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Relief Morphometry of Nayaseri Watershed: A Case Study in Northern Slopes of Shimla, Himachal Pradesh, India

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The study of relief elements is very significant in geography. Relief set the stage for all types of development of cultural features on the surface of the earth. To make planning regarding development of cultural landscape, for sustainable development, the study of relief is must, particularly in mountainous regions. The study of relief enlighten many characteristics of the area, like - slope, dissection of area, stability and instability of topography, erosion capacity of area, hydrological aspects and stages of sequential development of landforms etc. In the light of this need, relief morphometry of catchment has been studied. To study the Morphometry of the watershed, parameters like – relative relief, absolute relief, dissection index, slope, hypsometric integral curve, clinographic curve, relief ratio and ruggedness number, relief profile have been taken. The topographical map published by Government of India is the database of the analysis. Instruments, like- Rotameter and Planimeter have been used for various measurements. The observations per square kilometer are taken to calculate the areal coverage of absolute and relative relief, average slope and dissection index. The study reveals that the watershed has

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experienced tectonic incidences in the recent past. Fault, submergence, upliftment, tilt and sudden breaks of slopes are imprints of these activities on topography of the area. Indicators like - Slope, relief ratio, ruggedness number and relief profiles suggest that the watershed has Steep slopes, unstable landmass and capacity of intense erosion. Various measures of relief also imply that the area is in the youthful phase of its sequential development.

Keywords: Clinographic curve; nayaseri; ruggedness number; relief ratio; relative relief; relief profile; tectonic activities.

1. INTRODUCTION

The analysis of relief morphometry of the watershed helps in recognising major characteristics of landform. To make planning regarding development of cultural landscape, for sustainable development, the study of relief is must, particularly in mountainous regions. The area under study is the watershed of river Nayaseri. This watershed lies in Shimla district of Himachal Pradesh. It is bounded by 77°6' 45″ E to 77°14'15″ SE longitude and 31°5'45" N to 31°13'45" N of latitude. The watershed lies in topographical sheet number 53 E/4, covering an area of 108.8 sq. kilometers. The study area falls in the lower part of the middle Himalaya. Its average relief is moderate i.e. about 1400 m. The height of the watershed ranges from 943 to 2400 meters. The watershed has 4 mountainous ranges namely- Durgapur -Mashobra, Dumi-Barmu, Bhaili- Fatenchi and Shimla (Jutog-Dhalli) ranges (Fig. 2). Durgapur -Mashobra range extends in NW to SE direction and is found in the eastern part of the watershed. This range is covered by agricultural land. Dumi - Burma range in the central portion of the watershed extends NW to SE direction. It is covered by dense pine forests. Bhaili-Fatenchi range, covered with barren land; extending in North - South direction, is located in the western part of the watershed. Shimla range joins the above stated three ranges in the southern portion of the catchment. This is the range on which Shimla is situated. The average slope of the catchment ranges between 9° to 51.5°

