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Quantitative analysis of Nayaseri watershed in the northern slopes of Shimla (Himachal Pradesh, India)

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Abstract
The Nayaseri watershed has been analyzed in this research paper using quantitative techniques. This watershed lies in the Northern slopes of Shimla mountainous range and forms the part of Shimla district of Himachal Pradesh. The basin has rocks of tertiary age with beds belonging to the carbonaceous system (Karol and Blaini groups). The metamorphic rocks of the basin consist of mostly black carboniferous, garnetiferous, phyllites, slates, quartzites and highly crushed dolomite. Overall climate of the basin is cool and moist. The pattern of streams in the catchment is pinnate and dendritic mixed with parallel patterns. The linear, areal and relief aspects are involved in quantitative analyses of watershed. The linear and areal investigation of the watershed indicates the incidences of truncation, upliftment, subsidence and tilt in the basin. Hypsometric integral value, elongation ratio, sinuosity index and channel gradient suggest a young stage of landforms development of drainage basin.

Keywords: Morphometric analysis, hypsometric analysis, linear analysis, drainage density, clinographic curve, bifurcation ratio

Introduction

The river Nayaseri is a 5th order stream in the catchment. This area lies in the Northern slopes of Shimla mountainous range and forms the part of Shimla district of Himachal Pradesh (Fig-1). It is bounded by 77° 6 '15" E to 77° 14' 45" E longitude and 31° 5 '45" N to 31°13' 45" N latitude. The drainage basin falls in topographical sheet number 53 E/4. The area under the watershed is 108.81 sq. kilometers. The watershed falls in the lower section of the lesser Himalayas. The study area has height range of 943 to 2400 meters. The basin has four mountainous ranges namely, Durgapur-Mashobra, Dum-Barmu, Bhaili-Fatenchi and Shimla. The main stream of the basin is Nayseri. Kalar Nadi, Naug Nadi, Pajog Nadi originating from Shimla ranges are the main tributaries to the main stream (Fig-1, 3). The basin has rocks of tertiary age with beds belonging to the carbonaceous system garnetiferous, phyllites, slates quartzites and highly crushed dolomite. Overall climate of the basin is cool and moist. Apparently there are two drainage patterns in the basin one is pinnate and the other is dendritic mixed with parallel patterns (Fig-2). Morphometric analysis of drainage basins is very significant. Such a type of study enlightens the litho-structural control of the area. Such a investigation also reflects the stages of sequential development of the basin, tectonic incidences in the area, erosional and hydrological aspect as well. These studies are also important to evaluate basin hydrology.

Methods and data base

Quantitative study of Nayaseri catchment has been executed using a topographical map of Survey India. The scale of the map is 1:50000. Morphometric analysis of drainage basin involves the linear, areal and relief (gradient) parameters of watershed. Planimeter is used to compute the area of the watershed. Distances have been measured by rotameter. Methods involved in morphometric analysis are tabulated below:

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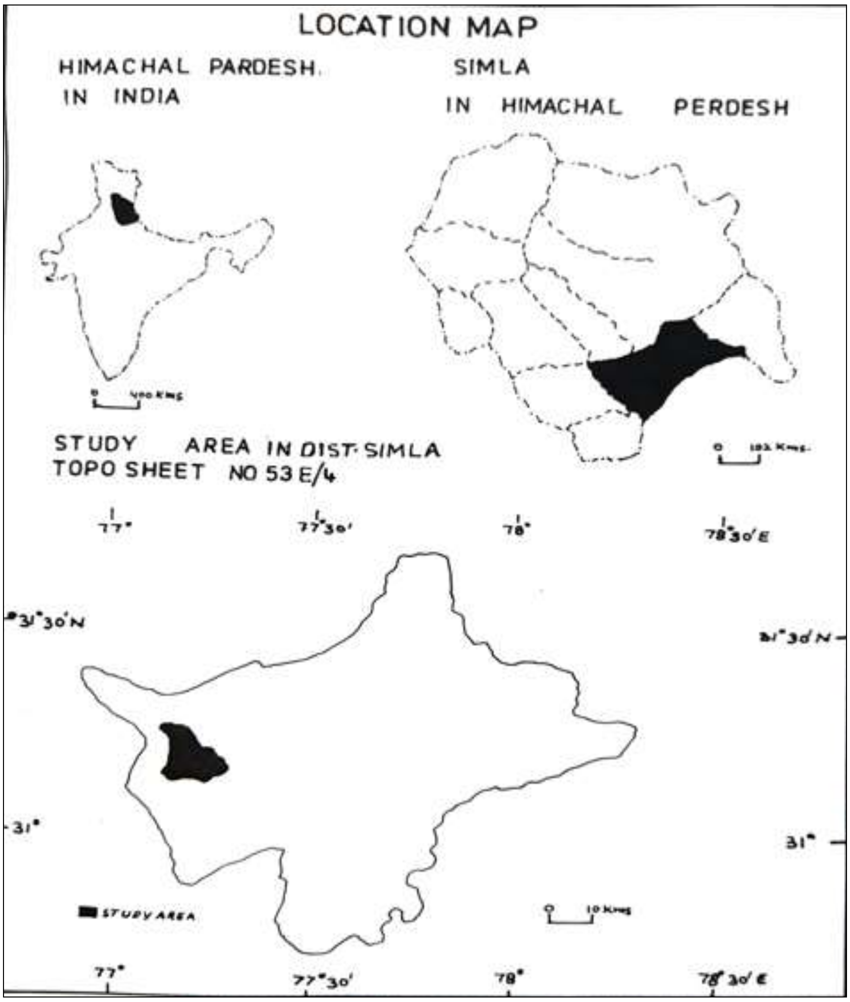

