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ANALYSIS OF WATERSHED CHARACTERISTICS AND BASIN MANAGEMENT USING RS AND GIS

A CASE STUDY FROM UPPER PROVENANCE OF KARAMANA RIVER, TRIVENDRUM DISTRICT, KERALA

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Abstract

Qualitative and quantitative analysis of Watershed Characteristics of a river basin is necessary for the evaluation of its resources and their sustainable management. Watershed Characteristics of Upper Provenance of Karamana River Basin in Trivendrum District, Kerala are evaluated using Remote-Sensing data and GIS applications. The Karamana river basin has a catchment area of 128.75 sq.km. and a length of 16.75 km of major stream. Morphometric analysis shows that the river is of sixth-order and the basin contains 671 total number of streams. The average bifurcation ratio for the basin is 4.22 indicating that the drainage pattern is not influenced by geological structures. Total length of drainage inclusive of all order streams is 276.56 km and that of sixth-order stream alone is 7.91 km. The mean length of streams increased with the order of stream. A relief map is prepared. It shows that elevation gradient is highly fluctuating in the Eastern and North-Eastern parts. The streams are with Potential Energy and less sinuosity. Hypsometric curve is hyperbolic indicating a matured stage of the basin within the limits of watershed area. The hypsometric integral value implies that 78% of the area was eroded by various processes. Digital terrain map of the study area is prepared using ArcGIS. Land-use is analysed by dividing the area into 11 categories and comparing the data from 1967 to that of 2008. Forest area is found to be decreased by 24% in the last 40 years. Socio-economic compulsions has an impact in the environment degradation of the region. Remote-Sensing and GIS applications are found to be highly useful in extracting the precise data for the evaluation and analysis of watershed characteristics.

Introduction

Analysis of watershed characteristics of a river basin is necessary for the resource assessment of the area that includes classification of landforms, erosion and transportation processes operative in the area, landuse patterns and landuse changes. Quantitative analysis of these characteristics forms a strong basis for the study of geometrical and mechanical aspects of drainage basins [16]. Remote Sensing and GIS based approach in watershed assessment is handy and effective for its treatment conservation [1]. Spacial data application in watershed characteristics and management covers a precise inventory of the watershed [14].

Upper provenance of the Karamana river basin in Trivandrum district has been taken up to evaluate the watershed characteristics using remote sensing data and GIS applications. Karamana river originates from the base of the Chemmunji Mottai peak from a height of 1717 m, the highest topographic feature of the Western Ghats in the region. The main stream has a length of 68 km and drains over an area of 702 sq.km.. The river is dammed at Aruvikkara and at Peppara, near the confluence of Attingal todu after which the river flows in south-westerly direction and debouches into a lagoon 3km south of Thiruvananthapuram. The Upper Provenance of the Karamana Basin extends from 8°34’73” to 8°41’17” N latitude and 77°4’10” to 77°13’20” E longitude and is shown in Fig.1. The stream flows as a sixth order major stream and has a length of 16.75 km and a catchment area of 128.95 sq. km. The area experiences tropical humid climate and receives 1800 cm of average annual rainfall. The top soil is mostly laterite and is mixed at some places with forest loams. Morphometric analysis of the Karamana drainage basin has been attempted. In this work, quantitative analysis of morphogenetic parameters haven been done and their inferences are drawn. Land use is categorised and their changes are compared from 1967 data to that of 2008.