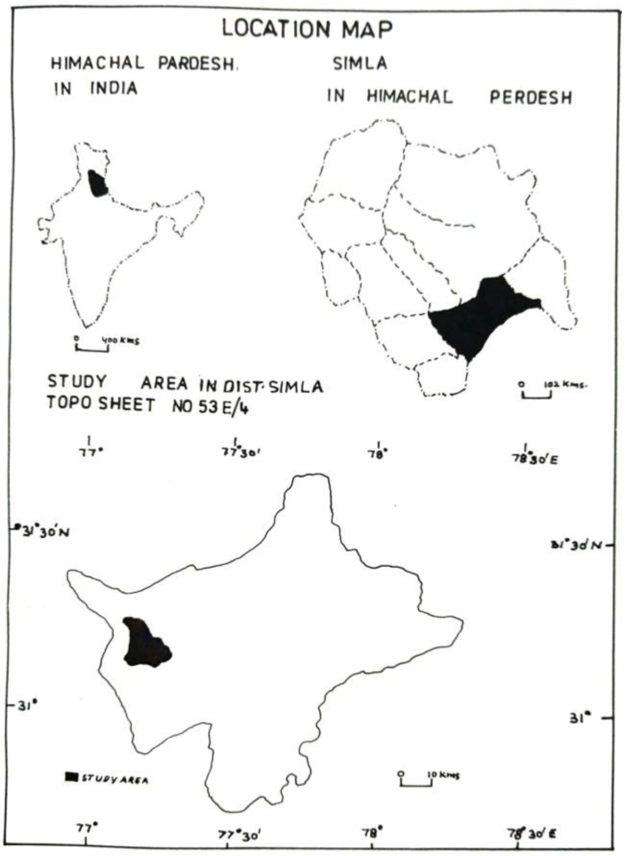

Fig. 1. Location map

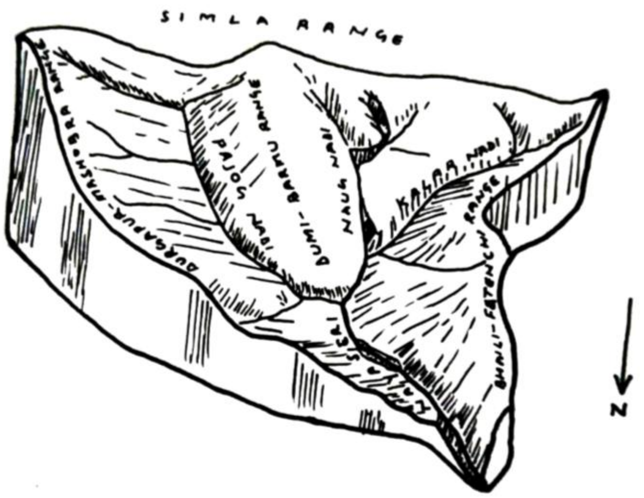

Fig. 2. Block diagrame

The major stream of basin Nayaseri flows from SE to NW direction. Kalar Nadi, Naug Nadi and Pajog Nadi originating from Shimla range are main tributaries to the stream Nayaseri. Nayaseri Lake which remains dry throughout the year except few rainy months is an important feature of the basin. The basin has rocks of tertiary age, with bed belonging to the carbonaceous system (Karol and Blaini groups). This area consists of metamorphic rocks. Metamorphosed rocks are overthrown on younger sedimentary of Silurian, Devonian and carboniferous age in this area. They consist of mostly black carboniferous, garnetiferous, phyllites, slate, quartzites and highly crushed dolomites.

2. METHODS

Topographical map on scale 1:50000, published by Government of India is the database of study of relief morphometry of the watershed. Relief morphometric of the area has been studied using parameters like- relative relief, absolute relief, average slope, dissection index, hypsometric integral curve, clinographic curve, relief ratio, ruggedness number and relief profiles.

Table 1. Methods of calculation of parameters of relief morphometry

Sr. No.	Relief parameter	Method	Reference	Result
1	Absolute relief	AR- highest point from sea level. calculated from spot heights trigonometric stations and contour lines	-	2400 M.
2	Relative relief	RR = H-h H is maximum elevation h is minimum elevation	Smith [1]	1957 M.
3	Average Slope	Tanθ=(no. of contour cutting per km x contour interval x 3.3)/3361	Wentworth [2]	9°-51°
4	Dissection index	DI =RR/AR, where: RR - Relative Relief AR - Absolute Relief	Dove Nir [3]	0 - 0.3
5	Hypsometric integral	h/H - Vertical Axis a/A - Horizontal Axis	Strahler [4]	81%
6	Clinographic curve	Tanθ = h/R-r, where h is contour interval, R-r is difference between radii of circles	Hanson-Lowe, J. [5]	-
7	Relief ratio	R.r = R/Lb; Here R =H-h	Suchmm [6]	0.088
8	Ruggedness number	R.n = R × Dd, where R = H-h & Dd is drainage density	Suchmm [6]	6.2

Rotameter has been used to measure the distance. The area has been calculated using the grid method and planimeter. Various relief parameter maps have been overlaid with a web of one square kilometer where the grid method is adopted. The parameters like - absolute and relative relief, dissection index (DI), average slope (AS) and have been calculated grid - wise. Grid of one square kilometer has been used for this purpose. To calculate the average slope, Wentworth's (1930) method has been adopted. This formula has been changed into the metric system for calculation of average slope. Strip method has been used to draw the cross sectional serial profiles. To prepare the longitudinal profile thread has been used to mark the cross section line along the stream path. The profile has been plotted on a scale of 1:50000. While plotting the profile, vertical scale has been exaggerated 2.5 times as that of horizontal scale. Methods of calculation of various relief aspects has been given in Table 1.

3. RESULTS AND DISCUSSION

The analysis of relief morphometry of watersheds is done in terms of relief elements, like- AR, RR, DI, average slope, relief profiles, hypsometric integral curve, clinographic curve, relief ratio, ruggedness number etc.

3.1 Absolute Relief (A_R)

AR is the basic parameter of height expression, which is the maximum height in a unit area from the mean sea level. Square grids of one square kilometer have been taken to calculate the absolute relief in unit area. The culminating point in the overlaid grid is calculated from spot heights, trigonometrical stations or from the contour line in present investigation. The watershed has been classified into 6 categories of absolute relief (Fig. 4). In general, absolute height is increasing from NW to SE direction. The area under study may be classified into three broad classes of absolute relief. High absolute relief, ranging from 2000-2400 meters falls in the south eastern portion of the watershed. This portion of the catchment covers about 16% of total area. Low absolute relief covering 30% of the total catchment area in the central and northern most part of the catchment is found in the form of a narrow strip along the main channel. Medium absolute relief which covers about 54% area of the watershed falls in between the two zones discussed [7-13].

