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GIS Applications in Morphometric Analysis of Koshalya-Jhajhara Watershed in Northwestern India

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Abstract: The present paper deals with morphometric analysis of Koshalya-Jhajhara (K-J) watershed, tributaries of Ghaggar in northwestern India. The area forms a rugged topography having elevation range from 399 m to 1810 m MSL. Aster DEM and SOI toposheets have been used to calculate various parameters using Geographic Information System (GIS). Linear, areal and relief aspects for morphometric analysis were calculated using GIS. Total number of streams in the watershed are 991 out of which 543 are of 1st order, 259 are of 2nd order, 124 are of 3rd order, 58 are of 4th order and only 7 are of 5th order. The order of stream determines the chances of flood in the stream. Higher the stream order more the probabilities of flood. The present paper indicates that K-J watershed is of 5th order and less elongated in shape having lower peak flows of longer duration with dendritic pattern and having fine drainage texture. Bifurcation ratio varies from 3 to 5 which indicate that geological structures don't have dominant influence on drainage pattern. High slope is witnessed in NE part and low slope in SW part with very low gradient ratio. Variables like stream frequency and drainage density determines the volume of the water discharge and its speed of flow in the river channels. Higher the stream frequency and drainage density more will be the probability of floods. These variables also effects temporal variations in the speed at which the water flows in the stream when flood reaches its peak.

Keywords: GIS, Watershed, Morphometric Analysis, Koshalya-Jhajhara Watershed, Ghaggar, Northwestern India.

INTRODUCTION

Morphometric analysis of a basin provides important parameters about the basin characteristics. Drainage pattern of the basin gives information about topography and geological structure. Drainage density in the basin varies with relative age of various rock formations, differing geology, drainage area etc and enables comparison of basins and streams (Zaidi et al 2011). There are basically three important aspects used for doing morphometric analysis of a basin. These are linear aspects, areal aspects and relief aspects. Linear aspects give the information about one dimensional parameters like: stream order, stream number and bifurcation ratio. Areal aspects deals with two dimensional parameters like: drainage density, stream length, stream length ratio, drainage texture, stream frequency, circularity ratio and form factor. Relief aspects deals with three dimensional parameters like: relief, relief ratio, slope and gradient ratio.

The main objective of the present study is the morphometric analysis of K-J watershed with an aim to understand hydrologic characteristics of the watershed. The study of drainage pattern and morphometric analysis also helps to delineate the groundwater potential zones in a watershed. Various hydrologic phenomena can be correlated with physiographic characteristics of drainage basin like: size, slope, drainage density etc (Rastogi et al. 1976). The morphometric characteristics of various basins have been studied by many (Horton, 1945; Strahler, 1957; Babar and Kaplay, 1998; and Kaplay et al., 2004) and by using Remote sensing and GIS methods (Lattman and Parizek, 1964; Bedi and Bhan, 1978; Karanath and Babu, 1978; Raju et al, 1985; Palanivel et al, 1996; Srinivasa Rao et al, 1997; Toleti et al., 2000, 2003; Babar 2001, 2002, 2005; Sreedevi et al., 2009; Babar et al, 2010; Muley et al., 2010 a and b; Babar and Shah, 2011; Vimal and Dubey, 2012; Jadhav et al., 2014).

STUDY AREA

The Koshalya-Jhajhara watershed covers an area of about 134 km^2 in districts Solan (Himachal Pradesh) and Panchkula (Haryana). It is covered by SOI Toposheet No. H43K13 and H43L01 and bounded by 31°0' to 30°45' north latitudes and 76°45' to 77°15' east longitudes. The area is

