresses fully the state of dynamic balance that has been attained due to dealings between matter and energy. In the present study, morphometric analysis has been carried out using Geographical Information System (GIS) techniques to assess the geo-hydrological characteristics of Vishav drainage basin and an attempt has been made to identify the ground water potential zones through geo-morphometric specs. The morphometric parameters are discussed about linear, areal and relief aspects. The basin is characterized by dendritic to sub-dendritic drainage pattern. The development of stream segments in the basin area is affected by rainfall, groundwater discharge and snow melt over. The analysis has revealed that the total number and length of stream segments is maximum in first order streams and decreases as the stream order increases. The bifurcation ratio (R_b) between different successive orders varies revealing the geo-structural control. The shape parameters ($R_c=0.52$, $R_e=0.15$ and $R_f=0.22$) indicate the elongated shape of the basin and in association with some areal (D_a , D_l etc.) and relief (H , S_b , etc.) parameters show that it has low discharge of runoff, generally permeable subsoil condition, moderate to high infiltration capacity and good groundwater resource and a flatter peak of flow of longer duration that is easier to manage than of the circular basins. The study reveals that morphometric analysis based on GIS technique is a competent tool for geo-hydrological studies. These studies are very useful for identifying and planning the ground water potential zones and watershed management (including the whole gamut of natural resources connected with the basin).

Keywords: Morphometry; Geo-hydrological; Geo-Spatial Technology; Vishav; GIS

Introduction

Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimension of its landforms [1,2]. Morphometric studies in the field of hydrology were first initiated by [3,4]. The morphometric analysis of the drainage basin and channel network play an important role in understanding the geo-hydrological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology, structural antecedents of the catchment. The relationship among various drainage parameters and the aforesaid factors are well recognized by many workers [5-9]. The drainage basin analysis is important in any hydrological investigation as assessment of groundwater potential, groundwater management, pedology and environmental assessment. Hydrologists and geomorphologists have recognized that certain relations are almost important between runoff characteristics, and geographic and geomorphic characteristics of drainage basin systems. Various important hydrologic phenomena can be correlated with the physiographic characteristics of drainage basins such as size, shape, slope of drainage area, drainage density, size and length of the tributaries etc. [10]. Geology, relief and climate are the primary determinants of running water systems functioning at the basin scale [11]. Geographical Information System (GIS) techniques are now-a-days in use for assessing various terrain and morphometric parameters of the drainage basins and watersheds, as it provide a flexible environment and an important tool for the manipulation and analysis of spatial information.

The objective of the present study was to analyze the linear, areal and relief morphometric attributes of Vishav drainage basin in south-eastern part of Kashmir Valley by using geo-spatial technology. This

study is attempted to use the morphometric technique vis-a-vis GIS to give an insight of the different geo-hydrological characteristics of the drainage basin to help in the identification of ground water potential zones and overall management of the basin with focus on groundwater.

Materials and Methods

The present study is based on Survey of India (SOI) topographic maps of 1971 with no. 43 K/10, 43 K/12, 43 K/14, 43 K/15, 43 O/1, 43 O/2 and 43 O/3 on the scale 1, 50,000. Topographical maps were rectified/referenced geographically and mosaiced and entire study area was delineated in GIS environment with the help of Arc-GIS 9.0 software assigning Universal Transverse Mercator (UTM), World Geodetic System (WGS dating from 1984 and last revised in 2004) and 43N Zone Projection System. Since, morphometric analysis of a drainage basin requires the delineation of all the existing streams, digitization of the drainage basin was carried out for morphometric analysis in GIS environment using Arc GIS 9.0 software. The attributes were assigned to create the digital data base for drainage layer of the basin. Various

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Received July 17, 2013; Accepted September 03, 2013; Published September 10, 2013

Citation: Hajam RA, Hamid A, Bhat S (2013) Application of Morphometric Analysis for Geo-Hydrological Studies Using Geo-Spatial Technology –A Case Study of Vishav Drainage Basin. Hydrol Current Res 4: 157. doi:10.4172/2157-7587.1000157

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morphometric parameters such as linear, aerial and relief aspects of the basin were computed. The different morphometric parameters were determined by using the standard methodologies as shown in Table 1. Moreover, GIS technology was used to generate several other layers of maps such as map of elevation zones of the basin, map of the geological setup of the area and map showing distribution and concentration of the natural springs irrespective of the size and discharge in different

geological zones to validate the results and inferences drawn through morphometric analysis. Finally, by assembling the whole data generated, groundwater potential zones were identified.

Study area

The Vishav drainage basin covering an area of 1083.48 km² (10 % of Jhelum drainage basin) occupies the south eastern part of the Kashmir

S. No.	Parameters	Symbol	Formula	Reference
1	Linear aspects			
1.1	Stream Order	S_{μ}	Hierarchical rank	[19]
1.2	Bifurcation Ratio	R_b	$R_b = N_{\mu} / N_{\mu+1}$ Where, R_b = Bifurcation ratio, N_{μ} = No. of stream segments of a given order and $N_{\mu+1}$ = No. of stream segments of next higher order.	[21]
1.3	Mean Bifurcation Ratio	R_{bm}	R_{bm} = Average of bifurcation ratios of all orders	[19]
1.4	Stream Length	L_{μ}	Length of the stream (kilometers)	[5]
1.5	Mean Stream Length	L_{sm}	$L_{sm} = L_{\mu} / N_{\mu}$ Where, L_{μ} = Total stream length of order 'μ' N_{μ} = Total no. of stream segments of order 'μ'	[19]
1.6	Stream Length Ratio	R_L	$R_L = L_{sm} / L_{sm-1}$ Where, L_{sm} = Mean stream length of a given order and L_{sm-1} = Mean stream length of next lower order	[5]
1.7	Length of Overland Flow	L_g	$L_g = 1/2D$ Km Where, D = Drainage density (Km/Km ²)	[5]
1.8	Basin Perimeter	P	P = Outer boundary of drainage basin measured in kilometers.	[21]
1.9	Basin Length	L_b	$L_b = 1.312 \times A^{0.568}$	[21]
2	Areal aspects			
2.1	Basin Area	A	Area from which water drains to a common stream and boundary determined by opposite ridges.	[19]
2.2	Drainage Density	D_d	$D_d = L_{\mu} / A$ Where, D_d = Drainage density (Km/Km ²) L_{μ} = Total stream length of all orders and A = Area of the basin (Km ²).	[24]
2.3	Drainage Frequency	F_s	$F_s = N_{\mu} / A$ Where, F_s = Drainage frequency. N_{μ} = Total no. of streams of all orders and A = Area of the basin (Km ²).	[24]
2.4	Infiltration Number	I_f	$I_f = D_d \times F_s$ Where, D_d = Drainage density (Km/Km ²) and F_s = Drainage frequency.	[43]
2.5	Drainage Texture	D_t	$D_t = N_{\mu} / P$ Where, N_{μ} = No. of streams in a given order and P = Perimeter (Kms)	[5, 44]
2.6	Form Factor Ratio	R_f	$R_f = A / L_b^2$ Where, A = Area of the basin and L_b = (Maximum) basin length	[24]
2.7	Elongation Ratio	R_e	$R_e = \sqrt{A} / \pi / L_b$ Where, A = Area of the basin (Km ²) L_b = (Maximum) Basin length (Km)	[21]
2.8	Circularity Ratio	R_c	$R_c = 4\pi A / P^2$ Where, A = Basin area (Km ²) and P = Perimeter of the basin (Km)	[40]
3.0	Relief Aspects			
3.1	Basin Relief	H	$H = Z - z$ Where, Z = Maximum elevation of the basin (m) and z = Minimum elevation of the basin (m)	[45]
3.2	Relief Ratio	R_r	$R_r = H / L_b$ Where, H = basin relief (m) and L_b = Basin length (m)	[21]
3.3	Dissection Index	D_i	$D_i = H / R_a$ Where, H = basin relief (m) and R_a = Absolute relief (m)	[46]
3.4	Channel Gradient	C_g	$C_g = H / \{(\pi/2) \times C_{lp}\}$ Where, H = basin relief (m) and C_{lp} = Longest Dimension Parallel to the Principal Drainage Line (Kms) = L_b	[47]
3.5	Basin Slope	S_b	$S_b = H / L_b$ Where H and L_b = given above	[42]