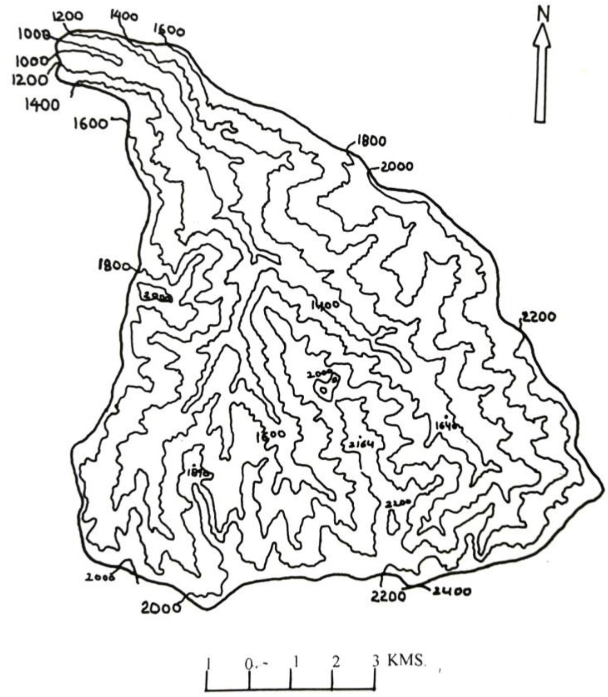

Fig. 3. Contour map

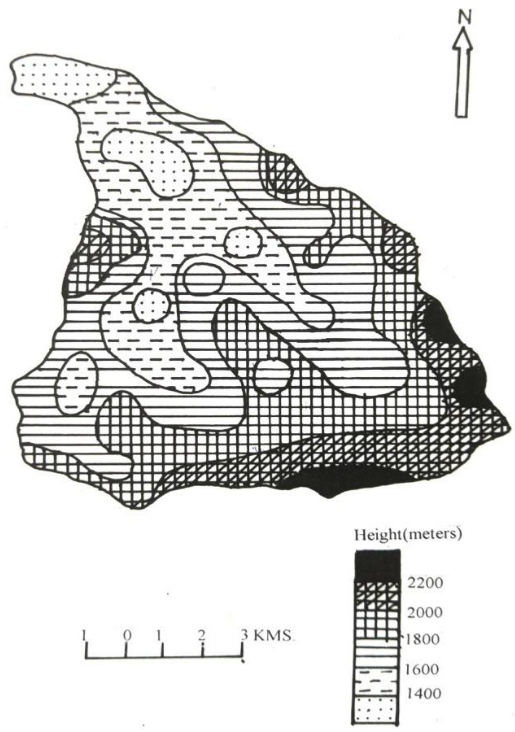

Fig. 4. Absolute relief map

Following the channel Nayaseri – Pajog, the watershed may be divided in eastern and western flanks. Eastern flank is narrower and demonstrates a higher proportion of high absolute relief (>1800 m). The Western half is wider and demonstrates considerably a large proportion of intermediate and lower relief i e 1800 meters and below. The basin tapers progressively North West ward with higher southern perimeter and lowest north western confluence point. The altitudinal zone extends in the parallel belts along the southern periphery but protrudes in finger-like pattern in north westerly direction. The lower height range below 1600 m receives the cusps of 1800 - 2000 m altitudinal belt in a funnel shape (Fig. 3). The arms of the funnel are marked by the stream Nayaseri and its tributaries Kalar and Naug. The arrangement of absolute relief zones nearly suggests a fault line along Nayaseri -Pajog and a tilt that does not rest and a block of upliftment in the eastern flank of Nayaseri.

3.2 Relative Relief (RR)

RR is a significant geomorphometric attribute for the evaluation of stages of terrain development. It is also referred as the diamension of available relief or maximum relief. It is calculated by taking the difference between summit point and bottom point in a unit area. Unit area may be in form of square or rectangle or minute grid. Several methods for determination of relative relief have been suggested by many scholars but here square grid methods have been applied. One square kilometer grid has been taken to calculate relative relief. Three categories of relative relief viz. low (≤200 m) medium (201 - 400 m) and high (>400 m) have been adopted for analysis (Fig. 5).