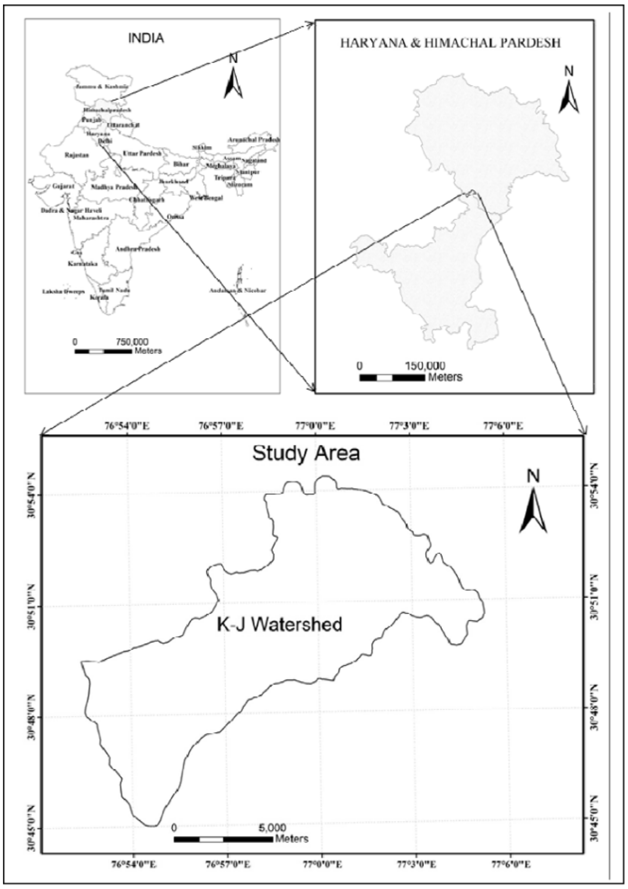

Fig.1. Location map of study area.

approachable by road and railways from both of state capitals. The maximum and minimum elevations in the area are 399 m and 1810 m from mean sea level (MSL) respectively. Geologically, the area falls in lesser Himalayas and also extends up to Siwalik Hills on south-west side. Many thrusts are present in the area like Jhajhara thrust, Koshalya Thrust, Pinjore garden fault (PGF) (Malik et al. 2005, Singh and Tandon, 2010) and the main thrust which passes through the area is Himalayan frontal thrust (HFT) that falls between Siwaliks and Lesser Himalaya (Singh and Tandon, 2010).

DATA BASE AND METHODOLOGY

In present study, SOI Toposheet Nos. H43K13 and H43L01 on scale 1:50,000 have been used for preparation of drainage map of the area. ASTER data (30m) have been downloaded from National Remote Sensing Centre (NRSC), Govt. of India website. It has been used to calculate the relief aspects of the area.

Watershed boundary was demarcated from SOI toposheet on the basis of catchment area characteristics of Koshalya and Jhajhara river. Various drains were digitized

Table 1. Formulae for calculation of various watershed parameters

Parameters	Formulae	References
Linear Aspects		
Stream Order (U)	The smallest permanent streams are called "first order". Two first order streams join to form a larger, second order stream; two second order streams join to form a third order, and so on. Smaller streams entering a higher-ordered stream do not change its order number.	Strahler (1964)
Stream Length (Lu)	The average length of streams of each of the different orders in a basin tends tends closely to drainage approximate a direct geometric ratio.	Horton (1945)
Stream Length Ratio (RL)	RL= Lu/(Lu-1)	
Bifurcation Ratio (Rb)	Rb = Nu/(Nu+1)	Horton (1932)
Areal Aspects		
Stream Frequency (Fs)	Fs = ΣNu/A	Horton (1945)
Drainage Density (Dd)	Dd = Lu/A	Horton (1945)
Drainage Texture (T)	T = Dd x Fs	Smith (1950)
Elongation ratio (Re)	Re = 1.128"A/L	Schumm (1956)
Circularity ratio (Rc)	Rc = 4"A/P2	Strahler (1964)
Form factor (Ff)	Ff = A/L2	Horton (1945)
Relief Aspects		
Relief (R)	R = H – h	Hadley and Schumm (1961)
Relief Ratio (Rr)	Rr = R/L	Schumm (1963)
Slope (Sb)	Sb = (H-h)/L'	Mesa (2006)
Gradient Ratio (Gr)	Gr = (H-h)/L	

by using SOI Toposheet. The K-J watershed was further sub-divided into 19 sub-basins on the basis of catchment area of different valleys and drainage pattern of all basins. Length and area of streams in the watershed were calculated by using Arc GIS 9.2. Horton (1945) technique was used for demarcating the stream order in the watershed. Linear and Areal aspects were calculated using standard formulae explained in Table 1 [Horton (1932, 1945), Strahler (1964), Smith (1950), Schumm (1956)]. Relief aspects were calculated using digital elevation model (DEM) from Aster (30 m) and formulae explained in Table 1 [Hadley and Schumm (1961), Schumm (1963), Mesa (2006)].