Table 1: Morphometric parameters with formulae.

valley as depicted in Figure 1 and is situated between 33°39' to 33°65' N latitude and 74°35' to 75°11' E longitudes with its major part (80 percent) in the Kulgam and Shopian districts, Jammu and Kashmir, India. The Vishav stream is the important left bank perennial tributary of the Jhelum stream. Having its birth from Kounsarnag (3,840 m.a.s.l.) lying on the gentler northern face of the Pir Panjal range of Kashmir Himalayas, it follows a sinuous course, first moves with moderate turbulence in northerly direction, then takes a very turbulent south-easterly course and finally flows laminarily in north-westerly direction till it merges with Jhelum at Niayun. Visually, Vishav stream seems to stem from a glacier fed stream near the base of Kounsarnag called Teri, that later joins the underground stream believed to originate from Kounsarnag 2 km downstream at Mahinag, dropping steeply north-northeast to reach the main strike valley [12]. The maximum discharge is available in the month of July and August and minimum in the month of December and January. The velocity of the stream varies from 121 cm/sec to 49 cm/sec [13]. The study area is elongated in shape and has varied topography. The soils of the Vishav catchment belong to the groups of the brown forest and mountain soils (> 3,000 m.a.s.l.), and Lacustrine or Karewa soils (1,800-3000 m.a.s.l.) and alluvial soils (<1,800 m.a.s.l.). Lithologically the alluvium consists of blue/grey silts and clay shales and sands of different texture and structure. The size of the grains varies from fine, medium to coarse. The valley possesses distinctive climatic characteristics because of its high altitude location and its geophysical setting, being enclosed on all sides by high mountain ranges. The valley is characterized by sub-Mediterranean kind of climate with nearly 70 per cent of its annual precipitation concentrated in winter and spring months [14].

Geology of the area

Kashmir Valley is characterized by a diverse geological record ranging in age from Pre-Cambrian to Recent [15,16]. The geology of the study area is dominated by the Alluvium, followed by Karewas, Jurassic formations and Triassic formations as shown in Figure 2. The Triassic rocks are surrounded by Palaeozoics (Agglomeratic Slates and Panjal Traps) and the later are overlain by Pleistocene and Recent sediments. The some of the Palaeozoic rocks are overlain by Triassic Limestone (~1000 m thick) occurring in the form of dissected ridges. The limestone is thin bedded, with common shale and sandstone horizons. The fluvio-glacial and fluvio-lacustrine deposits of Pleistocene locally known as Karewas consist of fine lacustrine sandstones, beds of loess and conglomerates. Small valleys between Triassic Limestone ridges and Karewas are filled with Recent Alluvium composed of fine muddy and silty sediments [16]. Alluvium covers half of the area in the plain areas hiding the primary geological set up of the area. However, along the streams the boulders and gravels predominate. Triassic Limestone is the almost significant and main aquifer of the area that supplies water to most of the people for domestic and agriculture purposes. The underlying Palaeozoic rocks are impermeable. The overlying Karewas are not productive aquifers but act as efficient filters owing to their high porosity [17]. Because of the low hydraulic conductivity, alluvium blocks the water flowing through the Triassic Limestone and the water emerges out in the form of springs at the contact between the alluvium and Triassic Limestone in the foothill areas (around 2000 m altitude) and moderately sloping plains [18].

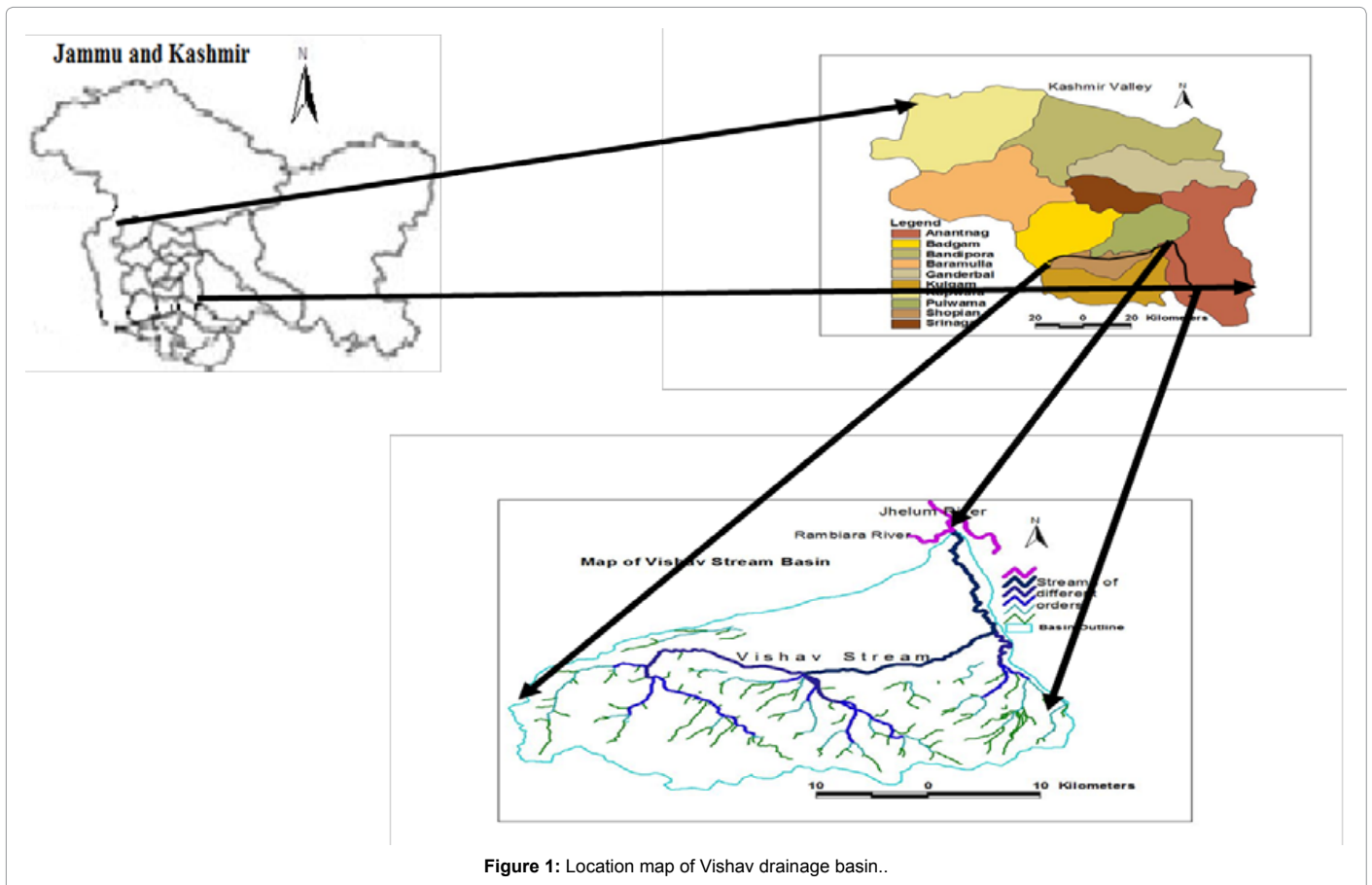


Figure 1: Location map of Vishav drainage basin..