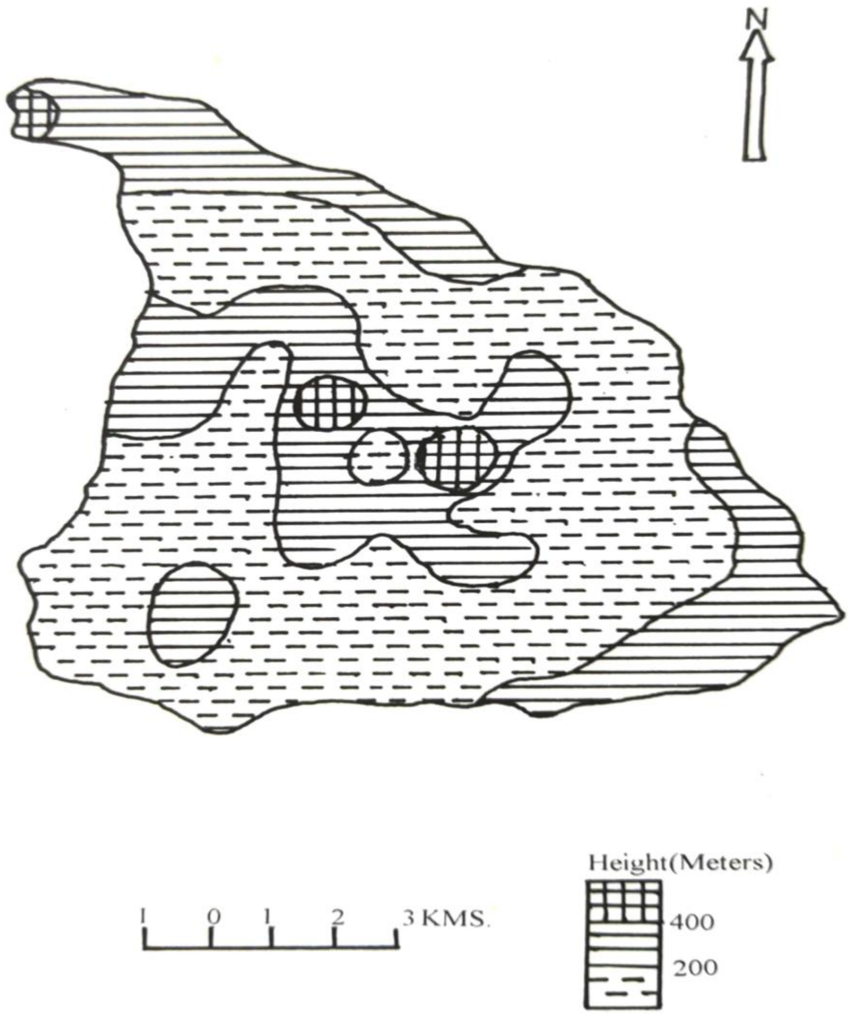

Fig. 5. Relative relief of watershed

More than 64% of the entire region falls under the category of low relative relief whereas 1.49% and 33% of total area of the catchment falls under high and moderate relative respectively. However, for the analysis, the catchment can be divided into two broad categories of relative relief viz. high (>200m) and low (<200m). Fig. 4 reveals that the relative relief is high in the southeastern fringe, junction area of Kalar, Naug and Pajog streams and in the northernmost part of the basin. In fact, the pattern of relative relief more or less corresponds to the observation of fault, uplifted block, submergence and tilt as mentioned in the context of absolute relief. The line of upliftment is marked by the patches of high relative relief (>400m) along the confluence of Kalar and Pajog streams, while tilt is broadly demarcated by the zone of low relative relief (<200 m). High relative relief along eastern periphery also confirm the assumption of upliftment block

3.3 Average Slope (S_A)

The complex of geology, the structure, the process of denudation and stages of landform development together determine the variety of slope. For the study of spatial distribution of slope analysis, Wentworth's method (1930) has been adopted for calculation of the average slope. The formula has been changed into a metric system. Slope of region has been classified into 5 classes viz very gentle (≤10°), gentle (11° -20°), medium (21-30), Steep (31-40) and Very steep slopes (>40°) (Fig. 6). The steep slope (>30°) in the region is distributed in the eastern part of Shimla range, north eastern fringe and in the central part of Bhaili-Fatenchi range. Gentle to moderate slope falls in western part of Shimla range, central part of Durgapur-Mashobra range and in the lake region of the watershed. Central part of the catchment exhibits moderately steep slopes.

Spatial pattern of average slope almost follows the spatial pattern of relative relief. After studying the geographical behavior of the watershed, it may be established that the catchment in general is governed by moderately steep and steep slopes. These two categories constitute approximately 75% area of the watershed.

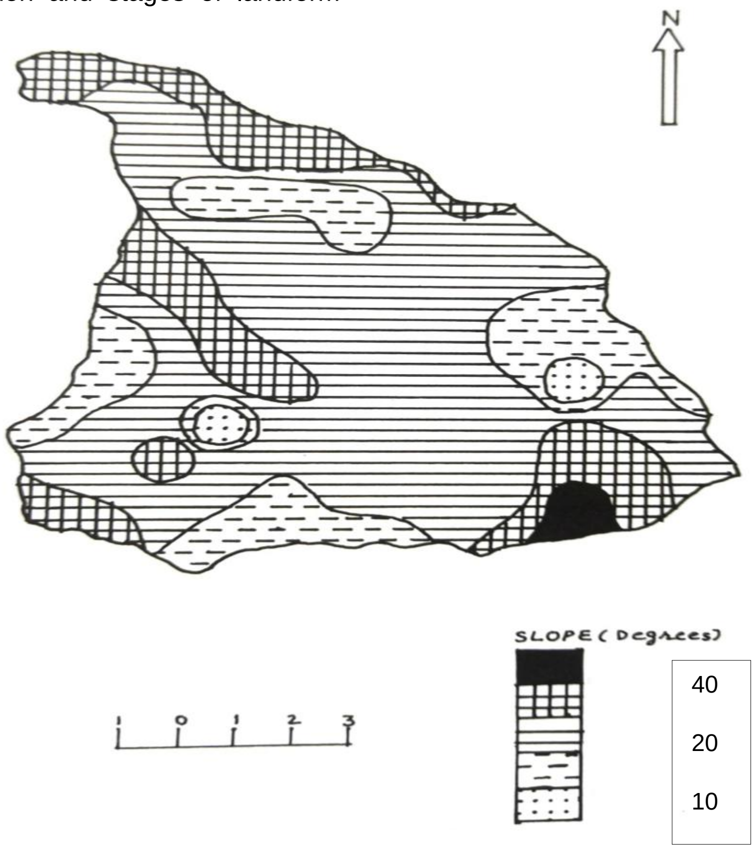

Fig. 6. Average slope of watershed

3.4 Dissection Index (D_I)

It is the ratio between two variables. The variables are RR and AR. Dissection index varies from 0 to 1. it is one (1) at the sea level where absolute relief and relative relief are the same and zero (0) at mountain peaks, where relative relief is zero but absolute is high.

Dissection index is generally used as geomorphometric determinants of the stages of terrain evolution. The values: 0-0.1, 0.1- 0.3 and above 0.3 are respectively related to in-equilibrium equilibrium and penultimate stages. The study area may be classified into two broad categories of dissection index: a) The central and northern portion covering about 70% area of the catchment have moderate dissection index ranging from 0.1 to 0.3 (Fig. 7). This means that this area is in a dynamic equilibrium stage. b) Low dissection index value i.e. (< 0.1) is distributed along the south eastern track. This category covers only 30% of the total area of the watershed. This area may be said in in-equilibrium phase.