Methodology

Quantitative and qualitative morphometric analysis have been done and the basin characteristics are correlated with basin hydrology. Remote Sensing (RS) data and Geographic Information System (GIS) applications are integrated for the morphometric analysis of watershed characteristics of the Upper Provenance of Karamana basin. The morphometric analysis include terrain analysis, computation of drainage characteristics, environmental evaluation and landuse pattern analysis [15]. The methodology includes primary data collection, field mapping, map analysis using 1:50,000 scale topographic sheets and other computer applications for data assimilation and display. Maps related to the Karamana basin are prepared using topographic sheets and imageries made from Remote Sensing data. The drainage map and the landuse maps have been prepared from the topographic sheets whereas geomorphology map is prepared from IRS images and toposheets. Drainage map of Karamana basin has been prepared in 1:50,000 scale using topographical maps and IRS images. Landuse maps are prepared for the years 1967 as well as 2008 and the changes in the landuse pattern are analyzed and interpreted. Visual image interpretation is followed by preparation of landuse map from IRS imageries and toposheets. In this process ground data are also collected through field-work and are integrated. Polygons are drawn around features like fields, land units, settlements etc and a label is given to each and characterized it by attributes. Image characteristics can be pattern, texture, color or tone on image [3]. These are then subjected to detailed field verifications. In this work, two images of Survey of India have been used for visual image interpretation. They are: IRS-1C, 58H/2(1:50,000), Feb, 1998 and IRS-P6, LISS-III,58H/2(1:50,000), Nov, 2007. ArcGIS (version 9.2) software is used for integrating maps and other data.

Results and Discussion

Watershed Characteristics make use of parameters like area, length, slope and shape of the watershed and they are useful in analyzing the geomorphology of the region. The drainage area reflects the volume of water that can be generated from rainfall. The slope of a watershed effects the momentum of runoff. The shape of a watershed reflects the way the runoff will bunch up at the outlet. A circular watershed results in runoff from various parts of the watershed reaching the outlet at the same time. These characteristics can give an idea about the physical processes that are being operative over the region and also the dynamic processes operative in the region.

Morphometry and Channel Pattern

Morphometric analysis has been done to understand the river geometry. Linear and areal aspects of the drainage basin have been studied to understand the erosional processes operating in various parts of the basin.

Linear aspects of the channel system

The linear aspects of a channel system deal with the quantitative analysis of landform in a watershed area, where the running water has been acted for a long period of time modifying the surface geometry. Linear aspects of channel system includes planimetric measurements that are projected upon a horizontal datum plane [12].

Stream ordering

The smallest fingertip channel is designated as order 1. A channel segment of order 2 is designated where two first order channels join together and the process is continued further. The trunk stream, through which all discharge of water and sediment flown, is given by the stream segment of highest order [16]. Fig.2 shows the streams of various orders and drainage pattern in the Karamana basin. Horton's law of stream order [8] states that the number of stream segments of various orders in a given drainage basin, forms an inverse geometric sequence with order number.

$\mathbf{Nu = R_b^{k-u}}$ where, k is the order of trunk segment,

$\mathbf{R_b}$ is bifurcation ratio

The upper part of the Karamana river under study is a sixth order stream. The stream number is a function of the basin area. The area of basin increases as the number of streams increase. The total number of streams in the study area, inclusive of all orders, is 671. The river basin has a catchment area of 128.96 sq. km. Therefore, the streams of all orders have been spread over a considerable area and the Karamana river basin has got considerable significance.

Bifurcation ratio

The bifurcation ratio is the ratio of the number of stream segments of a given order Nu to the number of segments of the higher order $\mathbf{N_{u+1}}$.

$$\mathbf{R_b = N_u/N_{u+1}}$$

Here, u denotes the order of the stream segment and $\mathbf{N_u}$ denotes the number of segments of a given order.

In this basin, there are 511 first order streams, 124 second order streams, 25 third order streams, 8 fourth order streams and 1 sixth order stream. Because of the likelihood of variation in watershed geometry, the bifurcation ratio may not be precisely the same from one order to the next, but it tends to be constant throughout the series. If the drainage pattern is not influenced by the geological structures, the bifurcation ratio will range between 3 and 5. The computed value for the average bifurcation ratio for the present basin is 4.22 which indicate that the drainage pattern is not influenced by geological structures.