Results and Discussion

The study of basin morphometry relates basin and stream network geometries to the transmission of water and sediment through the basin. Systematic description of the geometry of a drainage basin and its stream channel requires measurement of linear, areal and relief (gradient) aspects of the channel network and contributing ground slopes [19]. In the present study, the morphometric analysis has been carried out about parameters as stream order, stream length, bifurcation ratio, stream length ratio, basin length, drainage density, stream frequency, elongation ratio, circularity ratio, form factor, basin relief, relief ratio, channel gradient using mathematical formulae as given in Table 1 and the results are summarized in Tables 2-5. The properties of the stream networks are highly important to study the

landform making processes [20]. Morphometric parameters such as basin relief, basin shape and stream length also influence basin discharge pattern strongly through their varying effects on lag time. The natural runoff is one of the most potent geomorphic agencies in shaping the landscape of an area. The land area that contributes water to the main stream through smaller ones forms its catchment area or the drainage basin. The arrangement of streams in a drainage system constitutes the drainage pattern, that in turn reflects mainly structural/ or lithologic controls of the underlying rocks. The drainage pattern of Vishav Stream basin is dendritic to sub-dendritic in nature.

Linear morphometric parameters

Linear aspects of the basins are closely linked with the channel patterns of the drainage network wherein the topological characteristics

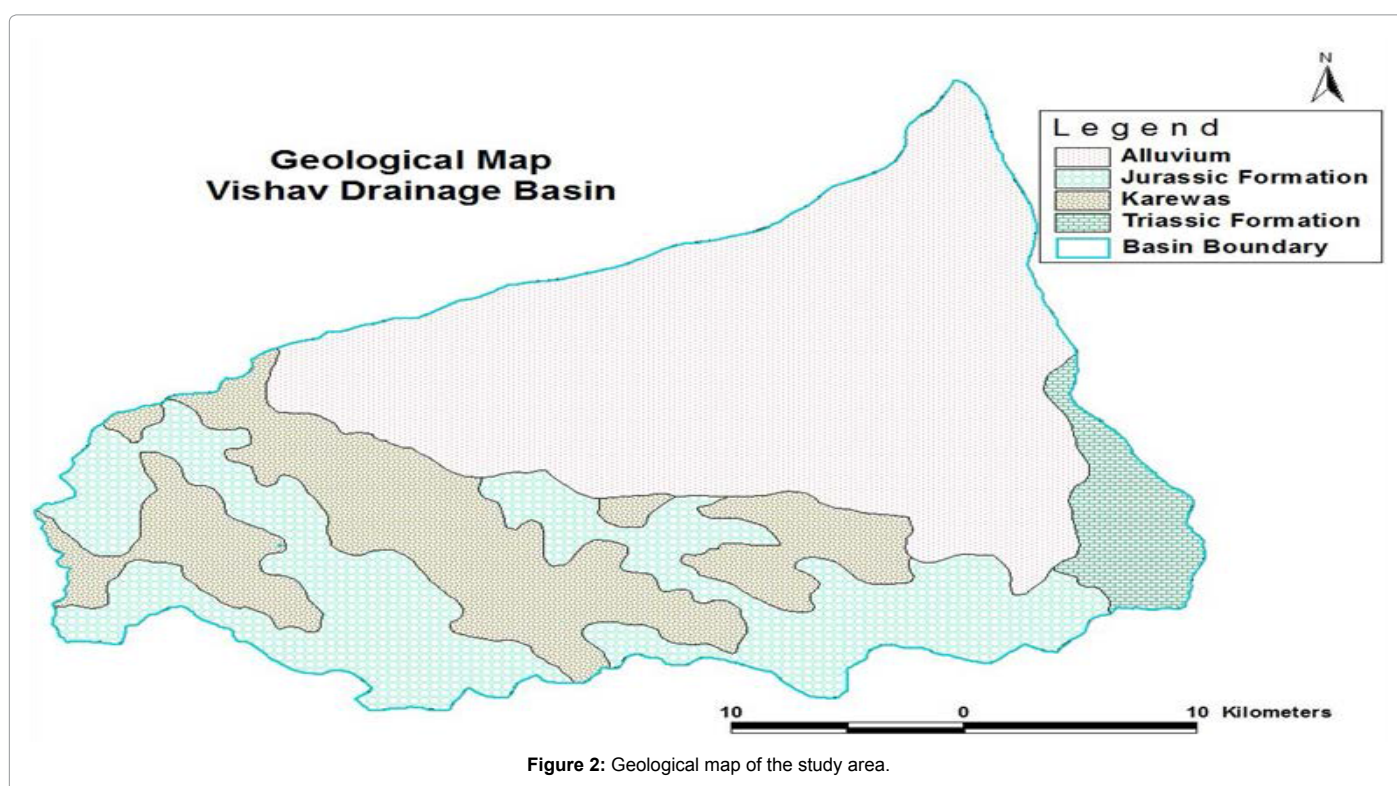


Figure 2: Geological map of the study area.

Stream order (S_{μ})	Stream number (N_{μ})	Bifurcation ratio (R_b)	Stream length (L_{μ}) (kms)	Mean stream length (L_{sm}) (kms)	Cumulative Mean stream length (L_{sm})	Stream length ratio (R_L)	Mean bifurcation ratio (R_{bm})
1 st	2005 (75.86)		1301.16 (59.01)	0.65	0.65		3.09
		4.16				1.47	
2 nd	482 (18.24)		465.30 (21.09)	0.96	1.61		
		4.26				1.88	
3 rd	113 (4.27)		204.15 (9.26)	1.81	3.42		
		4.03				1.95	
4 th	28 (1.06)		98.83 (4.48)	3.53	6.95		
		2.54				1.66	
5 th	11 (0.42)		64.64 (2.93)	5.87	12.82		
		3.66				1.86	
6 th	3 (0.11)		32.75 (1.48)	10.92	23.74		
		3.0				3.53	
7 th	1 (0.04)		38.52 (1.75)	38.52	62.26		
Total	2, 643		2205.35				

Note, Figures in parenthesis show Percentage stream length contributed by different stream orders

Table 2: Linear morphometric parameters of the drainage network of Vishav drainage basin.

S. No.	Parameter	Calculated value
1	Length of Overland Flow (L_g)	0.25 km
2	Basin Perimeter (P)	161.24 km
3	Basin Length (L_b)	69.46 km
4	Fitness Ratio (R_f)	0.44
5	Wandering Ratio (R_w)	1.02
6	Standard Sinuosity Index (SSI)	1.02

Table 3: Other Linear Parameters of Vishav drainage basin.

S.No.	Parameter	Calculated Value
1	Drainage Area (A)	1,083.48 km ²
2	Drainage Density (D_d)	2.03 km/km ²
3	Drainage Frequency (F_d)	2.44 / km ²
4	Drainage Texture (D_t)	12.43-0.01
5	Infiltration Number (I_i)	4.95
6	Form Factor Ratio (R_f)	0.22
7	Elongation Ratio (R_e)	0.15
8	Circularity Ratio (R_c)	0.52

Table 4: Areal Morphometric Parameters of the Vishav drainage basin.

S. No.	Parameter	Calculated value
1	Maximum Basin Height (Z)	4,726 ms a.m.s.l.
2	Minimum Basin Height (z)	1,597 ms a.m.s.l.
3	Basin Relief (H)	3,129 ms
4	Relief Ratio (R_r)	0.045
5	Dissection Index (D_i)	0.66
6	Channel Gradient (C_g)	28.69 m / km
7	Basin Slope (S_b)	0.045 (=4.5 %)

Table 5: Relief morphometric parameters of the drainage network of Vishav Drainage Basin.

of the stream segments in terms of open links of the network system are analyzed. The morphometric investigation of the linear parameters of the basins includes stream order (S_μ), bifurcation ratio (R_b), stream length (L_μ), mean stream length (L_{sm}), stream length ratio (R_L), length of overland flow (L_g), basin perimeter (P), basin length (L_b), fitness ratio (R_f), wandering ratio (R_w), sinuosity indices. Some of the important linear aspects have been computed as shown in Tables 2 and 3.