No part of the area exhibits patches of more than 0.3 indexes, which means that the denudation process is still active and the landform is in late youthful to mature phase of sequential development. The lower trunk of the watershed is experiencing greater incidence of denudation process, as exhibited by high relative relief and steep slope occurrences. A highly pronounced gorge is also in evidence, besides the formation of a lake along the channel way.

If the broad generalization of the physical parameters are made, we can distinguish three blocks in the drainage basin roughly demarcated by a schematic diagram (Fig. 8) labeled as block A, B & C. The physical attributes of these blocks are also shown in the Table 2. On the basis of distribution of physical attributes it can be broadly generalized that block 'A' (lower trunk) is the zone of subsidence while block 'B' is the zone of emergence and block 'C' is is the zone of tilt due northwest.

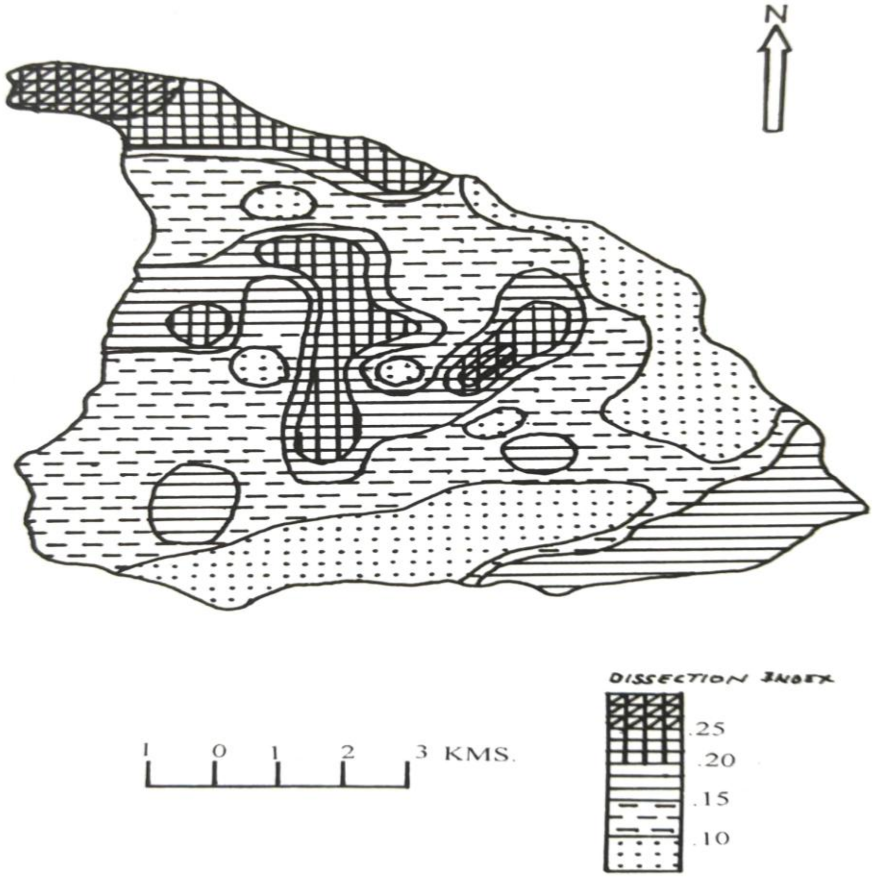

Fig. 7. Dissection index of watershed

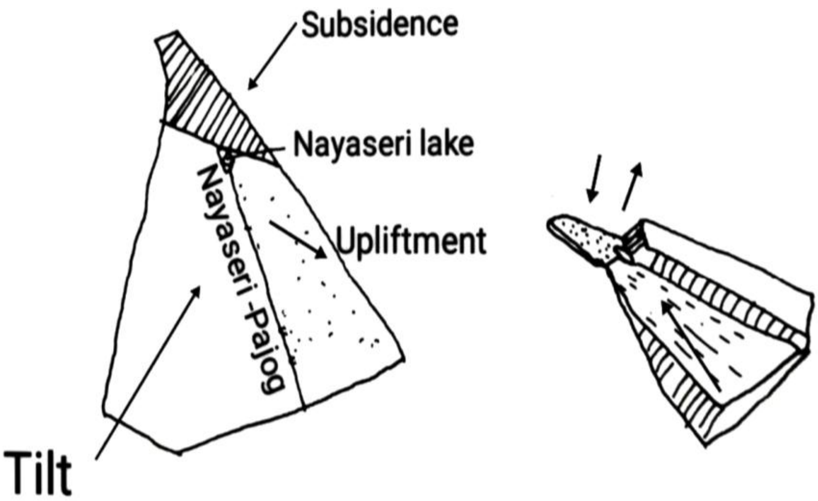

Fig. 8. Schematic diagram of subsidence upliftment and tilt in the area

Table 2. Physical attributes of different blocks

A Subsidence (Nayaseri Lake)	B Upliftment (Nayaseri –Pajog)	C Tilt (Kalar - Naug)
Low AR1400 M and less	High to moderate AR (1800 m. & more)	Moderate AR, tongue like extension due north -west
High RR (>400 m)	High RR (>400 m)	Low to moderate RR (<400 m.)
Steep Slope (>40°)	Steep Slope (40°) in two blocks, integrated by a patch of gentle and moderate slope (<20°)	Moderately steep slope (20°-40°)
High DI (> 0.20)	Low DI (< 0.15)	Moderate DI in the upper tract and high in lower tract

