SOME ASPECTS OF MORPHOMETRIC ANALYSIS OF KUNHAR RIVER WATERSHED

by

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Summary. *Kunhar is one of the main tributaries of river Jhelum and originates at a height of about* 14,000 *feet. The catchment known as Kaghan valley, has an area of* 1011 *square miles, of which,* 988 *square miles lie in Mansehra and Abbottabad tehsils of Hazara district and the remaining in Azad Kashmir. The total length of the valley is* 80 *aerial miles and width varies from* 10 *to* 30 *aerial miles. The catchment is predominently mountanous with steep and precipitous slopes.*

In order to provide numerical data of practical value to the hydrologists, the present trend is to describe the drainage basins and channel net works by means of quantitative methods instead of purely qualitative and deductive studies. The paper describes some aspects of morphometric analysis of Kunhar river watershed including stream order, bifurcation ratio,drainage density, constant of channel maintenance, stream frequency, shape, slope and elevation.

Introduction. The description of drainage basins and channel net works has been transformed from a purely qualitative and deductive study to a rigorous quantitative science capable of providing hydrologists with numerical data of practical value. Work in this direction has been done by several scientists including Horton, Langbein, Strahler, Melton, and Miller. According to Strahler (4) systematic description of the geometry of a drainage basin and its stream-channel system requires measurement of linear aspects of the drainage network, aerial aspects of the drainage basin, and relief (gradient) aspects of channel network and contributing ground slopes. Whereas the first two categories of measurements are plani-matric,the third category treats the vertical in equalities of the drainage-basin form.

The objective of the paper is to describe Kunhar river watershed quantitatively with a view to providing the watershed planners, particularly the hydrologists, a sound numerical basis of practical importance.

Described hereunder are only some aspects of the morphometric analysis of Kunhar Watershed.

Area and situation. Kunhar river catchment, known as Kaghan valley, covers an area of about 1011 square miles. Of this, 988 square miles lie in Mansehra and Abbottabad tehsils of Hazara district and the remaining 23 square miles are situated in the territory of Azad Kashmir. The area lies between 34°-17′ and 35°-10′ N latitudes and 73°-28' E and 74°-7' E longitudes. The total length of the valley is about 80 aerial miles but the road distance from Muzaffarabad in Azad Kashmir to Babusar pass in the north is about 125 miles. The width of the valley varies from 10 to 30 aerial miles. The valley is bounded on the north-west by Gilgit agency of the Indus watershed; on the east by the watershed of Neelam valley; on the south by the direct drainage of Jhelum river and, on the south west by the watershed of Siran and Daur rivers.

Size. Chow (1) says that"the factors affecting runoff generally tend to cause most large drainage areas to behave differently from most small drainage areas on the basis of hydrologic behaviour. Consequently, drainage basin may be classified as large and small, not on the basis of the size alone, but on the effects of certain dominating factors. Frequently two basins of nearly the same size may behave entirely differently in runoff phenomena. One drainage basin may show prominent channel storage effects, like most large basins, while the other may manifest strong influence of the land use, like most small basins. A distinct characteristic of small basins is that the effect of overland flow rather than the effect of channel flow is a dominating factor affecting the peak run off. Also small basins are very sensitive both to high intensity rainfalls of short duration and to land use. On large basins, the effect of channel storage is so pronounced that sensitivities are greatly suppressed. Therefore, a small drainge basin may be defined as one that is so small that its sensitivity to high intensity rainfalls of short durations and to land use is not suppressed by the channel characteristics. According to this definition, the size of a small basin may be from a few acres to 1,000 acres, or even upto 100 square miles. The upper limit depends on the condition at which the above mentioned sensitivity becomes minimized due to the over-whelming channel-storage effect".

The total area of Kunhar river watershed is 1011.12 square miles. The basin was subdivided into nineteen sections and the area of the individual section has been given in table under drainage density. Considering the total area of the catchment and other characteristics, it can safely be categorized as a large drainage basin.