Fig 1: Location Map of Watershed

Table 1: Methods of calculation of morphometric parameters (linear, areal and relief).

Sr. No.	Morphometric parameters	Methods of calculation	References
1	Stream order (U)	Ordering- Hierarchy; U_1 stands for 1_{st} order; U_2 for 2_{nd} order & U_n for nth order streams	Strahler (1952) [8]
3	Mean stream length ($L^{-1}{}_u$)	$L^{-1}{}_u = L_u/N_u$; L_u & N_u are respectively length & number of stream in any order	Horton (1945) [3]
4	Stream Length ratio (R_L)	$R_L = L_u/L_{(u+1)}$; L_u is stream length of order $_u$; $_{u+1}$ is next higher order	Horton (1945) [3]
5	Bifurcation ratio (R_b)	$R_b = N_u/N_{(u+1)}$; N_u = No. of streams of any order; $_{u+1}$ is next higher order	Horton (1945) [3]
6	Drainage density (D_d)	$D_d = L/A$; L is $\sum L(u_1+u_2+\text{----}+u_n)$; A is area of basin	Horton (1945) [3]
7	Stream frequency (D_f)	$D_f = N/A$; N is $\sum N(u_1+u_2+\text{----}+u_n)$	Horton (1945) [3]
8	Form factor (R_f)	$R_f = A/(L_b)^2$, here L_b is air distance along the longest diamension of basin	Horton (1932) [2]
9	Circularity ratio (R_c)	$R_c=4\pi A/P^2$; A = area; P = perimeter of basin; π = 3.143	Miller (1953) [4]
10	Elongation ratio (R_e)	$R_e = 2\sqrt{(A/\pi)}/L_b$, where A is area of watershed, π is 3.143, L_b = length of basin	Schumm (1956) [7]
11	Length of overland flow (L_g)	$L_g = 1/2\ D_d$;	Horton (1945) [3]
12	Constant of channel maintenance (C)	$C = 1/D_d$	Schumm (1956) [7]
13	Coefficient of Compactness (C_c)	$C_c = P/2\sqrt{\pi A}$	Horton (1945) [3]
14	Sinuosity index (I_s)	$I_s = CD/AD$, where CD curved distance & AD air distance of river	Mueller (1968) [5]
15	Basin relief (R)	R=H-h; H & h is respectively maximum and height & minimum height within watershed	Strahler (1952) [8]
16	Relief ratio (R_r)	$R_r = R/L_b$; Here R =H-h	Schumm (1956) [9]
17	Ruggedness (R_n)	$R_n = R\times D_d$	Schumm (1956) [7]
18	Clinographic Curve	$\tan\theta = h/R\text{-}r$, where h is contour interval, R-r is difference between radii of circles	Hanson Lowe (1935) [1]

Quantitative study of watershed has been executed under the heads of linear, aerial and relief analysis.

Exposition

Linear Analysis

The data obtained for various parameters of linear aspects have been presented in table (2) and same has been analyzed in following sections.