3.5 Hypsometric Integral Curve

The Hypsometric integral curve proposed by Strahler [4] has been used as an index to understand the stages of sequential development of this mountainous area. While plotting this curve two ratios are to be taken:

- a/A is taken on the horizontal axis. Where, a stands for area between successive contours (height zones) and A is the total area of the region.
- h/H is taken on the vertical axis. Where h stands for height of zone and H is the total height of region.

After plotting this curve (Fig. 9), it was found that the area under curve is 81%, which suggests the youthful phase of watershed in of its sequential development and large volume of landmass is yet to be eroded.

3.6 Clinographic Curve

This curve illustrates the average slope between selected successive contours. It expresses these successive average slopes in the form of a single curve. It is always plotted starting from top to bottom. It is very sensitive to the small changes in relief. In fact, this curve indicates the sudden changes in relief and exact breaks of slopes as well. The formula employed for this purpose is as under:

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

h is contour interval of height zone,
R is the radius of circle equal to the area surrounded by lower value contour in height zone
r is radius of circle equal to the area surrounded by upper value contour in height zone

Fig. 10 indicates sudden breaks of slope in the height zone of 1400 to 1800. It can be concluded from this figure that the above stated height zones have experienced major tectonic incidences.

3.7 Relief Ratio (Rr)

Rr testify the intensity of erosion and overall steepness of the region. This ratio tells about per unit length drop in height from originating point to confluence point of the principal stream or river. It may be defined as "the 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". Suchmm [3] Relief ratio (0.088 = 88 meter /Km.) indicates moderately steep slope and capacity of intense erosion in the area.

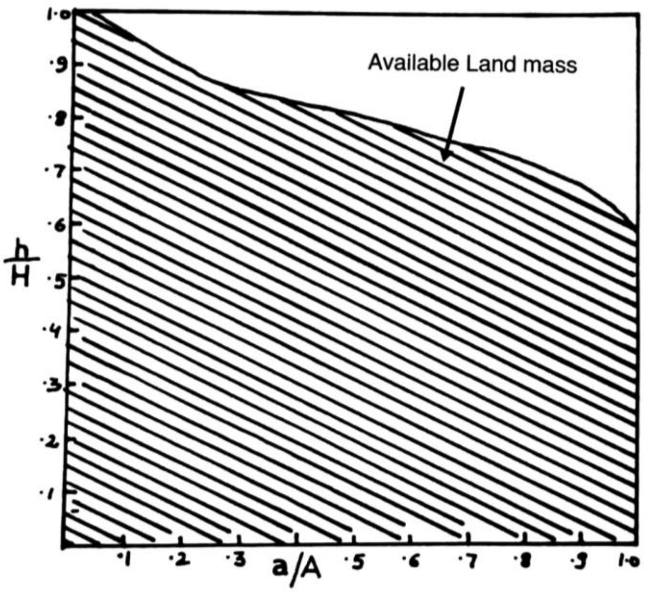

Fig. 9. Hypsometric curve of watershed

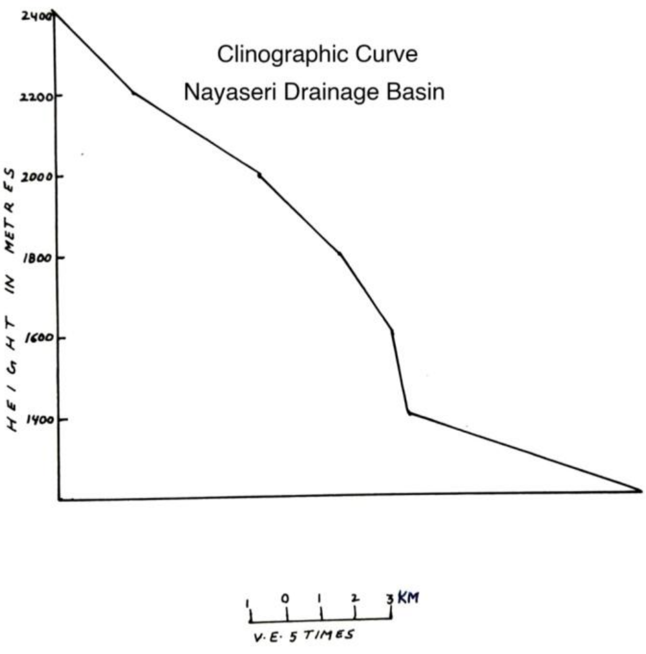

Fig. 10. Clinographic curve of watershed

3.8 Ruggedness Number (Rn)

It is the outcome of two parameters. The parameters are relative relief (H-h) and drainage density (Dd) (Suchmm, 1956). To calculate Rn both the parameters are taken into a similar unit of measurement. The number manifest the stability / instability of landmass and runoff [4]. The higher the value of Rn, the more will be instability and more will be the runoff in the watershed. The ruggedness number of area is 6.2. This value indicates high relief, unstable landmass, high runoff and more erosion capacity in the catchment

3.9 Relief Profile

Relief profiles from the contour map may be helpful in visualizing the relief. These also help in description and explanation of landforms. The cross sectional and longitudinal profile has been drawn for above said purpose. Eight cross sectional serial profiles are drawn to acquaint with the undulation of surface morphology across the stream Nayaseri (Fig. 11).