Stream length

Horton's law of stream length states that the mean length of stream segment of each of the successive order of a basin tends to increase according to a constant length ratio [8]. To obtain the mean length of channel Lu of order u, the total length is divided by the number of segments Nu of that order. The total length will decrease with increase of order of stream, while the mean length will increase with the increasing stream order. The total length of the first, second, third, fourth, fifth and sixth order streams are 276.56 km, 79.25 km, 44.61 km, 20.87 km, 7.69 km and 7.91 km, respectively. The total length of streams has been divided by the respective number of segments of each order to get the mean length of a stream . In that procedure, the mean length of the streams from lower to higher order is obtained as 0.54 km, 1.56 km, 0.56 km, 2.61 km, 3.85 km and 7.91 km, respectively. The data implies that the total length of stream increases with decrease of the order of stream and average length of the stream increases with the order of the streams. The basin consists of only one sixth order stream with maximum stream length of 7.91 km and is considered as major stream that flows across the Karamana basin. Therefore, sixth order stream is contributing sufficiently to the basin.

Length of overland flow

The length of overland flow affect both the hydrologic and physiographic development of drainage basins [8]. It is the mean horizontal length of flow path from the water divide to the stream in a first order basin and indicates the amount of stream spacing and degree of dissection. The average length of overland flow is half the average distance between stream channel and is approximately equal to half the reciprocal of drainage density [5].

$$L_g = 1/2D$$

The length of overland flow for the sixth order basin is 0.15 km. There are two fifth order basins - namely, 5A and 5B, and theirs values are 0.14 km and 0.13 km, respectively. Length of overland flow one of the fourth order streams of is 0.13 km. These values show that the stream spacing decreases with the decreasing stream order.

Areal aspects of the channel system

Areal aspects of drainage basin include measurement of areal elements such as basin shape, drainage density, constant of channel maintenance, stream frequency and texture in a systematic way [12]. Horton [8] stated that the mean basin area of successive orders tend to form a geometric series and the basin area increases with the increase in stream order. Area of a higher order stream includes the total area covered by all streams of lower order [16]. The drainage areas occupied by the streams of sixth-order, fifth(A and B)-order, fourt-order and third-order are 128.95 sq.km, (51.43 and 33.35) sq.km, 23.56 sq.km and 10.09 sq.km, respectively.

Basin shape

The geometry of the basin shape indicates the genesis of the basin. The circularity (low, medium or high) of the basin relates to the different stages of basin evolution. The shape of a drainage basin can be expressed in terms of form factor (Rf). Form factor is the ratio of basin area to square of basin length [8]. The value of form factor would always be less than 0.79, if the basin is perfectly circular.

$$R_f = A/L_b^2$$

where A = Area of the basin and Lb = Axial length of the basin.

The value of form-factor of sixth-order stream basin is 0.32 and less for all other order of streams. Therefore, the shape of all the basins of all order are circular in their shape.

Drainage density

Drainage density is the total length of the stream inclusive of all orders within the basin per unit of area. Drainage density is an important aspect of morphometric analysis of a drainage basin as it can be correlated to the dynamic nature of the stream and the area of the basin.

$$\text{Drainage density, } D = L_k/A_k$$

Where, L_k is the total length of the channel inclusive of all orders.

And, A_k is the total basinal area.

Drainage densities of the basin for sixth order to third order are obtained as 3.39, (3.68 and 3.79), 3.76 and 2.93 km/km2, respectively. Only fifth and fourth streams are closely spaced in the basin and the total number of streams of these orders are (289+186) and 131, respectively.

Stream frequency

Stream frequency gives the number of streams per unit area [8].

$$F_s = N/A$$

Where **N** = Total number of streams inclusive of all order.

A = Total area of the basin.

The sixth to fourth order sub-basins of the Upper Provenance of the Karamana river have a stream frequency of 5.20, (5.91 and 5.99) and 5.86, respectively. In general, the stream frequency increases with decrease in order. But in the present case, fourth order sub-basin shows some anomaly. It has a stream frequency less than the fifth order sub-basin. But its drainage density is considerably high. It implies that fourth order streams are closely spaced in a limited drainage area comparatively.