Stream order (U)

Drainage ordering is an assumption that the strength and vigour progressively increases as it is joined by another stream. Strahler method (1952) [8] has been used for the present analysis. This method is a little transformed version of Horton's method of stream ordering. Accordingly, the fingertip tributaries are of the first order channels (U_1). When two first order channels join with each other a second order channel (U_2) comes into existence. Similarly, two second order channels have joined to produce a U_3 stream and so on. But if a lower order channel joins with another higher order channel then the order of later remains unchanged. Accordingly, Nayaseri is a fifth order stream. Order-wise details of streams are tabulated under table (2). Horton studied two type of relationship: one was between order and average length of stream and the other between order and numbers of streams in the respective order. He proposed two laws on the basis of his studies, which are discussed below.

Fig 2: Strahler System of Drainage Ordering

Stream Order and Number Relationship (First Law of Horton)

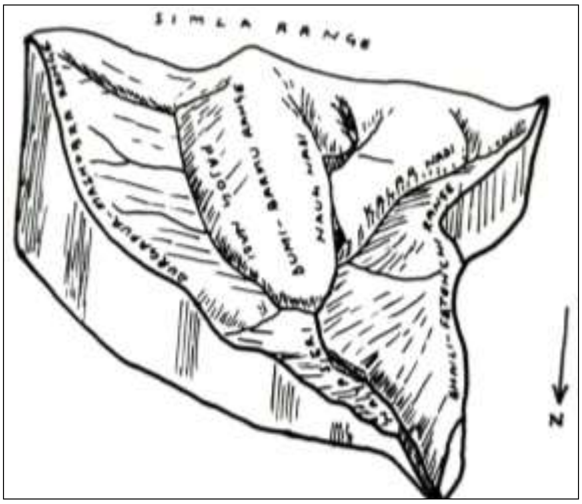

Fig 3: Block diagram Nayasari drainage basin

"The number of streams of different order in a drainage basin tends closely to approximate an inverse geometric series in which the first term is unity and the ratio is bifurcation ratio" (Horton, 1945) [3]. Horton showed that in watershed "there is a progressive decrease in the number of streams with the increase of stream order". This relationship follows a geometric series which can be demonstrated by graphing stream number against the order on a semi-logarithmic graph (fig-4). This behaviour can be converted into straight line equation i.e. Log y = mx+c where 'y' is number of channels in any given order; 'x' is the order, m denotes the R_b and 'c' is the constant. Deviation of numbers or length from the straight line helps in establishing the geomorphic history of the basin. Deviation can be related to tectonic activities, climatic fluctuation or heterogeneous character of rocks. Order wise number of tributaries in Nayaseri watershed is given in table (2). Plotting of order and number on semi logrithamic graph (Fig-4) indicates that the result is almost straight line except for very little deviation of stream numbers from straight line. The straight-line equation of this relationship is Log y = - 0.7363X + 3.3685. The Nayaseri drainage basin follows the First Law of Horton.

Table 2: Values of Linear Parameters of Nayaseri Dainage Basin

Order U	Number N_u	Bifurcation Ratio (R_b)	Length Kms. (L_u)	Aver. Length Kms ($L^{-1}{}_u$)	Length Ratio (R_L))
1	490		305.7	0.62	1.33
2	105	4.6	87.2	0.83	1.95
3	25	4.2	40.5	1.62	2.46
4	5	5	19.9	3.99	2.89
5	1	5	11.4	11.48	

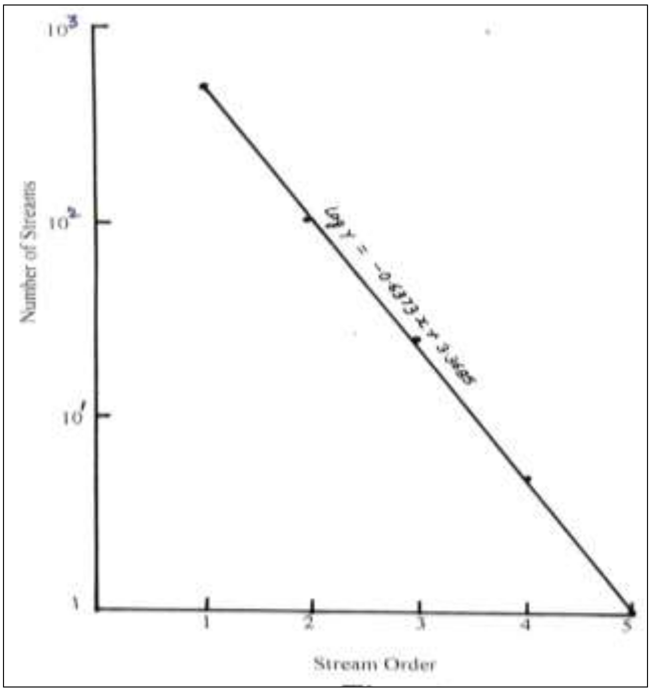

Fig 4: Relation between stream order and number nayaseri drainage basin

Bifurcation ratio (R_b)