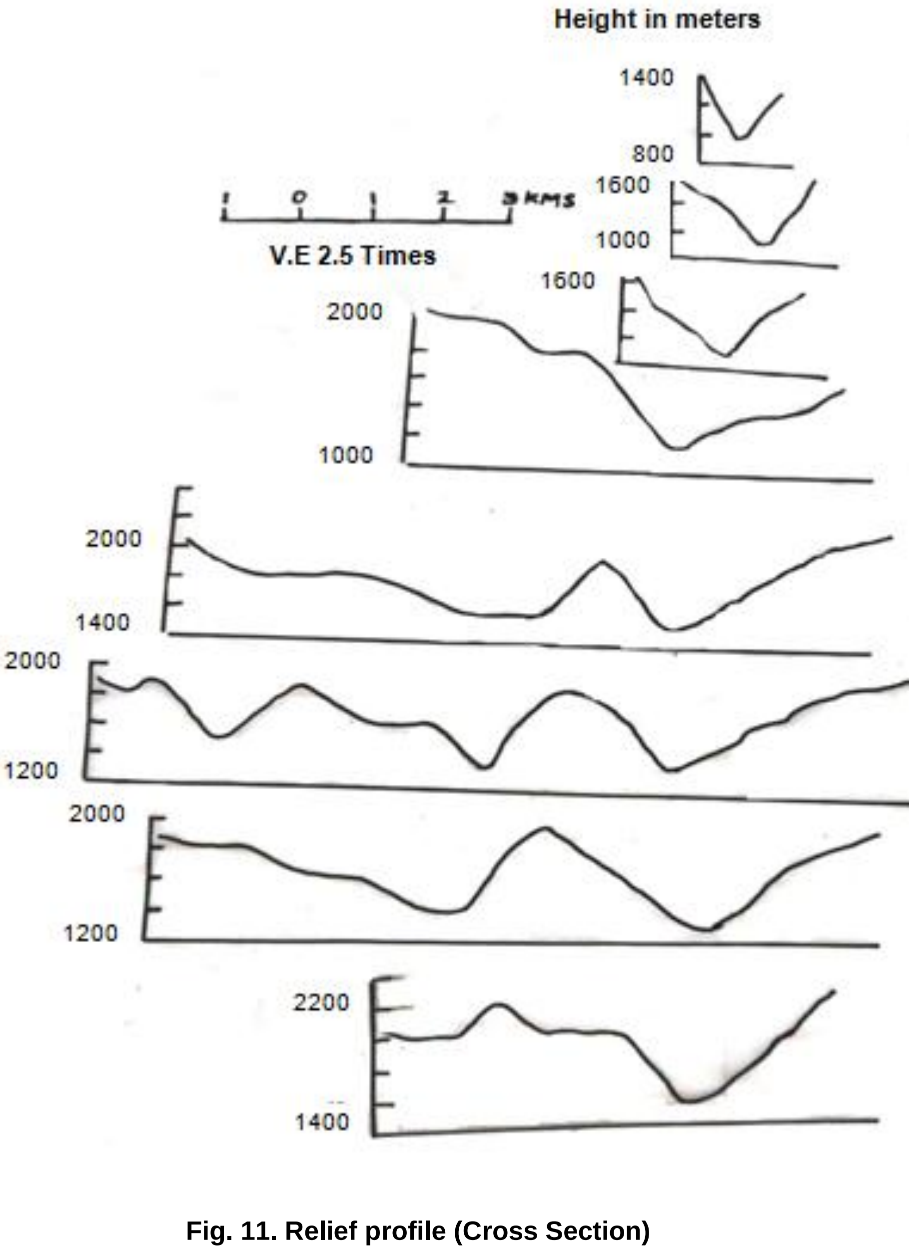

Fig. 11. Relief profile (Cross Section)