Aspect. Slope affects the rainfall-runoff relationship principally because of the speeding of the volume of overland flow, thereby shortening the period of infiltration and producing a greater concentration of surface runoff in stream channels. However, there is an other factor which has its secondary influence on these parameters and that is aspect. It affects the transpiration and evaporation because of the unequal amounts of heat received from the sun on different aspects. It also affects the time of melting of snow. On southern and western aspects each successive snow fall would melt and either infiltrate or produce runoff. On northern and eastern aspects the snow accumulates until late spring.

The general aspect of Kunhar river watershed is eastern on the right bank and western on the left bank and has the corresponding qualities as described above.

Stream orders. Designation of the stream order is the first step in a drainage basin analysis as introduced by Horton (2) and slightly modified by Strahler (4). In a drainage basin, where all intermittent and permanent channels are available, the smallest fingertip tributaries are designated as order 1. Where two first-order channels join, a channel segment of order 2 is formed; where two of order 2 join, a segment of order 3 is formed, and so forth. The trunk stream through which all discharge of water and sediment passes is, therefore, the stream segment of the highest order.

According to Strahler (4) "the usefulness of the stream order system depends on the premise that, on the average, if a sufficiently large sample is treated, order number is directly proportional to size of the contributing watershed, to channel dimensions, and to stream discharge at that place in that system. Because order number is dimensionless, two drainage net works differing greatly in linear scale can be compared with respect to corresponding points in their geometry through use of order number".

The stream order numbers were assigned to all the major tributaries of Kunhar river according to the principle given above and are recorded in Table 1.

Table : 1—Tributaries of Kunhar River and Their Stream orders.

Serial No.	Tributary	ORDER NUMBER 1	2	3	4	5	6	7
1.	Gittidas Nala ..	377	91	23	5	1		
2.	Purbi Nar ..	260	57	9	1			
3.	Aputha Nar ..	151	34	4	1			
4.	Saadullah Nar ..	120	25	4	1			
5.	Jalkhad Nar ..	270	47	8	2	1		
6.	Burawai Katha ..	42	13	3	1			
7.	Wettar Katha ..	259	45	10	1			
8.	Jora Nala ..	562	122	27	2	1		
9.	Baz Katha ..	106	24	3	1			
10.	Dunga Katha ..	42	11	1				
11.	Dabukanda Nar ..	152	37	6	1			

Serial No.	Tributary	ORDER NUMBER 1	2	3	4	5	6	7
12.	Dadar Nar ..	475	116	26	5	1		
13.	Shanak Katha ..	136	29	2	1			
14.	Sapat Katha ..	682	151	23	7	2	1	
15.	Kinarida Katha ..	162	34	6	1			
16.	Barjalida Nar ..	143	37	10	4	1		
17.	Saiful Maluk Nala ..	263	67	16	3	1		
18.	Kapanda Katha ..	33	11	1				
19.	Gorianda Katha ..	31	7	1				
20·	Dana and Battal Katha..	106	20	5	1			
21.	Derseri Katha ..	166	21	13	5	1		
22.	Chitta Katha ..	56	12	1				
23.	Bhimbal Katha ..	705	129	26	5	2	1	
24.	Jamal Pati ..	35	9	3	1			
25.	Gori Katha ..	75	18	4	1			
26.	Chambar Katha ..	38	6	1				
27.	Bhakrian ..	66	15	3	1			
28.	Parla gran ..	75	17	4	1			
29.	Agla Gran ..	45	11	3	1			
30.	Bagner Katha ..	454	111	28	7	1		
31.	Manur Nala ..	823	189	37	8	2	1	
32.	Natsri Katha ..	280	66	11	2	1		
33.	Chushal Katha ..	113	24	6	1			
34.	Bhunja Katha ..	276	53	16	2	1		
35.	Phagna Katha ..	134	34	8	2	1		
36.	Bhorian Katha ..	761	170	30	7	3	1	
37.	Jalora Katha ..	479	102	24	1			
38.	Ban Katha ..	230	92	15	1			
39.	Satbani Katha ..	290	87	12	1			
40.	Barna Katha ..	238	55	8	4	1		
41.	Shisham Nala ..	256	47	12	6	1		
42.	Sori da Kash Kan ..	127	27	5	1			
43.	Khairabad Katha ..	315	27	16	4	1		
44.	Sihali da Katha ..	118	21	7	1			
45.	Naroka Katha ..	55	12	3	1			
46.	Boi da Katha ..	335	53	13	2	1		