Horton (1945) [3] stated that the bifurcation ratio is "the ratio of number of streams of an order to the number of streams of the next higher order" ($R_b = Nu/N_{(u+1)}$). The R_b of the watershed ranges from 4.2 to 5.0. The average R_b is antilog of m value in the equation of straight. The average R_b of the Nayaseri watershed is 4.718. This R_b value indicates mountainous and highly dissected basins of the humid region. The shortfall in N_{u1} & N_{u2} streams suggests truncation of existing network by river capture which might have occurred by tectonic imbalance.

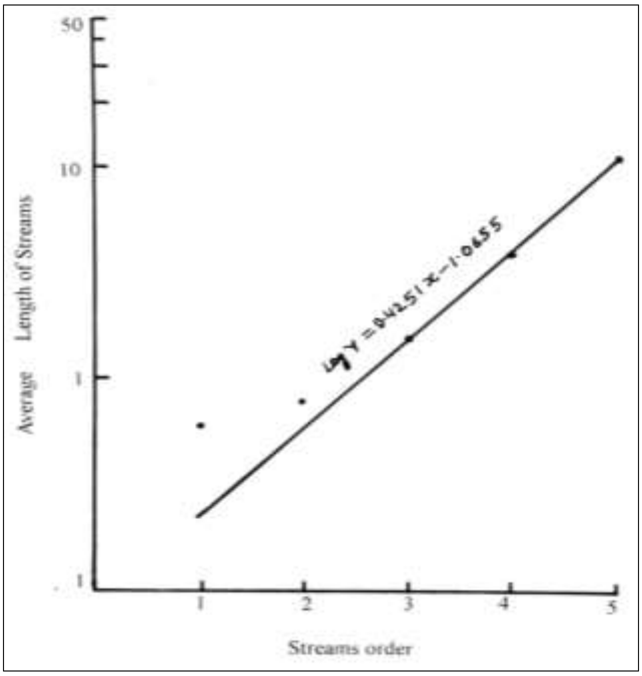

Fig 5: Relation between stream order and average length nayaseri drainage basin

Stream length and Order Relationship (Horton- Second law)

This law tells that "the average length of stream of each of different orders in a drainage basin tends closely to approximate a direct geometric series in which the first term is the average length of the stream of first order and the ratio is the length ratio" (Horton, 1945) [3]. Table (2) exhibits that the L^{-1}_{U} is increasing with increasing streams orders in Nayaseri drainage basin. The straight-line equation of this aspect is Log y = 0.4251 X - 1.0665 (Fig. 5). The average length ratio of the basin comes out to be 2.662, which is antilog of m value in the straight-line equation. The straight-line equation of this relationship indicates the abnormal increase (63%) in the average length of U_1 and moderate increase (31%) in the U_2 streams.

Study of number and length of U_1 & U_2 streams indicates that these streams in general are less in number but longer in length. This behaviour is expected in truncated streams where a certain portion of the basin is captured by another system of river or stream. Longer streams may develop due to tilting or dipping of the area in a certain direction. Similarly, the behaviour of second order streams suggests a well-marked zone along the eastern flank of Pajog. The second order streams in this zone are straight lengthier and join at about right angles to the mainstream. Such behaviour is possibly due to the upliftment along fault plane of Pajog stream (Fig.10)

Length ratio (R_L)

It is the "ratio of mean length of stream of a given order to the mean length of stream of next lower order" Horton (1945) [3]. High R_L value indicates that large number of lower order streams to supply water for subsequent order channels. The average length ratio of stream Nayaseri is 2.662. However, it is different within different order of stream it range is from 1.33 to 2.89.

Areal analysis

Form factor (R_f)

Horton (1932) [2] expressed "form factor as "the ratio of basin area to the square of basin length" Its value varies between0 to1.0. Values near extreme ends (0, 1.0) respectively indicate highly elongated and circular shape of basin. Study of the R_r of the basin has hydrological importance. The peak flow will be high in a circular basin and duration of flow will be shorter while there will be flatter peak flow in an elongated basin. Floods can easily be managed in elongated basins. The value R_f in the present basin is moderate (0.4).