Stream order (S_μ)

The designation of stream order is the first step in the drainage basin analysis. The primary step in drainage basin analysis is to designate stream orders [5]. As per the Strahler's (1964) ordering scheme, the study area is a 7th order drainage basin as shown in Figure 3. Higher stream order is associated with greater discharge. The trunk stream, Vishav, through which all discharge of water and sediment passes is therefore the stream segment of highest order.

Stream number (N_μ)

The count of stream channels in a given order is known as stream number [5]. Results of the study revealed that Vishav stream is having 2,643 streams linked with 7 orders of streams as shown in Figure 2 sprawling over an area of 1,043.48 km². Stream frequency decreases as the stream order increases. Stream number is directly proportional to size of the contributing basin and to channel dimensions as shown in Table 2. A higher stream number indicates lesser permeability and infiltration. Vishav stream basin shows a negative correlation among the stream orders and stream numbers as shown in Figure 4. It means that the several streams usually decreases in geometric progression as the stream order increases. The variations in rock structures in the basin are responsible for inequalities in stream frequencies of each order.

Bifurcation ratio (R_b)

Bifurcation ratio is closely related to the branching pattern of a drainage network [21]. From the Table 2, clearly the bifurcation ratio values for the Vishav basin vary from 2.54 to 4.26 because of possibility of variations in basin geometry and lithology, but tend to be constant throughout the series with the mean bifurcation ratio of 3.09. The highest R_b (4.26) is found between 2nd and 3rd order that indicates corresponding highest overland flow and discharge attributable to hilly less permeable rock formation associated with high slope configuration. The relatively high bifurcation ratio indicates early hydrograph peak with a potential for flash flooding during the storm events in the areas in which these stream orders dominate [22,23]. As a whole in the basin, this minor vulnerability is compensated by the other streams. The relatively lower value of mean bifurcation ratio also suggests the geological heterogeneity, higher permeability and lesser structural control in the area.

Stream length (L_μ)

Stream length is indicative of chronological developments of the stream segments including interlude tectonic disturbances. In the present work, results show that the total length of stream segments is more in case of first order streams and decreases with the increase in the stream order except the 7th order stream whose length is more than the total length of the 6th order stream segments as shown in Table 2 and Figure 5. This discrepancy is attributable to variations in relief and lithology. It is noticed that stream segments up to 4th order traverse parts of the high to moderate altitudinal zones characterized by steep to moderate slopes while the 5th, 6th and 7th order stream segments occur in comparatively plain lands.

Stream length ratio (R_L)

The stream length ratio has important relationship with surface flow and discharge and erosion stage of the basin [5,23]. The values of R_L vary haphazardly from 1.47 to 3.53 attributable to differences in slope and topographic conditions. Since the Vishav stream basin shows changes in R_L from one order to the next, it is deduced that it is characterized by the late youth to early mature stage of geomorphic development [24].

Length of overland flow (L_g)

Length of overland flow is one of the most important independent variables affecting both hydrologic and physiographic development of drainage basins [25]. Overland flow is significantly affected by infiltration/percolation through the soil that vary in time and space [26,23]. The length of overland flow of the Vishav basin is 0.25 kilometers, which shows gentler slopes in the valleys and hence low surface runoff and longer flow paths.

Fitness ratio (R_f)

The ratio of main channel length to the length of the basin perimeter is fitness ratio that is a measure of topographic fitness [27]. The fitness ratio for Vishav drainage basin is 0.44.

Wandering ratio (R_w)

Wandering ratio is the ratio of the mainstream length to the valley length or basin length [27]. Valley length is the straight line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the drainage basin is 1.02.

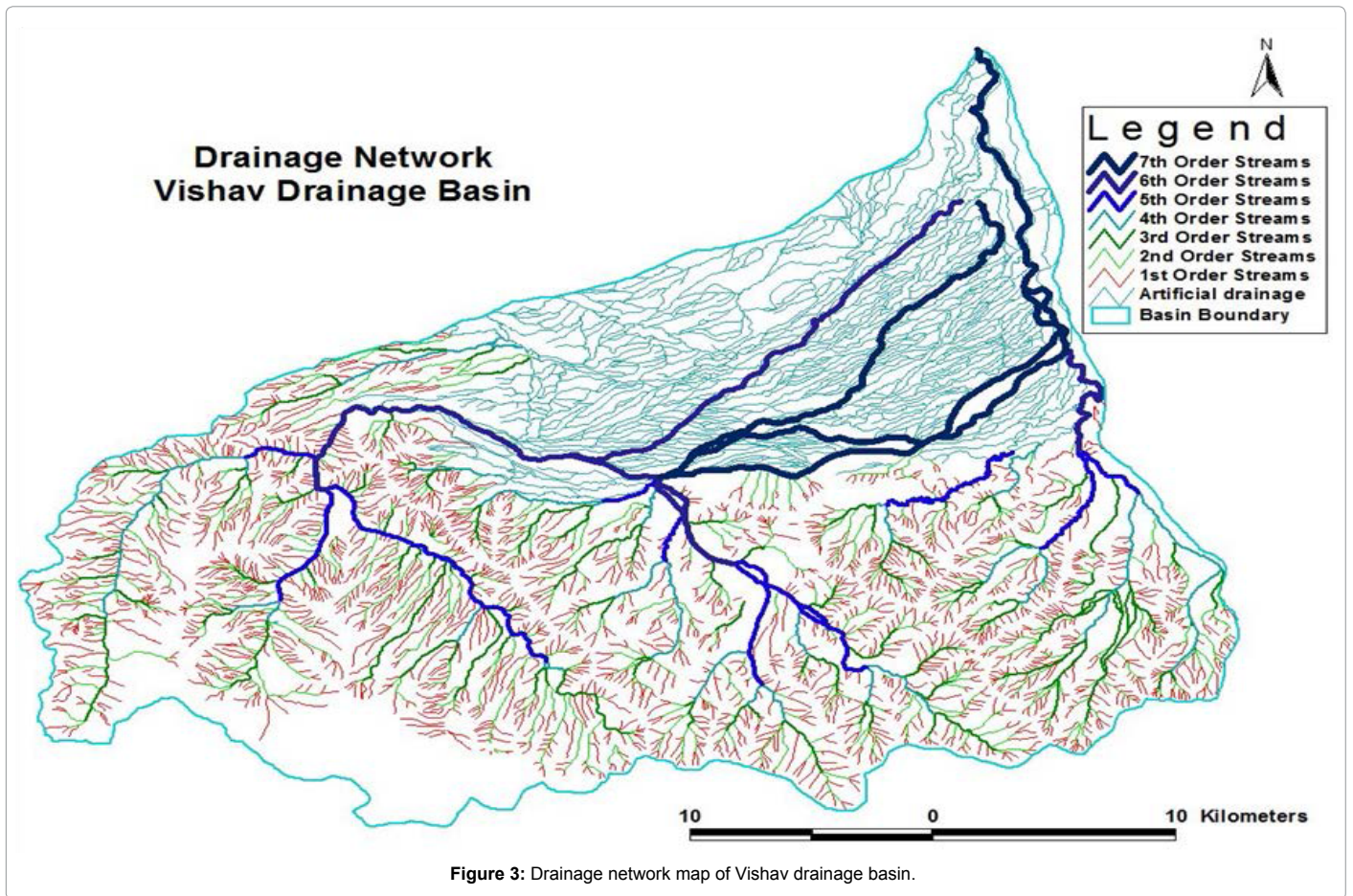


Figure 3: Drainage network map of Vishav drainage basin.