RESULTS AND DISCUSSION

The parameters determining nature and characteristic of the watershed have been calculated. These are described in detail here under:

Linear Aspects

The drainage network in watershed was analysed to

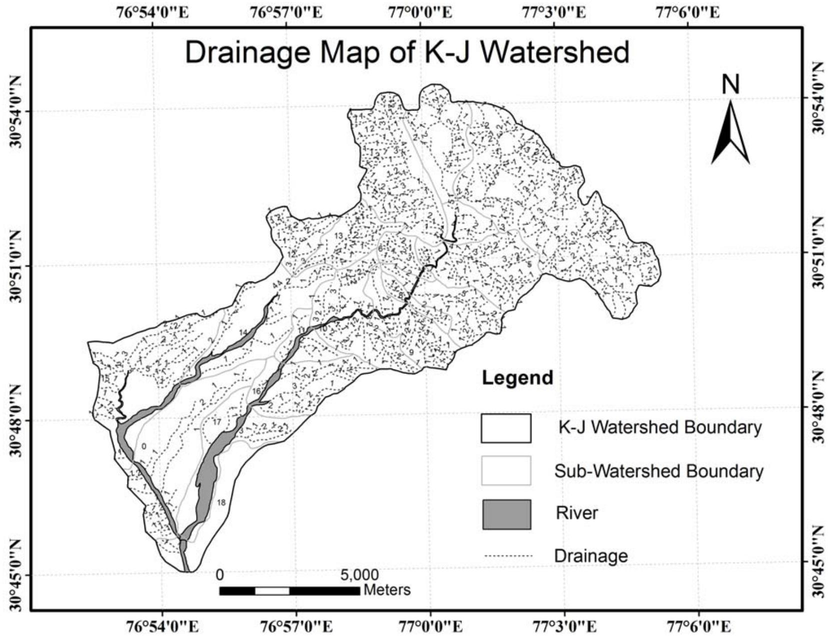

Fig.2. Drainage map of Koshalya-Jhajhara Watershed.

calculate various linear parameters like: stream order, stream number, stream length and bifurcation ratio for all the 19 sub-watersheds.

Stream Order (U)

There are four different techniques for ordering a stream: Gravelius (1914), Horton (1945) and Strahler (1957, 1964). The Koshalya-Jhajhara watershed has been ranked according to Strahler (1964) which is slightly modified by Horton's system. According to this system the junction of two 1st order channels produces channel segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When two channels of different order join then the higher order is maintained. Out of 19 Sub-watersheds only one sub-basin (3) is of fifth order, four sub-basins (1, 5, 14 and 15) are of fourth order, ten sub-basins (2, 4, 6, 7, 9, 10, 12, 13, 16 and 17) are of third order and four sub-basins (0, 8, 11 and 18) are of second order.

Stream Number (Nu)

The total no. of streams present in each order is stream number. It is found that as the stream order increases the stream number decreases in all sub basins. The first order streams are maximum in the Himalaya and minimum in alluvial plain. There are 543 streams of first order, 259 streams of second order, 124 streams of third order, 58 streams of fourth order, and 5 streams of fifth order.

Stream Length (Lu) and Average Stream Length (Lu^1)

The total length of individual stream segments of each order is the stream length of that order. The stream length in each order increases exponentially with increasing stream order. Total length of first order streams is 278.44 km, second order streams having length of 79.1 km, third order streams having length of 38.45 km, fourth order streams having length of 13.54 km and fifth order streams having length of about 2 km in Koshalya-Jhajhara watershed. Mean stream length is the ratio of total length of a particular ordered stream to total no of streams of same order and is given in Table 2.