Circulatory Ratio (R_c)

Circulatory ratio is also a dimensionless ratio, like the form factor. R_c reflect layout of watershed. R_c is the "ratio of area of river basin to the area of circle having the same perimeter as the basin" (Miller, 1953) [4]. He found the "circulatory ratio 0.6 to 0.7 in homogeneous geological material and 0.4 to 0.5 in quartzite terrain". The basin circulatory ratio has been found to be 0.65 in the study area, which indicates homogeneous geologic material of the catchment.

Sinuosity index (I_s)

Sinuosity may be expressed as the "ratio between the curved distance of the river and the air distance between mouth and source of stream" (Mueller, 1968) [5]. Sinuosity index of various tributaries ranges from 1.1 to 1.5. Sinuosity index of the main river is 1.2. This index is 1.1 for the tributaries in the southern and central part of the basin. It is slightly higher (1.2 to 1.5) of the streams joining the main river in the north of Lake Nayaseri. This index indicates that the streams are more or less circular drainage basins. Straight stream suggest the control of slope and tectonic uplands, which are recent in origin and not yet grade.

Elongation ratio (R_e)

It is the "ratio between the diameter of circle with the same area as the basin and maximum length of the basin" Schumm (1956) [6]. When, shape of watershed basin approaches a circle, its value is found to near 1.0. Strahler (1964) [10] stated that R_e is found "between 0.6 to 1.0 over a wide variety climate and geologic type. Values near 1.0 are found in typical reasons of law relief while values from 0.6 to 0.8 are generally associated with strong relief and steep ground slopes". R_e of present watershed is 0.7, which indicates that drainage is moderately circular, suggesting, steep surface slopes and young stage of sequential development of the basin.

Coefficient of Compactness (C_c)

Basin shape has been defined by alternative descriptors based on perimeters rather than area. The C_c is expresses the ratio between perimeter (P) of catchment and perimeter of circle having equal area to the catchment. This ratio comes out to be 1.22 for the Nayaseri basin.

Table 3: Values of Areal and relief Parameters of Nayaseri Catchment

Sr. No.	Parameters	Value	Sr. No.	Parameters	Values
1	Basin area in Sq. Kms (A)	108.8	11	Drainage Frequency (D_f) per Sq km	5.75
2	Basin Perimeter in Sq Kms (P)	45	12	Drainage Density (D_d) per Sq. Km	4.27
3	Basin Length in Kms (L_b)	16.5	13	Basin Relief in meters (H)	1453
4	Form Factor (R_f)	0.4	14	Relief Ratio (R_r)	0.088
5	Circulatory Ratio (R_e)	0.65	15	Hypsometric Integral value (I_H)	81
6	Sinuosity Index (I_s) 4^{th} & 5^{th} order streams	1.1 to 1.5	16	Channel Gradient	.
7	Elongation Ratio (R_e)	0.7	I	Main Channel	4^o
8	Coefficient of Compactness (C_c)	1.22	ii	Fourth order channels	5^o-7^o
9	Length of Overland Flow (L_g) in meters	117	iii	Third order channel	9^o-14^o
10	Constant of Channel Maintenance (C) in Sq m	234	17	Ruggedness Number (R_n)	6.2

Drainage density (D_d)

It may be expressed as $\sum L_{(u_1+u_2+ ---- +u_n)}$ per unit area. The unit of measurement in the present study is length of km per sq. kilometer. Nautiyal, (1994) [6] stated that "low values of D_d are associated with highly permeable material of relief with vegetative cover and low relief. High value of D_d indicates region of weak and impermeable material of mountainous relief". High D_d (>5) in the catchment is seen in the northernmost and central part of the basin in the form of patches. This category is also seen along the eastern, southern and western border of the basin. Moderate drainage density (3.5 to 5.0) in the area is mainly found in the west of Pajog tributary and in the east of Kalar nadi. Coarse drainage density (< 3.5) is mainly confined in the area between Kalar nadi and Pajog nadi (Fig-6).