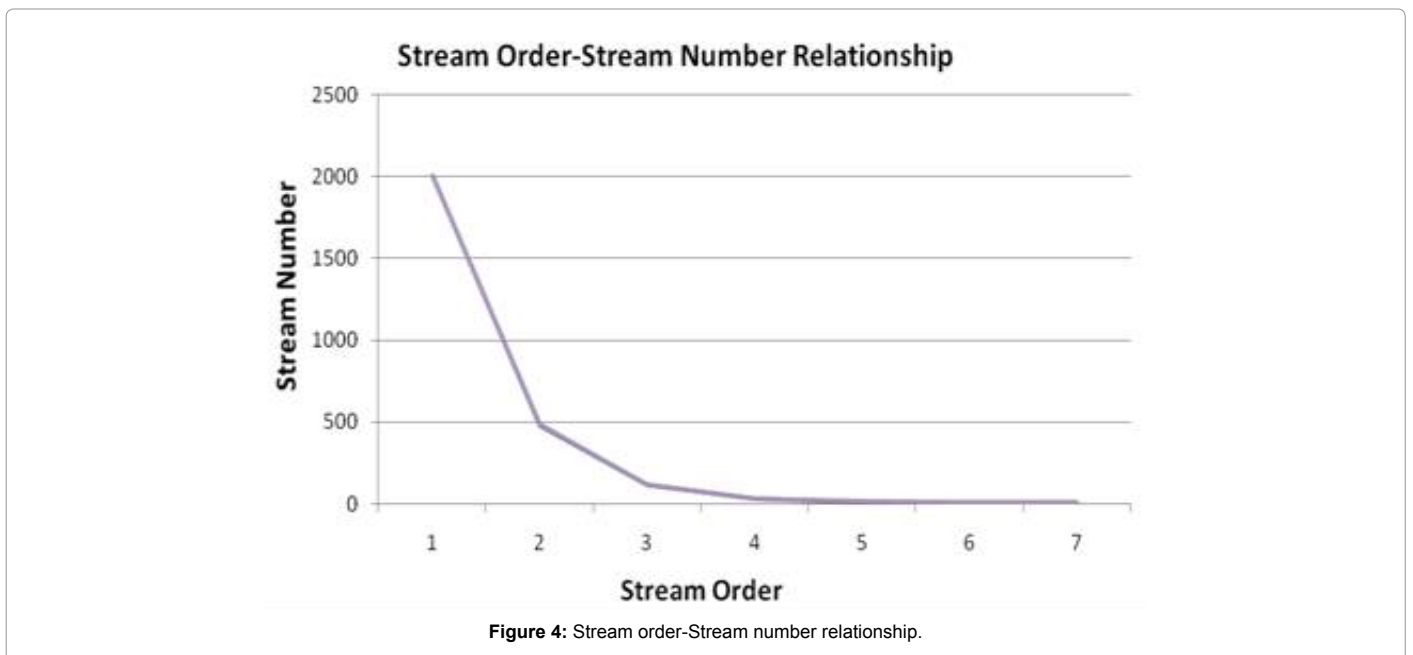
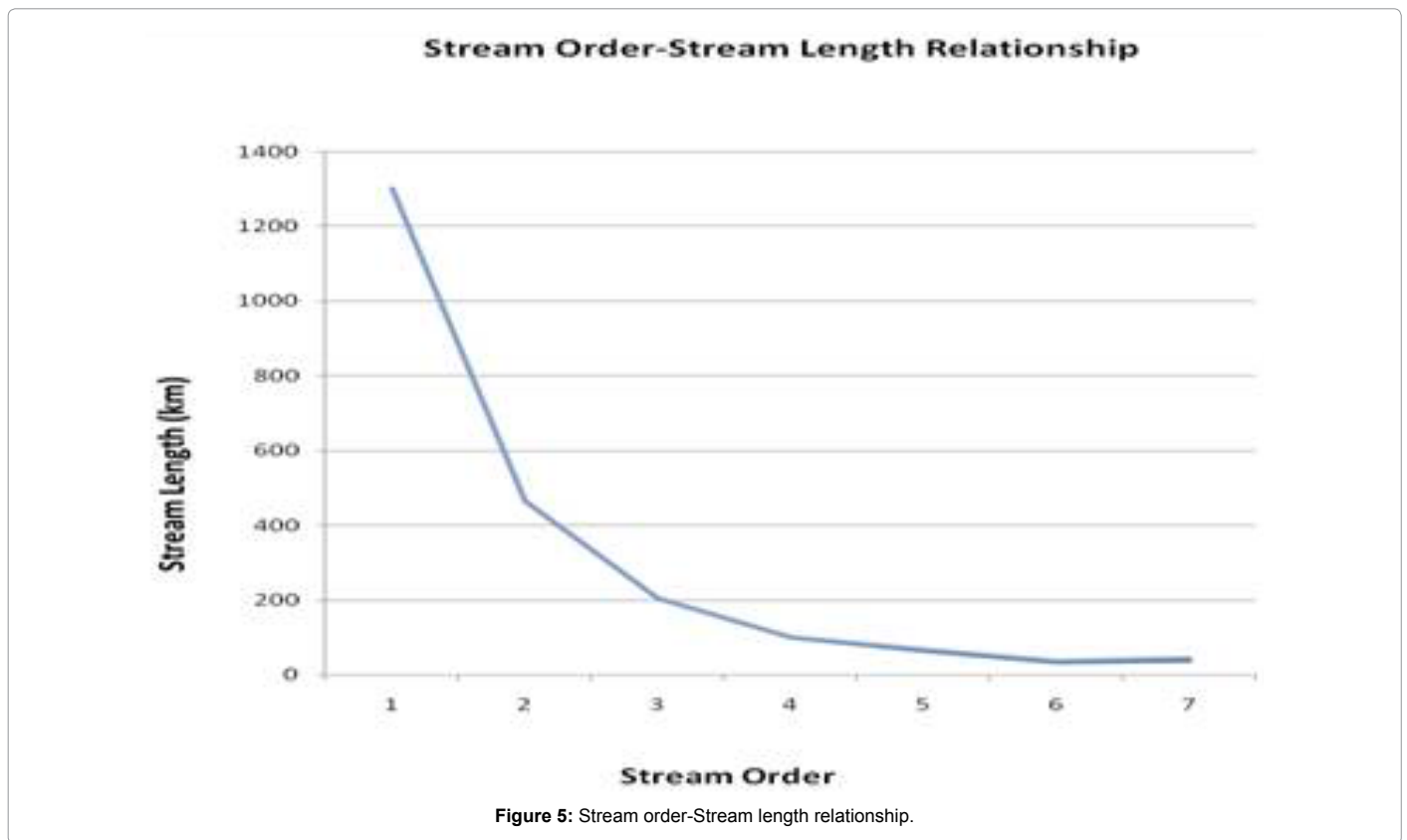


Figure 4: Stream order-Stream number relationship.

Standard sinuosity index (SSI)

Sinuosity is highly significant in studying the affect of terrain characteristics on the river course. The calculated value of the Vishav

basin is 1.02 that shows the stream has sinuous course. It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial for geomorphologists, hydrologists, and geologists.



Areal morphometric parameters

Area of a basin (A) and perimeter (P) are the important parameters in quantitative geo-morphology. Basin area directly affects the size of the storm hydrograph, the magnitudes of peak and mean runoff. The maximum flood discharge per unit area is inversely related to size [28]. The total area of the Vishav drainage basin is 1,083.48km². The aerial aspects of the drainage basin such as basin area (A) drainage density (D_d), stream frequency (F_s), texture ratio (R_t), elongation ratio (R_e), circularity ratio (R_c) and form factor ratio (R_f) were calculated and results have been given in Table 4.

Drainage density (D_d)

The drainage density determines the time travel by water [21]. The measurement of D_d is a useful numerical measure of landscape dissection and runoff potential [29]. A high drainage density reflects a highly dissected drainage basin with a relatively rapid hydrological response to rainfall events, while a low drainage density means a poorly drained basin with a slow hydrologic response [27]. D_d is the result of interacting factors controlling the surface runoff and in turn influences the output of water and sediment from the drainage basin [30]. D_d is known to vary with climate and vegetation [31], soil and rock properties [32], relief and landscape evolution processes. In general, the hydrology of basin changes significantly in response to the changes in the drainage density. The D_d of the Vishav drainage basin is moderate (2.03 km/km²) indicates clearly that the basin has permeable subsurface material, good vegetation cover and medium relief [33], causing more infiltration of water and recharging groundwater aquifers. There exists a close relationship between drainage density and mean annual flood [34]. So, the basin as a whole is less prone to flooding.