Stream Length Ratio (RL)

The stream length ratio is the ratio of mean or average length of segment of order 'u' to the mean or average length of order 'u-1'. During the study it is found that the whole watershed has the stream length ratio in the range of 0.6 to 1.22, while the sub-basins have the ratio in the range of 0.23 to 2.75 (Table 2).

Bifurcation Ratio (Rb)

Bifurcation ratio is the ratio of number of streams of order (u) to the number of streams of higher order (u+1) (Strahler 1964). Chow (1964) stated that the bifurcation ratio values lies between 3 to 5 for those watersheds where geological structures do not have more influence on the drainage pattern. Mean bifurcation ratio of Koshalya-Jhajhara watershed is 3.65. But in the sub-basins, the value of bifurcation ratio lies between 0.71 and 8.00 (Table 3). The higher Rb for sub-basins is the result of large variation in frequencies between successive orders and indicates mature topography

Areal Aspects

The areal aspects are two dimensional properties of a basin. It is possible to delineate the area of the basin which contributes water to each stream segment. Total area of the basin is 134.93 km^2. The aerial aspects of the drainage basin such as drainage density (Dd), stream frequency (Fs), drainage texture (T), elongation ratio (Re), circularity ratio (Rc) and form factor ratio (Rf) were calculated (Table 4).

Drainage Density (D_d)

The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the

Table 2. Stream Analysis of Koshalya-Jhajhara Watershed

Sub Water sheds	Area (km^2)	Length (km)	No. of Streams of each Order (Nu)						Stream Length of each Order (Lu) in km					
			1	2	3	4	5	Total	1	2	3	4	5	Total
0	11.72	5.31	18	5	0	0	0	23	12.54	6.35				18.89
1	10.71	5.04	69	29	16	17	0	131	29.46	8.07	3.8	4.47		45.80
2	6.45	3.78	25	10	14	0	0	49	12.42	3.48	4.02			19.92
3	24.83	8.13	135	68	30	31	5	269	68.88	16.81	8.26	6.31	1.4	101.69
4	2.10	2.00	7	2	2	0	2	13	3.46	1.36			0.5	5.39
5	7.80	4.21	43	21	7	7	0	78	20.33	4.74	2.05	1.71		28.83
6	1.93	1.91	13	7	2	0	0	22	5.79	2.06	0.91			8.76
7	4.93	3.24	23	10	10	0	0	43	10.52	2.18	3.24			15.94
8	1.32	1.53	7	4	0	0	0	11	4.03	1.57				5.60
9	5.10	3.31	27	10	9	0	0	46	13.13	3.78	2.01			18.92
10	7.66	4.17	42	24	6	0	0	72	19.02	6.01	2			27.03
11	2.50	2.21	6	1	0	0	0	7	4.68	0.18				4.86
12	3.21	2.54	17	10	6	0	0	33	8.57	2.37	1.85			12.79
13	4.16	2.95	30	15	12	0	0	57	13.03	3.02	3.26			19.31
14	9.53	4.72	16	7	2	2	0	27	11.33	4.04	1.35	0.88		17.60
15	12.83	5.59	31	16	5	1	0	53	22.8	5.53	3.43	0.17		31.93
16	6.41	3.77	23	16	2	0	0	41	10.64	5.27	1.81			17.72
17	7.39	4.08	9	4	1	0	0	14	5.98	2.28	0.46			8.72
18	4.32	3.01	2	0	0	0	0	2	1.83					1.83
K-J	**134.93**	**21.27**	**543**	**259**	**124**	**58**	**7**	**991**	**278.4**	**79.1**	**38.45**	**13.54**	**2**	**411.53**

average length of stream channel for the whole basin. High drainage density is the resultant of impermeable sub-surface material, sparse vegetation and mountainous relief. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture (Strahaler, 1964). The drainage density (D_d) of study area is 3.05 km^{-1} while 19 sub-basins with a range of 0.42 to 4.64 km^{-1} as shown in Table 4 indicate higher drainage densities. It signifies that K-J watershed is predominated by impermeable surface materials.