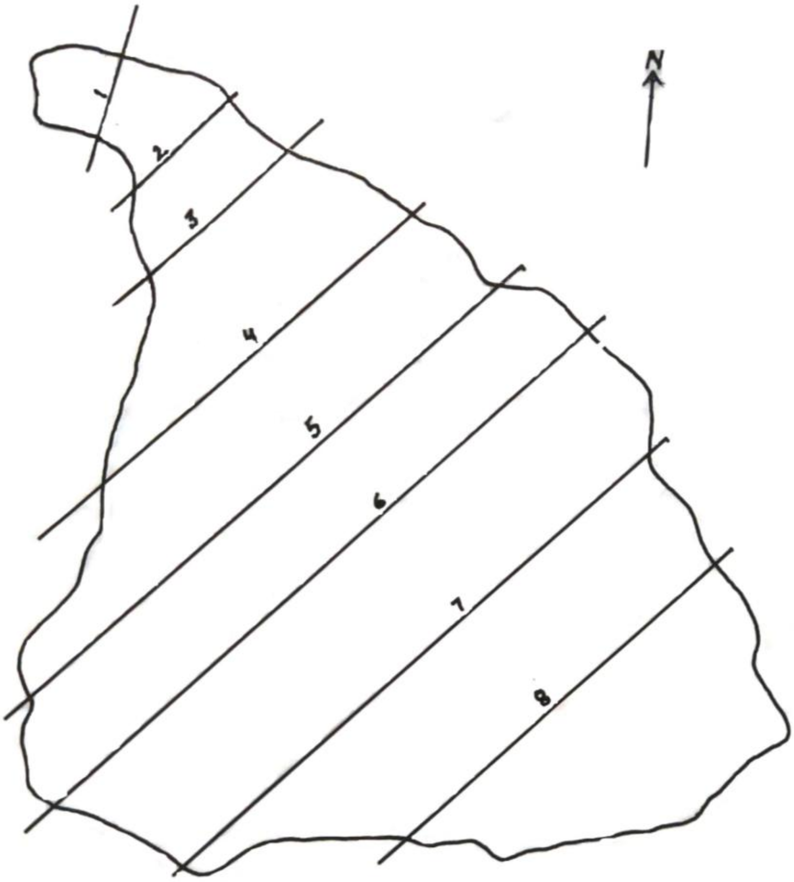

Fig. 11A. Section lines on map

The serial profiles of the watershed indicate that:

1. The interfluves are high and extensive. Various streams have dissected the surface considerably.
2. Valleys are deep and side slopes of valleys are very steep in the catchment. This suggests that catchment is in the young stage of its erosion cycle.
3. Profile No. 7 & 8 indicates that Nayaseri stream has formed a gorge near the conference point. This fact suggest the young topography of watershed
4. Profile No 6 & 7 expresses the brakes of slope at the height of about 1400 meters in the western flank of the stream Nayaseri which indicates the tectonic incidences in this area.
5. Breaks of slope at the height of about 1800 meters in serial profile No. 2 suggest tectonic incidences or structural control in the area.

The study of serial profiles of the area indicates that the area is in the youthful phase of its development and the catchment has experienced tectonic incidences in the recent past.

The longitudinal profile of the stream expresses the gradient of the stream path from source to conference point. It also expresses the breaks of slope in the path of the stream. These breaks of slopes are imprints of endogenic forces on the topography. The longitudinal profile of the catchment has been drawn on the scale to get an accurate picture of channel course along the profile line (Fig. 12). The elevation has been taken on the vertical axis whereas the length of stream from the source to the confluence point on the horizontal axis. The vertical scale is exaggerated 2.5 times that of horizontal scale in order to emphasize the topographic feature. The longitudinal profile (Fig. 12) reflects the sudden break of slope at a height of about 1600 m. This sudden break of Slope indicates that the area has experienced tectonic activities.

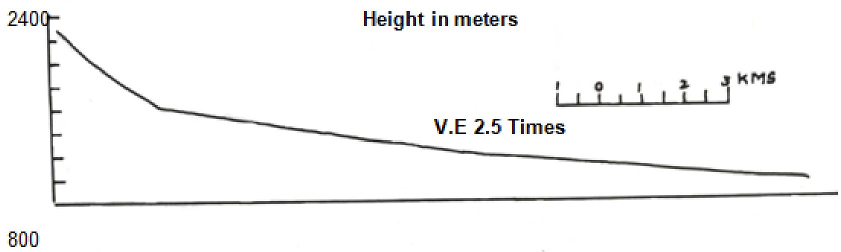

Fig. 12. Longitudinal profile of area

4. CONCLUSION

The arrangement of absolute relief suggests a fault line along Nayaseri - Pajog and a block of upliftment in eastern flank, block of tilt in western flank and zone of submergence in north- west of Lake Nayaseri. The pattern of relative relief also more or less corresponds to the observation of fault, uplifted block, submergence and tilt as mentioned in the context of absolute relief. The line of upliftment is marked by the patches of high relative relief (>400m) along the confluence of Kalar and Pajog streams, while tilt is broadly demarcated by the zone of low relative relief (<200 m). High relative relief along the eastern periphery also confirms the assumption of upliftment block.

Spatial pattern of average slope almost follows the spatial pattern of relative relief. After studying the slope aspects of the study area it may be concluded that the catchment in general is governed by moderately steep (20° - 30°) and steep slopes (30°-40°).These two categories constitute 75% area of the watershed. Hypsometric integral value of 81% suggests that the watershed is in youthful phase of its sequential development and large volume of landmass is yet to be eroded. Clinographic curve indicates sudden breaks of slope in the height zone of 1400 to 1800 meters which suggest that this height zones have experienced major tectonic incidences. Relief ratio (0.088) indicates moderately steep slope and capacity of intense erosion in the area. The ruggedness number 6.2 also indicates high relief, unstable landmass, high runoff and more erosion capacity in the catchment. The serial profiles and longitudinal indicate sudden break of slopes in the area. These breaks indicated the youthful stage of catchment in its sequential development These also indicate that the catchment has experienced tectonic incidences in the recent past.

To sum up it may be concluded that the watershed has experienced tectonic incidences in the recent past. Fault, submergence, upliftment, tilt and sudden breaks of slopes are imprints of these activities on topography of the area. Indicators like - Slope, relief ratio, ruggedness number and relief profiles suggest that the watershed has Steep slopes, unstable landmass and capacity of intense erosion. Various measures of relief also manifest the youthful stage of watershed in its sequential development.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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