Relief aspects of the channel system

Relief is the difference in elevation between any two reference points. Relief measure of a region indicates the potential energy of a drainage system. A region having a high relief can transfer high energy into the drainage system. Maximum relief within a region is naturally the difference in elevation between the highest and lowest points. The relief map in Fig.3 shows that the eastern and northern parts of the area are very steep with a relief ranging from 700 to 1700 m. The contours are very close to each other and dense with high gradients. Towards the western part of the study area, the steepness slowly decreases with an altitude varying from 100 to 200 m. The contours are widely spaced with small gradients.

Sinuosity

The Karamana river shows a number of sinuous stretches. In the Weatern Ghats region where the altitude is very high and in the upper reaches of the midlands, the sinuosity is structurally controlled i.e., the river didn't get enough space to develop meanders as well as the stream possess high potential energy and hence run mostly in a straight-line path. In the lowlands and the coastal regions, sinuosity depends on the fluvial parameters like the velocity of the river, sediment load, gradient of the surface. It is understood that the more energy the river has, the less sinuous it will be [10],[13]. In highlands having high valley gradient, the stream velocity is relatively high and is capable of eroding the banks. The channel slope increases at a slower rate than the valley slope and the stream attains more energy and power. In lowlands, the stream velocity is usually less and gradient of slope is very less below which the flow is not capable of eroding the banks. Velocity and power of the stream decreases. The stream deposits its sediment load and hence takes meandering. Hence in low altitudes the sinuosity of the stream increases.

The sinuosity of the main stream that flow through the Karamana basin is divided into five segments, designated as A to E in Fig.2 from higher altitude to lower altitudes and their sinuosity is tabulated in Table-1. Segment-A has the highest slope and other segments have slopes in the decreasing order and segment-E has the least slope. The sinuosity is in the increasing order from highlands to midlands with a value from 1.08 to 1.43.

Hypsometric Analysis

Hypsometric analysis gives the relationship between area and altitude of a region by which the action of different erosional agencies during the development stage of the basin can be understood. Hypsometric analysis has been done on the basin area of the Upper Provenance of the Karamana river. The area enclosed between successive contours is calculated from base to top and the area percentage is calculated with respect to the total area of basin and the net cumulative percentage has also been calculated. Then the cumulative frequency has been plotted along the horizontal axis and the height has been plotted in the vertical axis in order to obtain a hypsometric curve as shown in Fig. 4. The hyprosmetric curve for the Karamana basin is a hyperbolic. The hypsometric integral value is calculated from the hypsometric curve and is obtained as 21.97%. This means that about 78% of the area is eroded by various erosional processes and 21.97% of the area is only left for erosion to form a plain and/or featureless area. Hypsometric curve for the upper provenance of the Karamana basin is a hyperbolic curve and also the magnitude of the hypsometric integral (HI) value indicates a very matured stage of the basin. The maturity is inferred confining to the area of the basin, 128.95 sq.km., only.

Digital Terrain Model (DTM)

A Digital Terrain Model (DTM) of the study area is prepared from the relief map (Fig.3) using ArcGIS software. The relief map is first projected in to 3D projection using Projected Coordinate System and then Triangulated Irregular Network (TIN) is created with the help of 3D analyst tool. From the TIN data a DTM is prepared for the Upper Provenance of the Karamana basin and is shown in Fig.5. DTM has got the advantage that it can be integrated with any type of data collected from the same area.

Geomorphological mapping

Geomorphological mapping is an effective tool in terrain evaluation to identify the significant features of relief. This technique relates morphology, material and erosional processes operative over the area. Geomorphological map for the area is prepared and presented as Fig.6. Geomorphological mapping makes use of recognition and plotting of breaks and change of slope in the landscape.

Karamana river basin form a natural unit of landform and both the denudational and aggradational processes have been operative in this region. The major part of the upper provenance of the Karamana river basin falls under the highland area. Only very small area around the reservoir falls under midland and lowland. The river basin is classified into escarpments, very steep areas, steep areas, moderately undulating areas and riverine plains. Escarpments are those areas having a slope percent greater than 95. The areas having a slope percent between 75 – 95 are classified as very steep areas. Steep areas are those having a slope percent between 55 – 75. Moderately undulating areas have a slope percent between 35 – 55. Riverine plains are almost uniform and has a slope percent less than 10. About 30.46 percent of the total study area falls under very steep areas and 31.87 percent are categorized as steep areas. Moderately undulating area constitute 29.70 percent of the total area while escarpments and riverine plains occupies 7.97 percent of the area of the basin.