Table 3. Bifurcation Ratio of Koshalya-Jhajhara Watershed

Sub Water sheds	No. of Streams of each Order (Nu)						Linear Aspect Bifurcation Ratio (Rb)			
	1	2	3	4	5	Total	Nu/ (Nu+1)	Nu/ (Nu+1)	Nu/ (Nu+1)	Nu/ (Nu+1)
0	18	5	0	0	0	23	3.60			
1	69	29	16	17	0	131	2.38	1.81	0.94	
2	25	10	14	0	0	49	2.50	0.71		
3	135	68	30	31	5	269	1.99	2.27	0.97	6.20
4	7	2	2	0	2	13	3.50	1.00		
5	43	21	7	7	0	78	2.05	3.00	1.00	
6	13	7	2	0	0	22	1.86	3.50		
7	23	10	10	0	0	43	2.30	1.00		
8	7	4	0	0	0	11	1.75			
9	27	10	9	0	0	46	2.70	1.11		
10	42	24	6	0	0	72	1.75	4.00		
11	6	1	0	0	0	7	6.00			
12	17	10	6	0	0	33	1.70	1.67		
13	30	15	12	0	0	57	2.00	1.25		
14	16	7	2	2	0	27	2.29	3.50	1.00	
15	31	16	5	1	0	53	1.94	3.20	5.00	
16	23	16	2	0	0	41	1.44	8.00		
17	9	4	1	0	0	14	2.25	4.00		
18	2	0	0	0	0	2				
K-J	543	259	124	58	7	991	2.10	2.09	2.14	8.29

Stream Frequency (F_s)

Stream frequency is directly related to the lithological characteristics. The number of stream segments per unit area is termed as stream frequency or channel frequency or Drainage Frequency (Fs) (Horton 1945). Total stream frequency of study area is 7.34 km^{-2}. Range of stream frequency for all sub-basins is 0.46-13.71 km^{-2} (Table 4).

Drainage Texture (T)

Drainage texture may be defined as the total number of stream segments of all order in a basin per perimeter of the basin. It is important to understand geomorphology which means the relative spacing of drainage lines. Drainage texture depends on the underlying lithology, infiltration capacity and relief aspect of the terrain and on natural factors such as climate, rainfall, vegetation, rock and soil type, relief and stage of development. Smith (1950) has classified drainage texture into 5 different classes i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The drainage texture of whole K-J watershed is very fine.

Elongation Ratio (R_e)

Elongation ratio (Re) may be defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The value of R_e varies from 0 (in highly elongated shape) to unity i.e. 1.0 (in circular shape).

Elongation ratio	Shape of basin
<0.7	Elongated
0.7-0.8	Less elongated
0.8-0.9	Oval
>0.9	Circular

Table 4. Areal Aspects of Koshalya-Jhajhara Watershed

Sub Water sheds	Drainage Density (Dd) 1	2	3	4	5	SW	Stream Frequency (Fs)	Drainage Texture (T)	Circularity Ratio (Rc)	Elongation Ratio (R_e)	Form Factor (Ff)
0	1.07	0.54	0.00	0.00	0.00	1.61	1.96	3.16	0.42	0.73	0.42
1	2.75	0.75	0.35	0.42	0.00	4.27	12.23	52.27	0.55	0.73	0.42
2	1.92	0.54	0.62	0.00	0.00	3.09	7.59	23.45	0.60	0.76	0.45
3	2.77	0.68	0.33	0.25	0.06	4.09	10.83	44.35	0.45	0.69	0.38
4	1.65	0.65	0.00	0.00	0.27	2.56	6.18	15.85	0.72	0.82	0.53
5	2.61	0.61	0.26	0.22	0.00	3.70	10.00	36.98	0.61	0.75	0.44
6	2.99	1.06	0.47	0.00	0.00	4.53	11.37	51.50	0.58	0.82	0.53
7	2.13	0.44	0.66	0.00	0.00	3.23	8.72	28.16	0.41	0.77	0.47
8	3.05	1.19	0.00	0.00	0.00	4.24	8.33	35.32	0.32	0.85	0.56
9	2.57	0.74	0.39	0.00	0.00	3.71	9.02	33.44	0.44	0.77	0.47
10	2.48	0.78	0.26	0.00	0.00	3.53	9.40	33.15	0.43	0.75	0.44
11	1.87	0.07	0.00	0.00	0.00	1.94	2.80	5.43	0.47	0.81	0.51
12	2.67	0.74	0.58	0.00	0.00	3.99	10.28	41.00	0.57	0.80	0.50
13	3.13	0.73	0.78	0.00	0.00	4.64	13.71	63.65	0.42	0.78	0.48
14	1.19	0.42	0.14	0.09	0.00	1.85	2.83	5.23	0.43	0.74	0.43
15	1.78	0.43	0.27	0.01	0.00	2.49	4.13	10.29	0.52	0.72	0.41
16	1.66	0.82	0.28	0.00	0.00	2.77	6.40	17.70	0.57	0.76	0.45
17	0.81	0.31	0.06	0.00	0.00	1.18	1.89	2.23	0.29	0.75	0.44
18	0.42	0.00	0.00	0.00	0.00	0.42	0.46	0.20	0.23	0.78	0.48
K-J	**2.06**	**0.59**	**0.28**	**0.10**	**0.01**	**3.05**	**7.34**	**22.40**	**0.03**	**0.62**	**0.30**