Drainage frequency (F_s)

The stream frequency (F_s) or channel frequency or drainage frequency of the whole basin is 2.44/km² as shown in Table 4. It mainly depends on the lithology of the basin and reflects the texture of the drainage network. It is an index of the various stages of landscape evolution. The Stream frequency depends on the rock structure, infiltration capacity, vegetation cover, relief, nature and amount of rainfall and subsurface material permeability. The stream frequency of Vishav basin shows that the basin has good vegetation, medium relief, high infiltration capacity and later peak discharges owing to low runoff rate. The stream frequency shows positive correlation with the drainage density. Lesser the drainage density and stream frequency in a basin, the runoff is slower, and therefore, flooding is less likely in basins with a low to moderate drainage density and stream frequency [35].

Drainage texture (D_t)

The drainage texture depends upon several natural factors such as climate, vegetation type and density, rock and soil type, infiltration capacity, relief and stage of development [36]. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture [31], that in turn depends on the infiltration capacity of the mantle rock or bed rock [37]. The drainage texture values are 12.43 (1st order streams), 1.67 (2nd order streams), 0.70 (3rd order streams), 0.17 (4th order streams), 0.07 (5th order streams), 0.02 (6th order stream) and 0.01 (7th order streams). Generally, the Vishav basin falls into very coarse to coarse texture category and indicates good permeability of sub-surface material and infiltration capacity, lower run off rate, and significant recharge of the ground water except the area occupied by the first order streams.

Infiltration number (I_f)

Infiltration number plays a significant role in observing the infiltration characteristics of the basin. It is inversely proportional to the infiltration capacity of the basin. The infiltration number of the Vishav basin is (4.95) very low. It indicates that runoff will be very low and the infiltration capacity very high.

Form factor ratio (R_f)

Basin shape can be indexed by simple dimensionless ratios of the basic measurements of area, perimeter and length [38]. The form factor value of the basin is low, 0.22 that represents elongated shape. Basin morphology has profound impact on basin hydrology. So, the Vishav drainage basin has flatter peaks of flow for longer duration that is easier to manage than of the circular basins [39].

Elongation ratio (R_e)

Elongation ratio (R_e) is a significant index in the analysis of basin shape which helps to give an idea about the hydrological character of a drainage basin. The influence of varied basin morphology on the hydrological response will be similar as that of the form factor discussed here [19,40]. The value of R_e in the study area was found to be 0.15 indicating relatively moderate relief of the terrain and elongated shape of the drainage basin.

Circularity ratio (R_c)

The circularity ratio (R_c) is used as a quantitative measure for visualizing the shape of the basin [41,19]. It is affected by the lithological characteristics of the basin. The ratio is more influenced by length, frequency (F_s), and gradient of streams of various orders rather than slope conditions and drainage pattern of the basin. The calculated R_c value, 0.52 indicates that the drainage basin is more or less elongated and is characterized by medium to low relief. Such drainage systems are partially controlled by the structural disturbances [42,40].

Relief morphometric parameters

The relief aspects of the drainage basins are significantly linked with the study of three dimensional features involving area, volume and altitude of vertical dimension of landforms to analyze different geo-hydrological characteristics. Some of the important relief parameters that are related to the study have been analyzed as shown in Table 5.

Basin relief (H)

Basin relief is an important factor in understanding the geomorphic processes and landform characteristics. The total basin relief of the Vishav drainage basin is 3,129 ms (=3.129 kms). The lowest basin relief of 203 ms is observed in the plains and highest of 1,726 ms in the mountainous areas as shown in Figure 6. It has been observed that a high degree of correlation exists among relief and drainage frequency and stream channel slopes.

Relief ratio (R_r)

Relief ratio (R_r) measures the overall steepness of a drainage basin and is an indicator of the intensity of erosional process operating on slope of the basin [21]. The relief ratio of the basin is 0.045 that indicates moderate relief and steep to moderate slope.

Dissection index (D_1)

Dissection index (D_1) is a parameter implies the degree of dissection or vertical erosion and expounds the stages of terrain or landscape development in any given physiographic region or basin [38,40]. On average, the values of D_1 vary between '0' (complete absence of vertical dissection/erosion and hence dominance of flat surface) and '1' (in exceptional cases, vertical cliffs, it may be at vertical escarpment of hill slope or at seashore). D_1 value of Vishav drainage basin is 0.66 that indicates the basin is significantly dissected as shown in Table 5. But, actually this is not the state of whole basin and is found in upper reaches or mountainous areas of the basin occupied by first order streams.

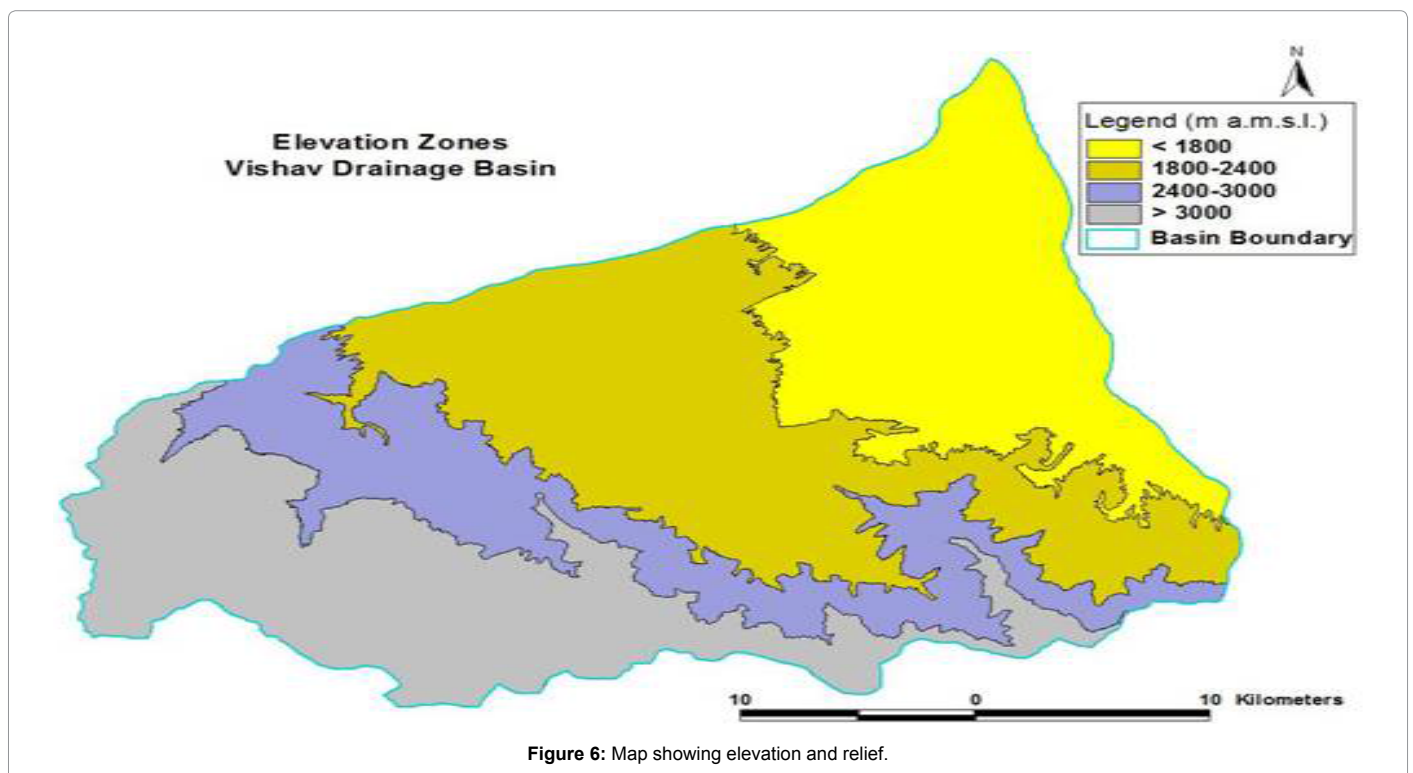


Figure 6: Map showing elevation and relief.