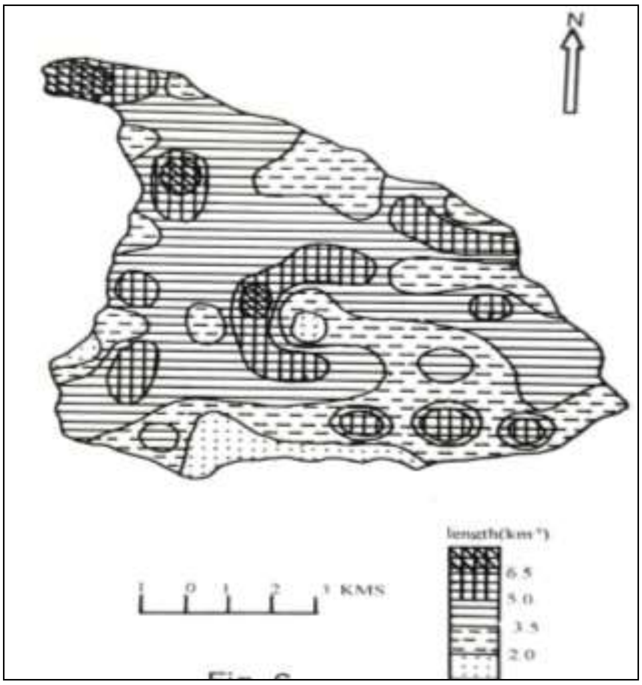

Fig 6: Drainage Density Nayaseri drainage basin

It can be broadly seen that the southern periphery of high absolute relief has coarser drainage density as compared to the northern confluence region, where fine or very fine drainage density is in evidence (Fig.-6). It may, therefore, be recorded that the study area follows a specific behaviour with respect to the distribution of drainage density. Higher absolute relief corresponds with coarse drainage texture. This correspondence suggests that the areas of higher absolute relief are comparatively young in the developmental sequence of landforms, while the confluence zone is relatively older and mature.

Drainage frequency (D_f)

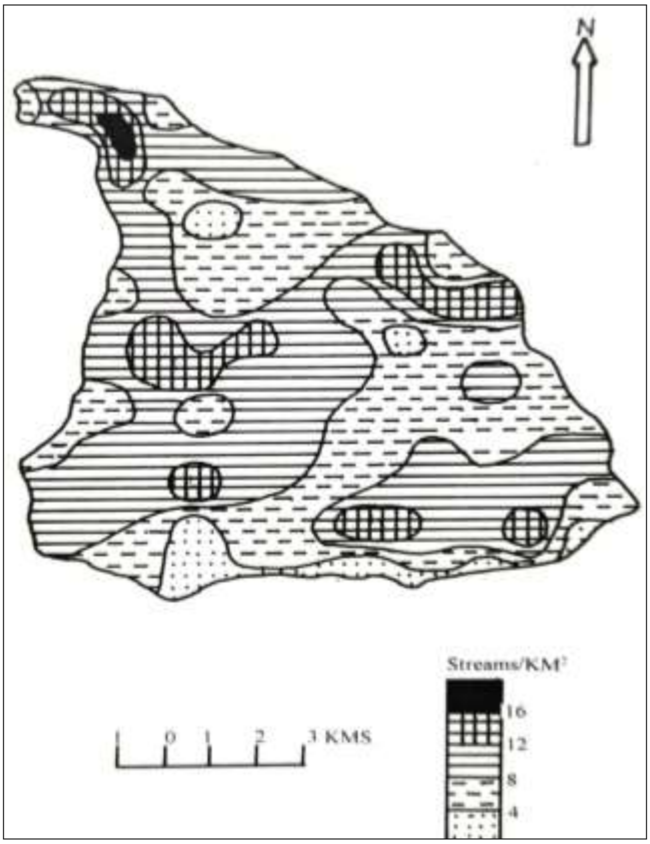

Fig 7: Drainage frequency Nayaseri drainage basin

Drainage frequency may be defined as $\sum N_{(u_1+u_2+ ---- +u_n)}$ per unit area. The unit of measurement in the present study is number of streams per sq. kilometer. Figure (7) reveals that spatial pattern of high drainage frequency (>12) is patchy. These patches may be seen along the northern, eastern and southern periphery of the catchment. Moderate drainage density (8 -12) areas are mainly confined to the catchment area of Kalar and Naug nadi and the upper catchment of Pajog tributary. Low drainage frequency (< 8) is seen in the lake region and south - eastern flank of the basin. In general, the frequency of stream follow normal behaviour of drainage development i. e. it is poor along the peak areas and moderate to high along the confluence point. The slope area or hollows of the drainage basin usually exhibit moderate frequency. There are some exceptions to the normalized behaviour *viz* along Nayaseri channel way (poor frequency), Nayaseri lake region (poor frequency). The former is the region of uplifted block (Fig.-10) while the later is probably the zone of limestone topography conspicuous of poor drainage.