Thus, higher the value of elongation ratio, more circular will be the shape of the basin and vice-versa. Values close to 1.0 are typical of regions of very low relief, whereas the values of 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964). Elongation ratio for the whole basin is 0.62 but for the 19 sub-basins it ranges from 0.69 to 0.85 as shown in Table 4. It shows that K-J watershed is less elongated in shape.

Circularity Ratio (R_c)

The circularity ratio is a similar measure as elongation ratio, originally defined by Miller (1953), as the ratio of the area of the basin to the area of the circle having same circumference as the basin perimeter. The value of circularity ratio varies from 0 (in line) to 1 (in a circle). Circulatory ratio is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. The R_c of the whole basin is 0.03, while those of the 19 sub-basins lies in the range from 0.23 to 0.72 (see Table 4). It is a significant ratio which indicates the dendritic stage of a basin.

Form Factor (F_f)

Form factor is the numerical index (Horton, 1932) commonly used to represent different basin shapes. The value of form factor is between 0.1-0.8. Smaller the value of form factor, more elongated will be the basin. The basins with high form factors 0.8, have high peak flows of shorter duration, whereas, elongated drainage basin with low form factors have lower peak flow of longer duration. The alluvial basins have low form factor value indicating elongated nature of the basins. The F_f value for K-J Watershed is 0.3, indicating elongated basin with lower peak flows of longer duration. Form factor of the 19 sub-basins ranges from 0.38 – 0.56 (Table 4) which indicates that all sub-basins are elongated with average peak flow of longer duration.

Relief Aspects

Linear and areal features have been considered as the two dimensional aspects on a plan. The third dimension introduces the concept of relief.

Basin Relief

Basin relief is the elevation difference of the highest and lowest point of the valley floor. Basin relief plays a significant role in landforms development, drainage development, surface and sub-surface water flow, permeability and erosional properties of the terrain. The relative relief of the basin is 1410 m MSL. Highest and lowest values of relative relief of the basin are 970 m and 180 m MSL respectively and values of all 19 sub-basins are given in Table 5.

Relief Ratio

It is the ratio of basin relief to basin length. While high values are characteristic of hilly regions low values are characteristic of pediplains and valley.

$$\text{Relative Relief} = \frac{\text{Maximum basin relief (H)}}{\text{Maximum basin length (Lb)}}$$