Land-Use Analysis

Landuse is the result of human interference and interaction with natural environment [17]. Landuse surveys are considered as basic to any assessment of resources [2]. Landuse-landform analysis forms an integral part of assessment of natural resource potential and terrain suitability of a particular area [11]. Sustainable development in agriculture, forestry and fisheries sector aims at conservation of land, water, plant and animal genetic resources and is environmentally non-degrading, technically appropriate, economically viable and socially acceptable [7].

Landuse

For the analysis of landuse pattern of the basin, landuse is categorized into nine categories using the Survey of India toposheet of 1967. For calculating the landuse pattern of 2008, IRS images and toposheets are used. Total nine categories are identified in the 1967 map. These categories are increased up to 11 in 2008. Landuse map is prepared and is shown Fig.7. The details are presented in Table-2. Some of the salient features are: The forest area which occupied 78.8 percent of the total area in 1967 is decreased to 60.08% in 2008. Areal spread of rubber plantation according to 1967 estimate is about 0.4 percent of the total area. But, it has significantly increased to 5 percent as per 2008 estimate. There were no major water bodies in 1967 map. Peppara reservoir was built in 1982 and it occupies about 4 percent of the total area after which landuse pattern has been changed. Rock outcrops at different patches of the area amounts to 3.1 percent and it has been increased to 3.8 percent from 1967 to 2008.

Changes in Landuse

Landuse change is a complex and dynamic process. Urbanization resulted in the changes of landuse pattern which also has resulted in environment degradation. Landuse changes can be observed from Figs.6 and 7. The tremendous increase in population has been lead to deforestation as more and more forest area is being acquired for mixed tree crop and only it shows a slight increase in the last 40 years. It has gone up covering an areal extent of 12.16 sq. km. in 2008 from 9.62 sq. km. in 1967 with a growth in area to the tune of 26.4% . About 5.25 sq. km. of the forest area was destroyed when the Peppara reservoir was built.

Deforestation

Spacial analysis of landuse indicates that, at lower altitudes (>300 m), the forest area is replaced by rubber plantation and at higher altitudes (>700 m) forest area is replaced by cardamom plantation [4]. Jha, et al [9] also observed that decrease in forest cover is replenished by agriculture and plantations. The Upper Proverance of Karamana basin had a thick forest cover extending an area of

101.61 sq.km. out of total area of 128.95 sq.km. in 1967. As per 2008 data, the forest cover has come down to 77.44 sq.km. and replaced by rubber, eucalyptus and acacia plantations after impounding of Peppara reservoir in 1982. In the last 40 years, deforestation of the region has reached to 23.79%.

Conclusions

Analysis of watershed characteristics, landuse pattern and landuse changes has been taken up for the Upper Provenance of Karamana basin. Remote Sensing and GIS applications have proved very much useful in analyzing the basin characteristics. It is observed that Karamana basin is experiencing severe deforestation and environmental degradation. Deforestation may lead to other serious threats causing ecological imbalance like soil erosion, landslides, sediment pollution and is also lead to changes in hydrological and climatic regime. Socio-economic compulsions caused an impact in the landuse changes and in turn environment degradation. The region needs monitor regularly with sustainable management schemes.