Channel gradient (C_g)

The altitude of the channel surface of the Vishav stream averagely falls at the rate of 28.69 m/km in the downstream direction. In the actual field the greatest fall is observed in the mountainous areas dominated by lower order streams and least in the plains occupied by higher orders that indicates that down cutting is more efficient in higher altitudes and stream widening with braided channels in the plains or lower altitudes. It means that the mean channel slope decreases with increasing order number. This testifies to the validity of Horton's Law of Stream slopes, which states a fairly definite relationship between the slope of the streams and their orders, which can be expressed by an inverse geometric series law.

Basin slope (S_b)

Basin Slope (S_b) enables the assessment of runoff generation, direction and volume [43]. The basin has a S_b of 0.045 that reflects the relatively mountainous and plateau nature of the terrain is shown in Table 5 and Figure 7. Approximately 50 percent of the main stream flows through the mountains and plateau and the relatively low values of S_b confirm the same. The general slope of the basin decreases towards north-northeast. Physiographically, the slope varies from one physiographic division to another with very steep slopes (30° - 45°) in the mountainous areas, moderate to steep slopes (10° - 30°) in the Karewas and gentle to moderate slope (2° - 10°) in the plains [12,40].

Identification of groundwater potential zones

Ground water is a resource of inestimable value that has been used by humans over centuries without paying any careful attention to manage it. Though it exists in almost every geological formation, but it exists more in certain aquifers such as sandstones, gravels, limestones, unstratified tills in a complex manner. The potential and quality of it in an area depends upon geological, geomorphological, biogeographical and socio-economic factors prevailing in the area. Quantitative morphometric analysis taken in association with geological, lithological, pedological and topographical setting are extremely helpful in investigating geo-hydrological state of an area and identifying and locating the ground water rich zones [44,45].

In the present area the people (80%) depend on ground water supplies for meeting their domestic and other needs. The area is studded with numerous springs of variable size and discharge and

it is pertinent to mention again here that Vishav stream has itself a ground water origin from Kounsarnag (high altitude lake) and Mahinag. The morphometric parameters as drainage density, stream frequency, drainage texture, infiltration number, length of overland flow, bifurcation ratio, basin relief, basin slope etc. are highly important and get along well with the rate of runoff, percolation, infiltration, overland flow, flooding stages and hence the ground water potential and availability. Drainage density, stream frequency, bifurcation ratio, infiltration number and basin slope are directly linked with rate of runoff as channel flow and overland flow and inversely related to rate of percolation and infiltration as absorption and downward movement of water. While the drainage texture is inversely related to the runoff rate and directly related to the infiltration capacity. The Vishav drainage basin has low to moderate values of drainage density, stream frequency, bifurcation ratio, infiltration number and high values of drainage texture. Taking the above discussion into nutshell consideration, study area has been largely divided into three ground water potential zones as shown in Figure 7 [45].

High groundwater potential zone

Generally, the area located below 2100 m altitude occupied mainly by the flood plain formed of sandy and silty clays and glacially originated gravel fills overlying the limestone conduits of Triassic period has high ground water potential [46]. This part of the basin is dominated by the 5th, 6th and 7th order streams and has lowest drainage density, very coarse texture, gentler slope and significant infiltration though delayed by locally existing clay shales. This area has maximum concentration of natural springs of variable size and discharge. About more than 60% of the population of the basin is concentrated in this area because of rich agricultural fields, leveled terrain, efficient surface and ground water availability. At least, among every 100 households, 70 are having hand pump tube wells/wells and about 5 electricity motored tube wells.

Moderate groundwater potential zone

Speaking largely, the area from 2100 to about 2800 m altitude has moderate groundwater capacity. This area is occupied mostly by the Karewas composed of fine silty clays with sand and gravel deposits. Karewas along with moraine debris overlie and obscure the Paleozoic Panjal traps, Jurassic formations and Upper Triassic compact limestones [16]. Since the silty clay deposits are selectively permeable to the water, this zone is relatively or moderately rich groundwater zone

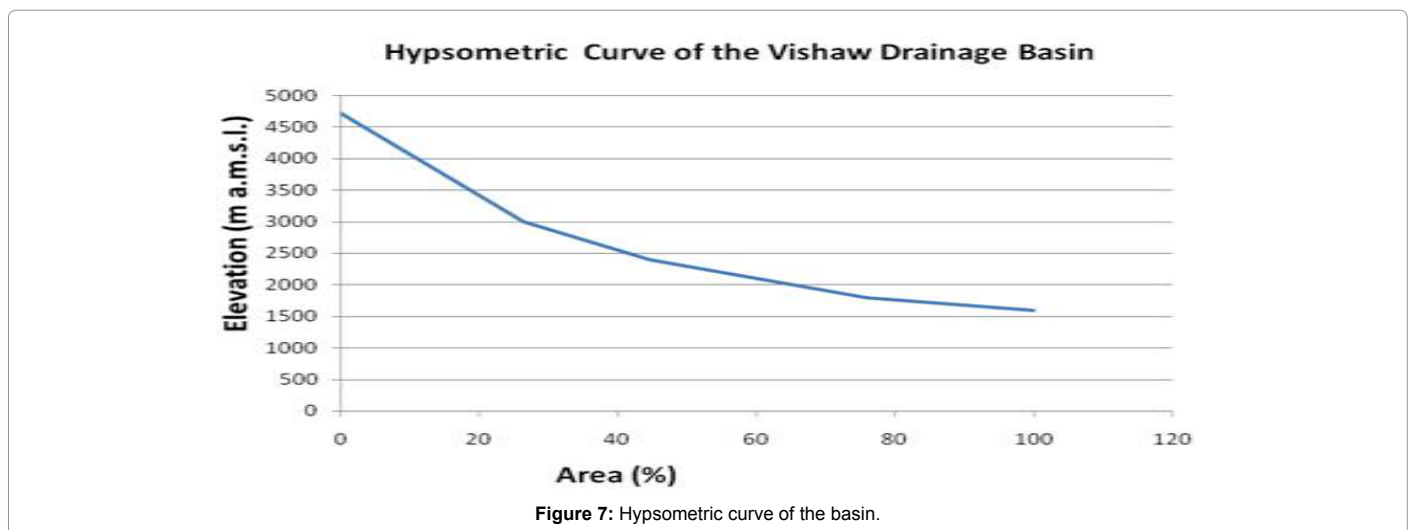


Figure 7: Hypsometric curve of the basin.

with local lenses found in gravel-sand deposits. This is also because of the following reasons that the area is mostly dominated by 3rd and 4th order streams and has relatively high drainage density, moderate slope, medium drainage texture and medium infiltration number. So, this area constitutes about 30-35% population and has comparatively lesser number of natural springs. In this area, least number of households has their own tube wells [47-50].

Low groundwater potential zone

This is the mountainous area above 2800 m altitude occupied by brown forest and mountain soils. Geologically, it is formed of Jurassic formations with or without overlying coarse Karewa sandy clays and glacio-fluviatile sediments along the banks of the streams. Gneissic granites, Agglomeratic slates, Panjal traps, and Upper Trias are overlaid by the Pleistocene and Recent deposits [16]. Because of the strong geological structure, having least primary permeability, steep slopes, high drainage density, low drainage texture and high infiltration number, this part of the basin has least groundwater potential and availability (Figure 8). However, groundwater rich lenses are promising in the valleys and high altitude depressions and deep Karewa gravel or sand beds. Some of the spring also exist in this area and that may be because of forest led infiltration and artesian pressure. A few settlements have come up here permanently over the centuries [50-52].