This is a dimensionless height-length ratio and allows

Table 5. Relief aspects of Koshalya-Jhajhara Watershed

Sub Water sheds	Relief Aspect H	h	Relief (R)	Length (km)	Relief Ratio (R_r)
0	0.67	0.41	0.26	5.31	0.05
1	1.81	0.90	0.91	5.04	0.18
2	1.67	0.96	0.71	3.78	0.19
3	1.81	0.97	0.84	8.13	0.10
4	1.40	0.93	0.47	2.00	0.24
5	1.62	0.83	0.79	4.21	0.19
6	1.60	0.82	0.78	1.91	0.41
7	1.55	0.79	0.76	3.24	0.23
8	1.49	0.77	0.72	1.53	0.47
9	1.62	0.69	0.93	3.31	0.28
10	1.57	0.60	0.97	4.17	0.23
11	1.11	0.56	0.55	2.21	0.25
12	1.49	0.75	0.74	2.54	0.29
13	1.71	0.76	0.95	2.95	0.32
14	1.11	0.54	0.57	4.72	0.12
15	0.64	0.46	0.18	5.59	0.03
16	1.27	0.53	0.74	3.77	0.20
17	0.71	0.42	0.29	4.08	0.07
18	0.63	0.40	0.23	3.01	0.08
K-J	**1.81**	**0.40**	**1.41**	**21.27**	**0.07**

Table 6. Gradient Ratio of Koshalya-Jhajhara Watershed

Sub Water sheds	Elevation at Source 'a'	mouth 'b'	Fall in height (a-b) (m)	Fall in height (a-b) (km)	Length (L) (km)	Gradient ratio (a-b/L)
0	637	431	206	0.206	5.31	0.038795
1	1704	999	705	0.705	5.04	0.139881
2	1622	998	624	0.624	3.78	0.165079
3	1500	980	520	0.52	8.13	0.063961
4	1358	992	366	0.366	2.00	0.183
5	1458	948	510	0.51	4.21	0.12114
6	1530	835	695	0.695	1.91	0.363874
7	1470	808	662	0.662	3.24	0.204321
8	1434	790	644	0.644	1.53	0.420915
9	1602	798	804	0.804	3.31	0.2429
10	1509	685	824	0.824	4.17	0.197602
11	970	580	390	0.39	2.21	0.176471
12	1460	760	700	0.7	2.54	0.275591
13	1625	775	850	0.85	2.95	0.288136
14	1096	700	396	0.396	4.72	0.083898
15	637	500	137	0.137	5.59	0.024508
16	1270	545	725	0.725	3.77	0.192308
17	654	542	112	0.112	4.08	0.027451
18	504	418	86	0.086	3.01	0.028571
K-J	**1570**	**440**	**1130**	**1.130**	**21.270**	**0.053**

comparison of the relative relief of any basin regardless of difference in scale or topography. Relief ratio is equal to the right angled triangle and is identical with the tangent of the angle of slope of the hypotenuse with respect to horizontal (Strahler, 1964). Thus the overall steepness of a drainage basin is an indicator of intensity of erosion processes operating on the slope of the basin. The relief ratio of the K-J Basin is 0.07, while those of the 19 sub-basins are shown in Table 5.

Slope

Slope analysis is an important parameter in geomorphic studies. The slope elements, in turn are controlled by the climatomorphogenic processes in the area having the rock of varying resistance. An understanding of slope distribution is essential as a slope map provides data for planning, settlement, mechanization of agriculture, deforestation, planning of engineering structures, morph conservation practices etc. (Sreedevi et al. 2005). In the present study, Aster DEM was used to prepare slope map, DEM and aspect map. Slope grid is identified as the maximum rate of change in value from each cell to its neighbour's, using methodology described in Burrough (1986). Slope varies from 0° to 56.58° with a mean slope of 16.86° and slope standard deviation 11.29° of K-J watershed. High slope is witnessed in the NE part and low slope in SW part of K-J watershed. The slope map of the area is presented in Fig.4.

Gradient Ratio

Gradient ratio is the total drop in elevation from the

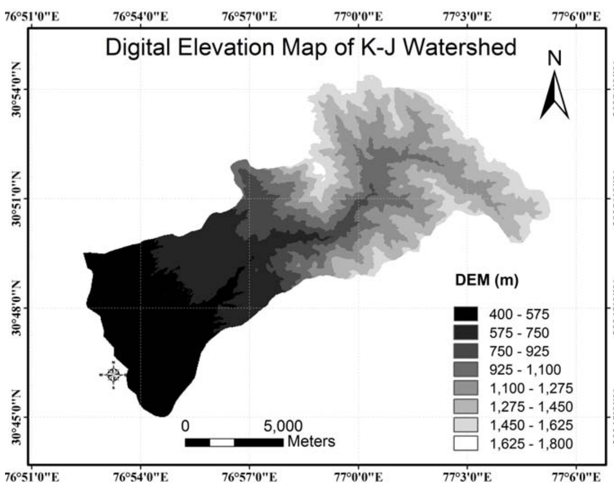

Fig.3. Digital Elevation map of Koshalya-Jhajhara Watershed.