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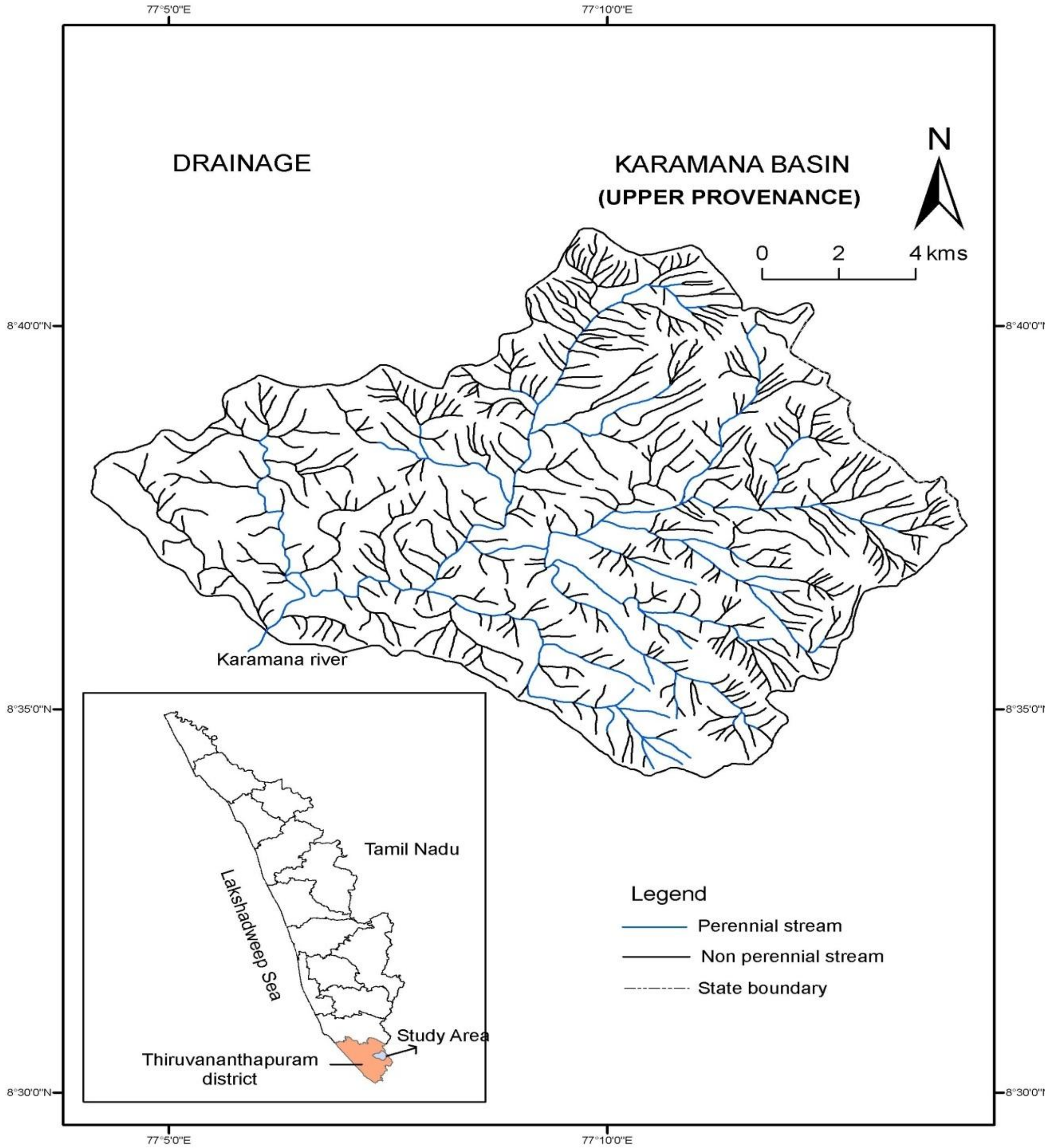
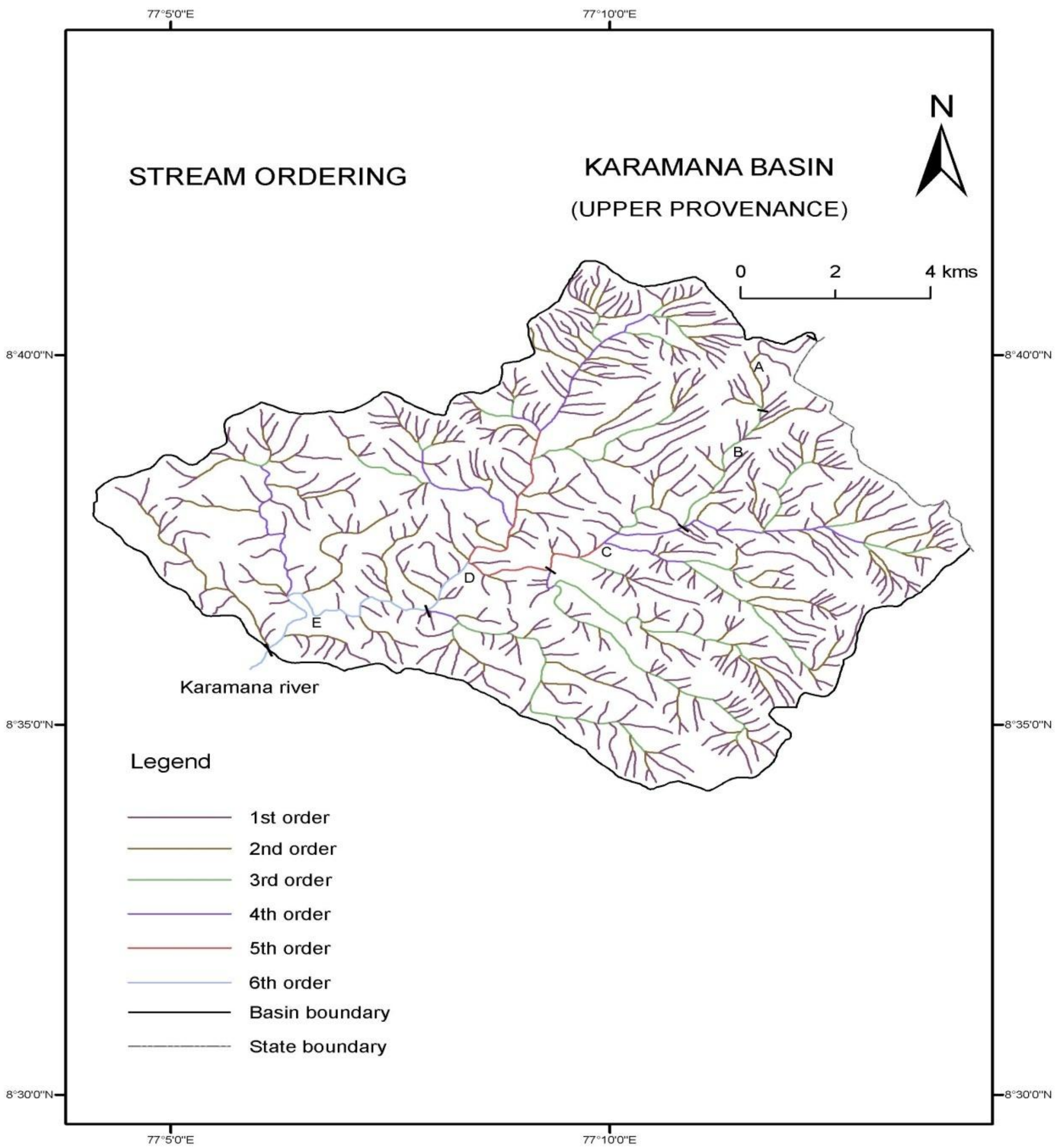