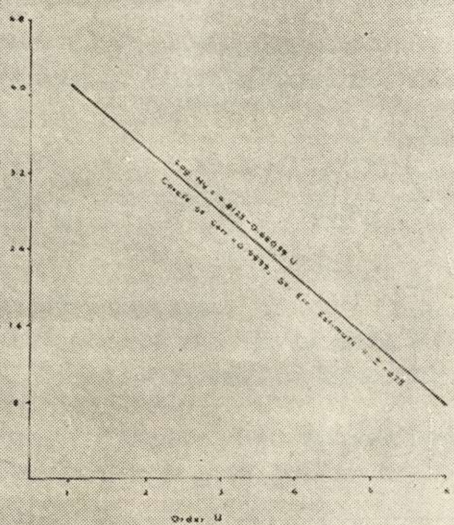

FIG: 1. REGRESSION OF LOGRITHMS OF NUMBER OF STREAM SEGMENTS ON STREAMS ORDER S

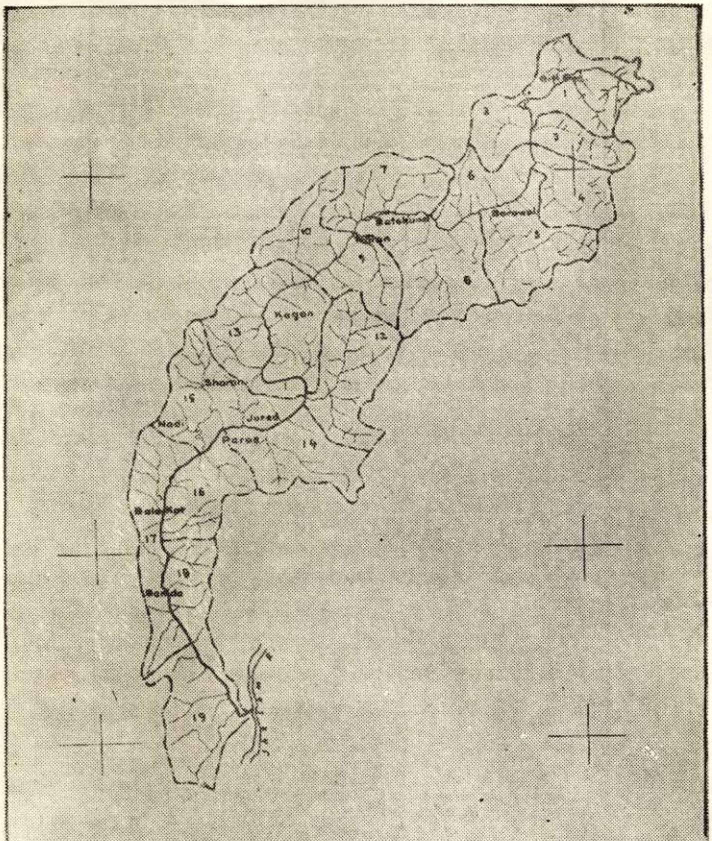

FIG. 2 KUNHAR RIVER WATERSHED SHOWING VARIOUS SECTIONS.

Serial No.	Tributary		ORDER NUMBER						
			1	2	3	4	5	6	7
47.	Sald Katha	..	634	117	24	6	2	1	
48.	Kagan Gali	..	78	21	5	1			
49.	Gul Deri	..	98	20	4	1			
50.	Nuri	..	60	13	3	1			
51.	Ochri Katha	..	127	25	8	2	1		
	Miscellaneous streams	..	1207	243	59	10			
	Total :	..	13121	2825	600	125	27	5	

Bifurcation ratio. The ratio of number of segments of a given order to the number of segment of the higher order is called the bifurcation ratio. It can be expressed as under.

$$Rb = \frac{Nu}{N_{u+1}} \text{ in which}$$

Rb = Bifurcation ratio

Nu = Number of segments of given order

Nu+1 = Number of segments of higher order.