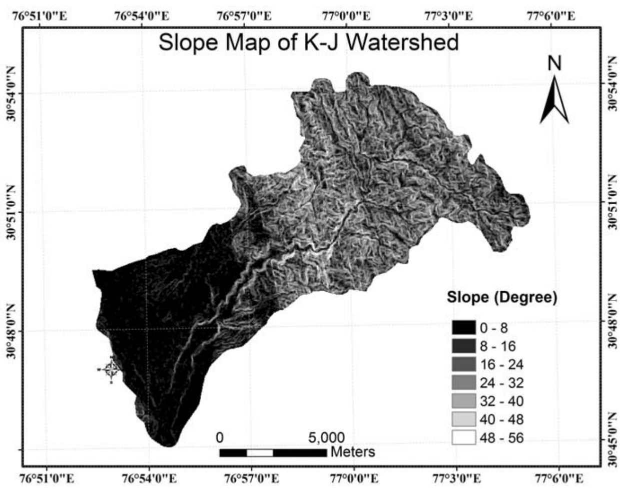

Fig.4. Slope map of Koshalya-Jhajhara Watershed.

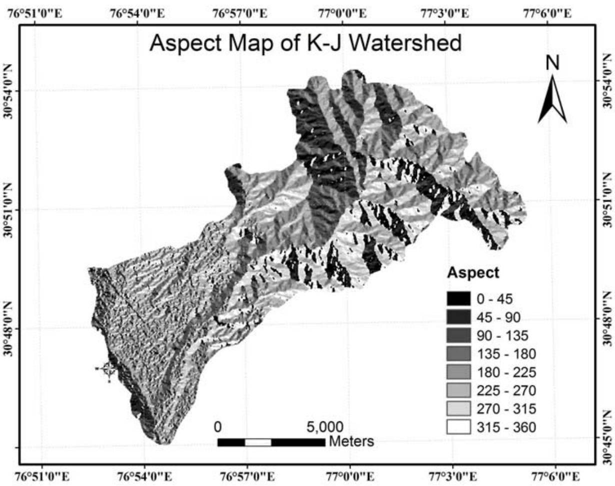

Fig.5. Aspect map of Koshalya-Jhajhara Watershed.

source to the mouth of the trunk channels in each drainage basin. In the present study, gradient ratio of K-J watershed is 0.053 which is very low. It indicates that a more nearly level stream bed and sluggishly moving water that may be able to carry only small amounts of very fine sediments. The maximum and minimum gradient ratios of 19 sub-basins are 0.421 & 0.024 (Table 6).

CONCLUSIONS

The morphometric analysis of the drainage network of the Koshalya-Jhajhara watershed exhibits dendritic pattern and signifies the homogeneity in texture and lack of structural control. Based on the drainage orders, the Koshalya-Jhajhara watershed has been classified as fifth order basin. The drainage density (Dd) of study area is 3.05 Km^{-1} which indicates impermeable surface materials. The drainage texture of watershed falls under the category of very fine drainage texture (>8). Elongation and circularity ratios for the basin are 0.62 and 0.03 which shows that K-J Watershed is less elongated with dendritic stage, having steep slope The characteristics of the water network, including the discharge density and the stream bifurcation ratio, have directly contributed in increasing the water discharge of the valley. These studies are very useful for rainwater harvesting and watershed management plans. 1^{st} and 2^{nd} order streams are not useful for constructing check dams in the study area because these streams are situated on hilly terrains and volume of water discharge through river tributaries in the basin is more due to presence of large number of streams of lower order in K-J watershed. The study successfully demonstrates that the GIS is very useful for morphometric analysis of the basin.

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