Length of Overland Flow (L_g)

Lg is an important indicator of spacing between streams in the watershed. This indicator was adopted by Horton (1945) [3] to find out the length of water flow on the relief before it drains into a specific channel. Horton expressed the Lg as "equal to half the reciprocal of drainage density" (L_g = 1/2D). The L_g of Nayaseri Catchment is 117 m

Constant of channel maintenance (C)

The "inverse of drainage density" was used by Schumm (1956) [6] as an attribute of constant of channel maintenance (C =1/D). Specifically, this constant indicates the area needed to feed one kilometer /mile of channel. Table (3) reveals that 234 square meters area is required for maintenance of one-kilometer channel

Relief Analysis

Relief Ratio (Rr)

It may be expressed as "ratio between the total relief of a basin (elevation difference of lowest and highest points) and the longest dimension of the basin parallel to the principal drainage line" (Schumm 1956) [7]. R_r may serve as an index of erosion intensity in the catchment. It also indicates the catchment-wide steepness of a watershed. Value of R_r in the Nayaseri watershed is 0.088. This value suggests steep slopes in the area.

Channel Gradient

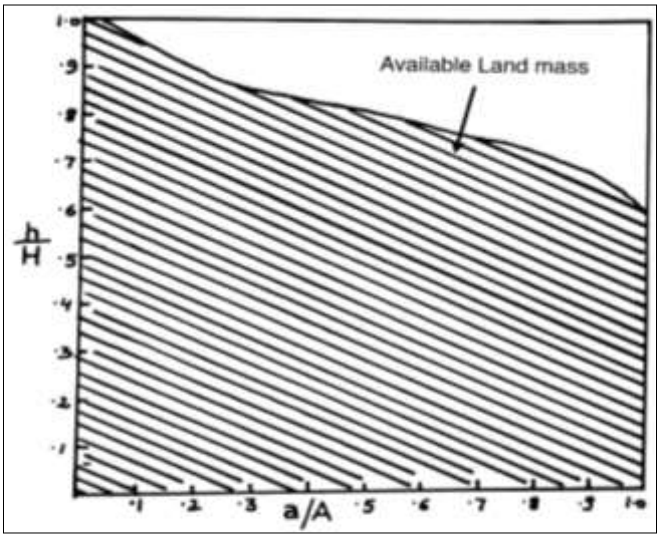

Fig 8: Hypsometric intergral curve nayasari drainage basin

The longitudinal slope of the Nayaseri stream is 4° in the catchment. Its main tributaries - Kalar, Naug and Pajog have an average slope of 5°, 6° and 7° respectively. Slopes of third order streams joining these tributaries have the slopes ranging between 9° to 14°. The graded river usually has a channel gradient of 2° to 2.5°, while all the streams in the watershed are stepper in channel gradient, suggesting, and the region to be young and ungraded.

Hypsometric Integral Curve

Hypsometric integral curve proposed by Strahler (1952) [8] is an important index of stages of development of the basin. This morphometric parameter involves two ratios.

- The ratio between area (a) of successive height zones and total area (A) of the basin (horizontal axis)
- The ratio between the corresponding height zones (h) and total height (H) in the basin (vertical axis)

The area downward the hypsometric curve line indicates the available relief to be eroded. Figure (8) shows that the available land mass for erosion is 81%, suggesting a young relief.

Clinographic Curve

The clinographic curve depicts the mean slope in between selected consecutive contours. It presents these calculated consecutive mean slopes in the shape of a series and these series of slopes constitute a single curve. Its great importance is that it reflects the unexpected changes in available relief of any basin and major breaks of slopes as well. In fact this curve illustrates the average gradient and breaks of slope. More significantly, this curve is highly sensitive to small changes in relief as compared to the hypsometric integral curve.