The bifurcation ratio for Kunhar river watershed alongwith the number of streams belonging to various orders is given as follows :

Stream order	No. of streams	Bifurcation ratio
1	13,121	4.6
2	2,825	4.7
3	600	4.8
4	125	4.6
5	27	5.4
6	5	

Total number of streams of all orders	=	16,703
Average bifurcation ratio	=	4.8

The above statement shows that the average bifurcation ratio for this watershed is 4.8 and which is indicative of the steepness of the area. It is also clear that the bifurcation ratios tend to be constant, particularly in the lower orders.This is in confirmity with Horton's law of stream numbers which states that the number of stream segments of each order form an inverse geometric sequence with order number, or

$$Nu = Rb\ k\text{-}u \quad \text{where}$$

k is the order of the trunk segment.This law has received verification by accumulated data from many localities of the world.

The logarithms of the n mber of streams was plotted against orders and it shows linear relationship (Fig. 1) and the regression equation is

Log Nu = 4.8125 — 0.68099 u with 0.99 as correlation coefficient and ± 0.025 as standard error of estimate.

Drainage Density. It is the ratio of total channel length of all orders to the area of the basin. It is an indicator of the closeness of spacing of channels in the catchment. It also expresses the complex relationship between rainfall, runoff and infiltration capacity. In addition it provides valuable information about the underlying rock formation.

Drainage density can be expressed by the following relationship.

$D = L/A$ in which

D = drainage density,

L = Length of the channels in miles;

A = Area of the basin in square miles

For calculating the drainage density of the Kunhar river watershed, the catchment was subdivided into 19 sections (Fig. 2). The data and calculations are given in table 2.

Table 2. Drainage Density of Kunhar River Watershed.

Section No.	Section Area (Sq. Miles)	LENGTH (MILES) Permanent Streams	Seasonal Streams	Total Length (L)	Drainage Density
1.	59.82	76.917	148.941	225.858	3.8
2.	27.53	54.046	110.460	164.506	6.0
3.	28.60	35.110	127.818	162.928	5.7
4.	42.60	55.623	58.386	114.009	2.7
5.	66.74	107.266	217.764	325.030	4.9
6.	37.68	36.110	147.471	183.581	4.9
7.	54.90	207.306	99.185	306.491	5.6
8.	85.35	100.714	348.161	448.875	5.3
9.	39.37	192.369	52.774	245.143	6.2
10.	44.75	65.775	239.850	305.625	6.8
11.	56.90	88.168	195.824	283.992	5.0
12.	62.28	78.998	186.204	265.202	4.3
13.	58.44	53.594	294.398	347.992	6.0
14.	57.21	62.331	73.185	135.516	2.4
15.	68.89	63.119	420.806	483,925	7.0
16.	51.05	48.521	172.001	220.522	4.3
17.	64.90	78.454	325.366	403.820	6.2
18.	42.13	47.340	236.736	284.076	6.7
19.	61.98	23.274	230.984	254.258	4.1
Total :	1011.12	1475.035	3686.314	5161.349	97.9

$$\text{Average Density} = \frac{5161.349}{1011.12} = 5.1$$

According to the above statement, the drainage density of the catchment under study is 5.1. However, for individual sections of the basin, the lowest density of 2.4 exists in section 14 and the highest 7.0 in section 15. The value of D for other parts of watershed ranges between these two extremes. The areas which have comparatively higher density are more eroded and are less vegetated.

Constant of channel Maintenance. This properity has been described by Schumm (5)who used the inverse of drainage density to express constant of channel maintenance as follows :—

$$C = \frac{1}{D} = \frac{A}{L}$$

This constant (C), in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the scale of the land form units increases. Specifically, the constant C tells the number of square feet of watershed surface required to sustain one ,linear foot of channel.

Applying the values of Kunhar river watershed in the above relationship the C has been worked out as 1034.4. In other words it means that on the average 1034.4 feet square surface is needed to support each linear foot of channel in catchment under study.