Besides, the conservation and management of groundwater resource is more important for the well being and over all development of the society. The mismanaged exploding population has created many problems. Due to increasing chemical inputs in the agricultural fields and horticultural land, high waste generation and unsafe disposal, open defecation, mismanaged latrines, and the like factors, the groundwater is becoming increasing polluted. The problem of pollution is greater in the plain area than the Karewas. Utilization of eco-friendly agricultural technology and practices, proper waste disposal, management of defecation sites, proper sewerage and sanitation systems, are some

key suggestions to improve the groundwater quality. The groundwater potential and availability in different areas of the basin and especially in the low lying areas can be increased by (i) stopping deforestation and overgrazing, (ii) following reforestation and afforestation practices in higher altitudes and (iii) trenching and furrowing in the area of 2nd and 3rd order streams to increase the percolation of runoff water through the primary as well as secondary permeability sites.

Since groundwater recharge depends upon a multiple number of factors, the identification of groundwater rich zones needs a multifaceted scientific investigation involving the lithological, structural, geological, geomorphological, biogeographical, socio-economic, climatic and the like factors. The aforesaid assessment is a preliminary touch to this aspect of hydrogeology and geomorphology. The geophysical techniques as resistivity, electromagnetics, seismicity, etc. and the remote sensing including the recently developed Light Amplification by Stimulated Emission of Radiation (LASER) techniques taken in collaboration with other factors are highly significant and best fit to investigate this complex and intricate phenomenon. Utilization of remote sensing, geographical information system and global positioning system technologies by different agencies and organizations as Geological Survey of India (GSI) and British Geological Survey (BGS) has produced promising results.

Conclusions

The drainage basin is often selected as a unit of morphometric investigation because of its topographic and hydrological unity. GIS softwares have resulted to be of immense utility in the quantitative analysis of the geo-morphometric aspects of the drainage basins. The study reveals that GIS based approach in evaluation of drainage morphometric parameters at river basin level is more appropriate than the conventional methods. GIS based approach facilitates analysis of different morphometric parameters and to explore the relationship among the drainage basin morphometry and topographical, geological, lithological, structural, biogeographical, pedological and hydrological

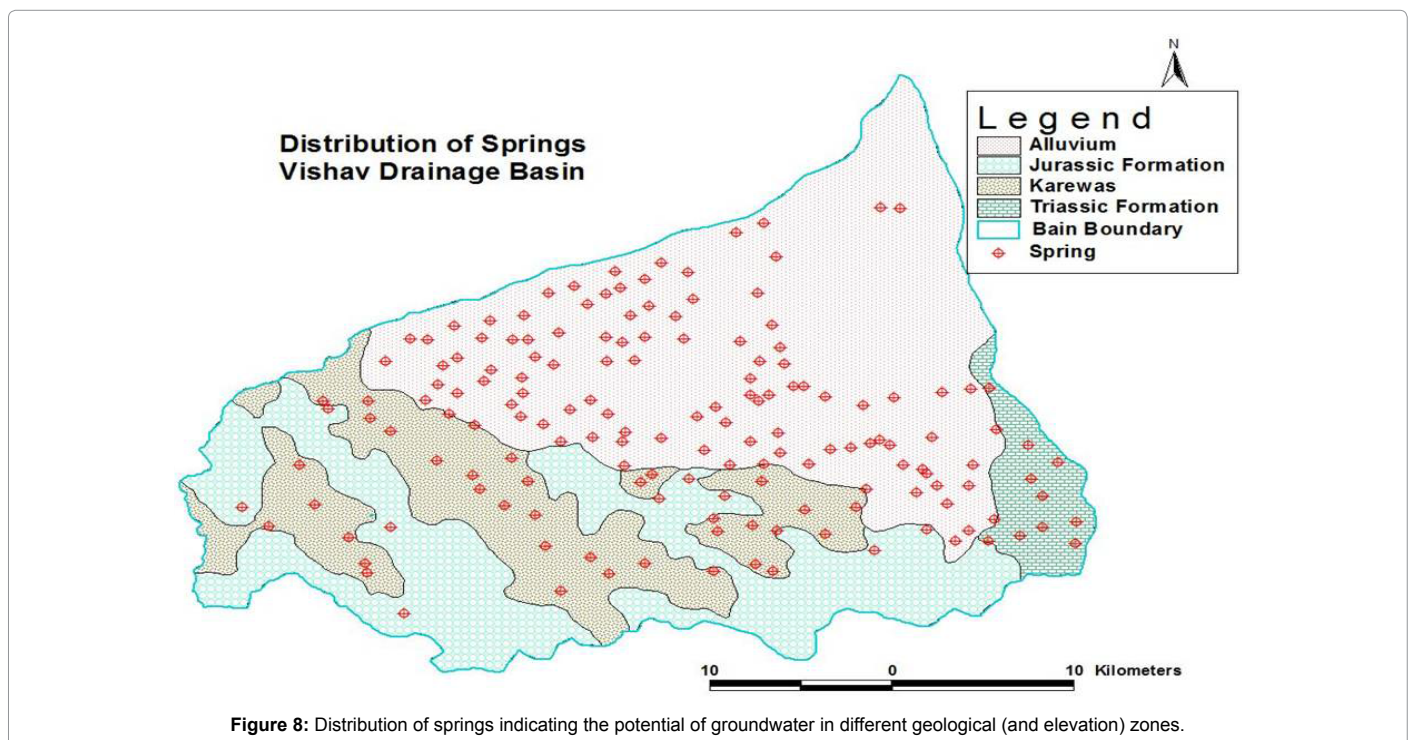


Figure 8: Distribution of springs indicating the potential of groundwater in different geological (and elevation) zones.

aspects. Vishav Basin is a seventh order basin. Lower order streams dominate the basin. The study reveals that the basin is passing through an early mature stage of the fluvial geomorphic cycle. The development of stream segments in the basin area is affected by rainfall, groundwater discharge and seasonally by meltover. The mean R_b indicates that the drainage pattern is not much influenced by geological structures. Horton's laws of stream numbers, stream lengths and basin slopes conform to the basin morphometric state. The D_d and F_s are the most useful criterion for the morphometric classification of drainage basins that certainly control the runoff pattern, sediment yield and other hydrological parameters of the drainage basin. The D_d of the basin reveals that the nature of subsurface strata is more or less permeable. This is a characteristic feature of coarse drainage as the density values are less than 5.0. The basin as a whole has course D_t and low I_f revealing the high infiltration capacity and low runoff rate. R_c , R_f and R_e show the elongated shape of the basin and point out the low and delayed discharge of runoff and medium relief of the terrain. It is noticed that stream segments of 1st, 2nd and 3rd order traverse parts of the high altitudinal zones characterized by steep slopes, while the 4th, 5th, 6th and 7th order stream segments occur in comparatively flat lands wherein maximum infiltration of precipitation occurs. Therefore, it is very unambiguous that the elongated basins having low to moderate D_d , low F_s , high D_p , low I_p and as the conditions are characterized by low runoff rates, high infiltration capacities and delayed flatter peaks of flow (in times of rainfall) that are easier to manage. It is also quite evident that the groundwater potential generally decreases from the plain areas to the mountainous areas via Karewas. Usually, the efficient groundwater potential zone are found in sandstone aquifers, followed by the limestones, gravels, silts, silty clays, and as this principle is locally applicable in the Vishav drainage basin. Hence from the study it is highly comprehensible that GIS technique is a competent tool in geomorphometric analysis for geo-hydrological studies of drainage basins. These studies are very useful for planning and management of drainage basin.

Acknowledgement

Authors express their thankfulness to Prof. T. A Kanth Senior Professor, Department of Geography and Regional Development and Prof. A. N. Kamili, Head Department of Environmental Science, University of Kashmir for providing necessary facilities to for carrying out the present study. We also acknowledge the constructive comments and suggestions provided by Dr. Arshid Jehangir, Assistant Professor Department of Environmental Science, and University of Kashmir.

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