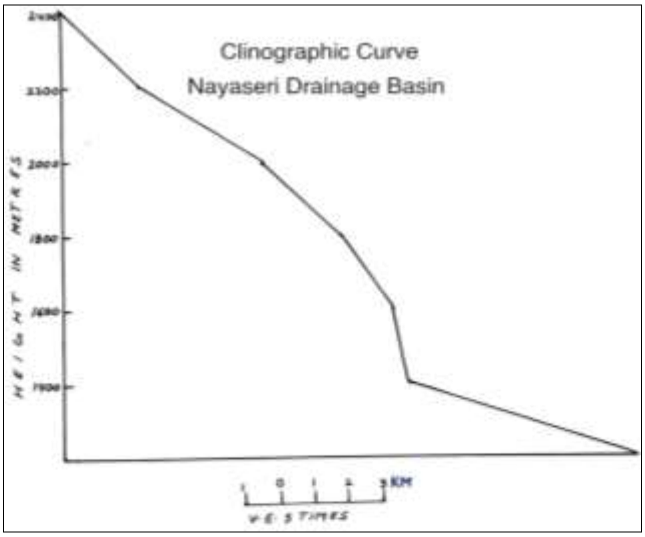

Fig 9: Clinographic curve

$\tan\theta = h/R\text{-}r$

Where, h stands for the contour interval. R-r is the difference between radii of successive circles, having the area equal to the area surrounding by a corresponding contour.

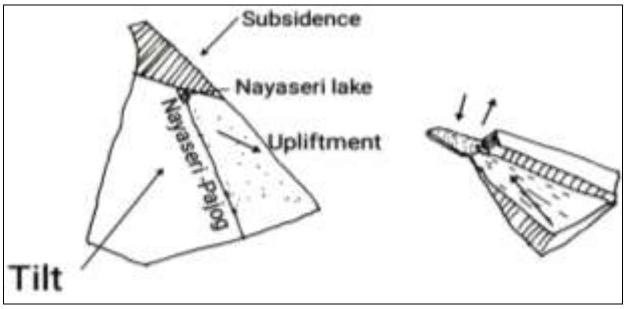

Fig 10: Schematic Diagram of Blocks of Watershed

Fig. (9, 10) reveals that the area above 1400 m. has very steep slope. Infract, the portion of this elevation is found in the narrow strip along the main channel and major tributaries. Hence we can conclude that the drainage basin has experienced major tectonic incidences in the height zone of 1400-1800 m.

Ruggedness number (Rn)

It combines two parameters, one is slope steepness and the other is length of streams. It is the "product of relief (R) and drainage density (D_d)" (Schumm, 1956) [7]. While calculating R_n both the parameters are taken into similar unit of measurement. "It indicates the instability of the land surface" (Strahler, 1964) [10]. Extremely high R_n occurred for high relief regions with high density of drainage. High R_n Indicates rugged topography and high runoff. R_n of Nayaseri basin is 6.2, which suggest high relief and rugged topography. Such type of watershed has been susceptible to soil erosion.

Conclusion

Streams in Nayaseri drainage basin follow the first and second law of Horton. The behaviour of first and second order channels indicates that the first and second order channels in general are less in number but longer in length. This behaviour is expected in truncated streams, where a certain portion of the basin is captured by another system of river or stream. Longer streams may develop due to tilting or dipping of the area in a certain direction. Similarly the behaviour of second order schemes suggests a well-marked zone along the eastern flank of the Pajog stream. The second order streams in this zone are straight lengthier and join at about right angles to the main street. Such behaviour is possibly due to the upliftment along fault plane of Pajog stream.

Study of drainage frequency in the area reveals that there are abnormal patches of poor drainage frequency along the eastern flank of Nayaseri stream and Nayaseri Lake region. The former seems to be the region of uplifted block, while the later is probably the zone of limestone topography. Parallel pinnate and dendritic drainage respectively also suggest uplifted, tilted and original land blocks.

Hypsometric integral values of 81%; channel gradient (5°) of Nayaseri stream; channel gradient of 5° to 7° in case of 4th order streams suggest watershed to be young and ungraded.

Clinographic curve reveals that the drainage basin has experienced tectonic incidences in the height zone of 1400 to 1800 m.

Values of relief ratio and ruggedness number suggest high relief with Steep ground slopes and rugged topography susceptible to erosion. Circulatory ratio indicates homogeneous geological material.

Values of elongation ratio and form factor also suggest strong relief, steep ground slopes and young stage of development of this moderately circular basin.

Finally, it may be established that the watershed has experienced tectonic incidences, the area has strong relief with steep ground slopes and topography is yet to be graded. Quantitative analysis is prerequisite for catchment management strategies.

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