Stream Frequency. It expresses the number of stream segments per unit area of the watershed and, like drainage density, indicates the texture of the drainage net but in a different way. Stream frequency can be expressed by the following relationship :

$$F = \frac{N}{A} \text{ in which}$$

F = Stream frequency
N = Total number of segments of all orders;
A = Area of the watershed in Sq. Miles.

Substituting the values for Kunhar river watershed,stream frequency works out as 16.52 per square mile as under :—

$$F = \frac{16703}{1011.12} = 16.52$$

Shape. Shape mainly governs the rate at which the water is supplied to the main stream as it proceeds along its course from the source to the mouth. In other words,shape of a basin has a direct effect on the stream characteristics.The outline of the watersheds is almost fixed and it may be of any shape. However, the majority of the basins ovoid or pear-Shaped with the outlet located at the narrow end. The triangular basins have thin vertex upwards and receive most of their water in the lower reaches. These are economically of least value. The shape of Kunhar river watershed is illustrated in Fig. 2.

Shape can be expressed by more than one mathematical expressions. Horton (2) used the term "form factor" which could be expressed by the following formula :

$$Rf = \frac{A_u}{L_b^2}$$

where R_f denotes form factor, A_u area of the basin and L_b is the length of the basin. According to this formula the form factor of Kunhar River water is 0.225 as calculated below :

$$Rf = \frac{1011.12}{4499.99} = 0.225$$

Schumm (5) suggests the use of the term "Elongation ratio" and defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The ratio is thus expressed by the following relationship.,

$$Re = \frac{2 \times \sqrt{\frac{A}{\pi}}}{Lb}$$

where Re = Elongation ratio,

A = Area of the basin ; and

Lb = Length of the basin.

Applying the values of the basin under study,the elongation ratio of Kunhar river watershed comes to 0.534 as under:—

$$Re = \frac{2 \times \sqrt{1011.12/3.143}}{67.082} = 0.534$$

The elongation ratio for a wide variety of climatic and geologic types, with application of above formula runs between 0.5 and 1.0. As a general guide, the basins having values near to 1.0 are located in regions of low relief while values ranging from 0.5 to 0.8 represent strong relief and steep ground slopes. The value which works out for Kunhar river basin reflects the conditions correctly to a great extent as they exist in the area. Miller (3) used another expression "Circularity ratio" which was defined by him as the ratio of basin area to the area of a circle having the same perimeter as that of the basin" This relationship is as under :—

$$Rc = \frac{Au}{Ac}$$

Where Rc = Circularity ratio

Au = Basin area; and

Ac = Area of circle having same perimeter.

According to this formula the values of circularity ratio for Kunhar river watershed works out as 0.280 as under :—

$$Rc = \frac{1011.12}{\pi(213.084.2/\pi)^2} = \frac{1011.12}{3611.745} = 0.280$$

Watershed form or shape is sometimes indicated by use of the "compaction coefficient". This index to watershed form is a ratio of the perimeter of a watershed to the circumference of a circle whose area is equal to that of the drainage basin and may be expressed as follows:—

$$Kc = \frac{P}{c}$$

Where Kc= Compactness coefficient,
P =Perimeter of the watershed; and
C = Circumference of the circle equal in area to the watershed

This coefficient is an absolute number independent of the size but dependent upon the shape only. It has a rare minimum value of unity for a circular basin. The larger values indicate that the irregularity of the basin will be greater and also the departure of its form that of a circle will be more. In case of two basins of the same size but of different forms, the maximum flood should be expected from the one which has the smallest compactness coefficient, other characteristics being the same in the two cases.

Applying the values of Kunhar river watershed its shape is calculated as below:—

$$Rc = \frac{213.084}{2\pi/1011.12/\pi} = \frac{213.084}{112.741}$$

$$= 1.89 \text{ or } 1.9$$

The shape of a basin can also be calculated by the following mathematical expression.

$$Kc = 0.28 \times P / \sqrt{A}$$

Where Kc = Compactness coefficient;
P = Perimeter of the watershed in miles
A = Area of the circle in miles.

The value of Kc for Kunhar river watershed is 1.9 as follows

$$Kc = \frac{0.28 \times 213.084}{1011.12} = \frac{28 \times 213.084}{31.8}$$

$$= 1.876 \text{ or } 1.9$$

The various values worked out above indicate that Kunhar river watershed has receive relief and sheep ground slopes. The value of compactness coefficient reflects the departure of the form or shape from that of a circle. It shows that the basin is neither circular nor is it extremely irregular in shape. In fact, it resembles and gourd as illustrated in Figure 3.

Slope. Slope is perhaps the most important factor as regards the time of surface-flow and concentration of rain fall in stream channels and is of direct importance for measuring the magnitude of flood. It may be defined as a rise or fall per unit area and has a complex relation to infiltration, surface runof soil moisture and ground water contribution to stream fllow :—

$$S = \frac{D \times L \times 100}{A} \text{ in which}$$

S = Average slope of basin in per cent,
D = Contour interval in feet;
L = Total length of contours in feet ; and
A = Area of basin in square feet.

Contours at an interval of 1,000 feet were measured from the topographic maps of the area and their lengths are recorded in Table 3 :

Table : 3—Contour Intervals and Their Lengths.

Contour Lines	Length (Ft).
3,000	343,459.84
4,000	1040,481.28
5,000	666,716.16
6,000	658,631.68
7,000	692,976.64
8,000	711,162.88
9,000	977,848.32
10,000	1030,379.52
11,000	1,464,755.20
12,000	1,678,909.44
13,000	1,909,232.64
14,000	793,994.24
15,000	129,300.48
16,000	20,203.52
	12,118,051.84

Thus the total length of all the contours is 12,118,052 feet and the average slope of Kunhar river catchment, as worked out by the above formula, is about 43 per cent.

FIG. 3 OUTLINE FORM OF THE WATERSHED OF KUNHAR RIVER

$$D = 1000 \text{ ft.}$$
$$L = 12{,}118.052$$
$$A = 28{,}188{,}407{,}808$$
$$S = \frac{1000 \times 12{,}118{,}052 \times 100}{28{,}188{,}407{,}808} = 42.99$$

Fall of the river. The total length of river is about 89.77 miles and considering the highest and the lowest elevation, its drop is 102.48 feet per mile.

Average elevation. Elevation of a point or area represents heights above mean sea level. The lowest locality of the Kunhar watershed is Domishahi near rope bridge at an elevation of 2086 feet and the heights is 16,121 feet.Thus the average of these two points is 9104 feet, which though describes the general elevation range in this catchment but fails to give a true picture.Perhaps a weighted average will be a better indicator for which purpose, the entire watershed was divided into half inch squares and their central points falling within the area counted which totalled 286. The exact elevation intersections were read from the topograph maps. The average of these points represents the weighted elevation of the Kunhar river watershed which is 10,435 feet as worked out in the following table :—

Table : 4 Map-Wise observations of elevation at Various Points.

Map No.	No. of points	Total Elevation	Average Elevation.
43 F/5	13	1,51,000	11,615
F/6	44	3,19,500	7,261
F/7	24	94,500	3,937
F/8	4	18,500	4,625
F/12	5	60,700	12,140
F/9	58	6,61,400	11,403
F/10	28	2,65,000	9,464
E/16	35	4,54,900	12,997
F/13	39	4,76,100	12,207
I/4	24	3,24,000	13,500
J/1	12	1,59,000	13,250
Total :	286	29,84,600	

Weighted (Average)

$$\text{Elevation} = \frac{29{,}84{,}600}{286} = 10{,}435 \text{ feet}$$

The map-wise average elevation, as given in the above statement, describes the changes in elevation in Kunhar river watershed.The variation in elevation and also the weighted elevation is an indicator of quite a few important factors such as evaporation, temperature, precipitation and snow characteristics, atmospheric pressure solar radiation and general climatic conditions.The temperature goes down as the elevation increases. The elevation has a profound influence upon water losses which are mostly evaporative in nature. The resulting differences in temperature with the change of elevation affect the rate of snow-melt and ultimately the river discharge and the water supply of lakes. At the same time the average elevation is also important in determining the impounded water of a watershed.

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