Figure.1-Location and drainage map of Upper Provenance of Karamana basin.



Figue.2-Details of streams and drainage pattern of Karamana basin.

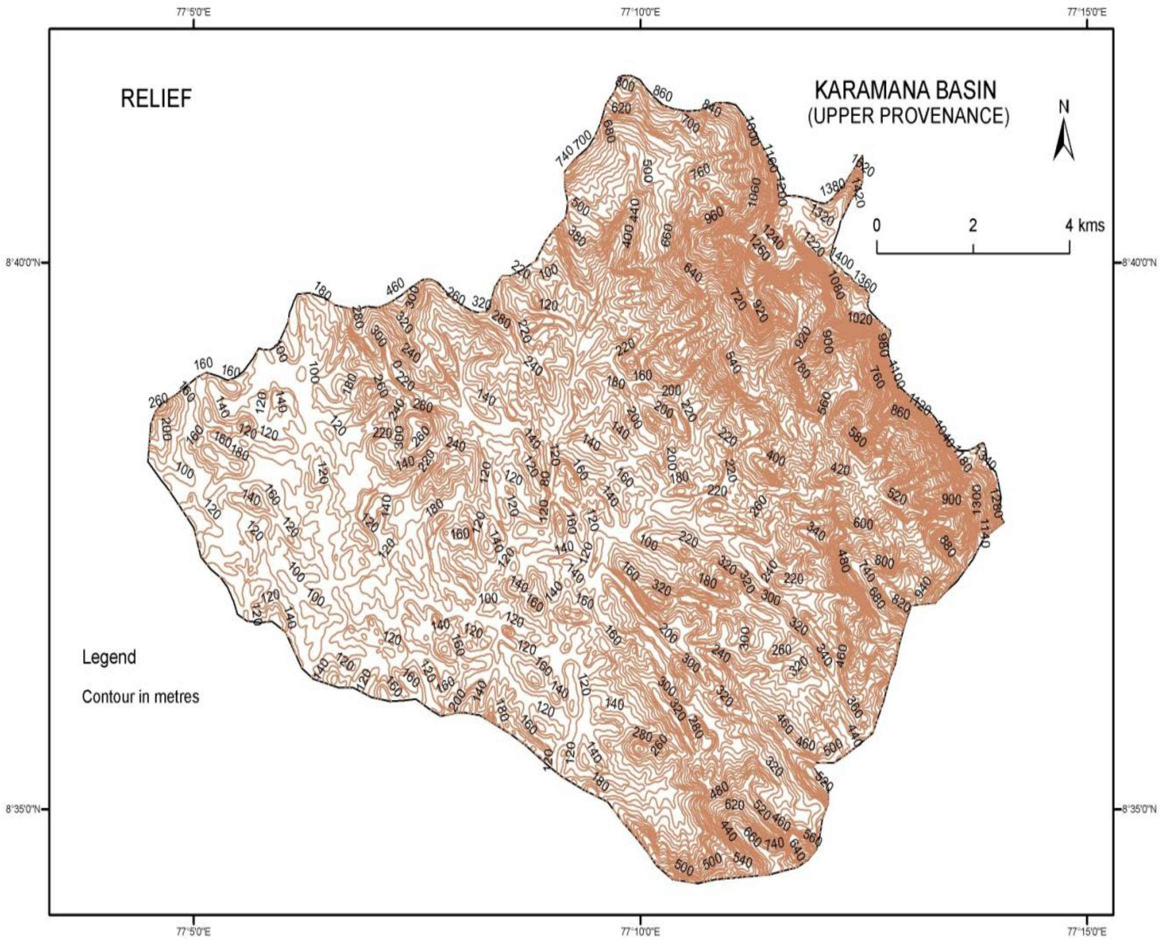


Figure.3-Relief map of Karamana basin.

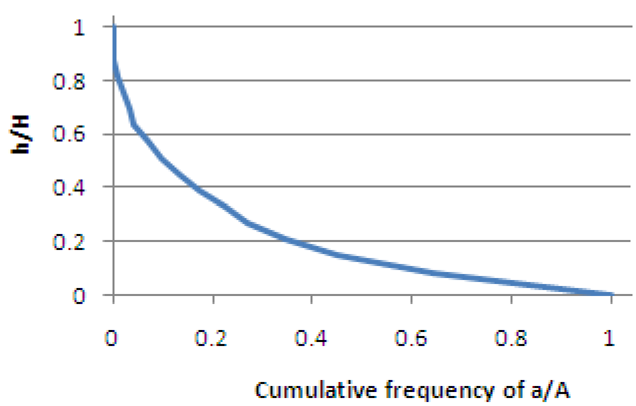


Figure.4- Hypsometric Curve for Karamana basin.

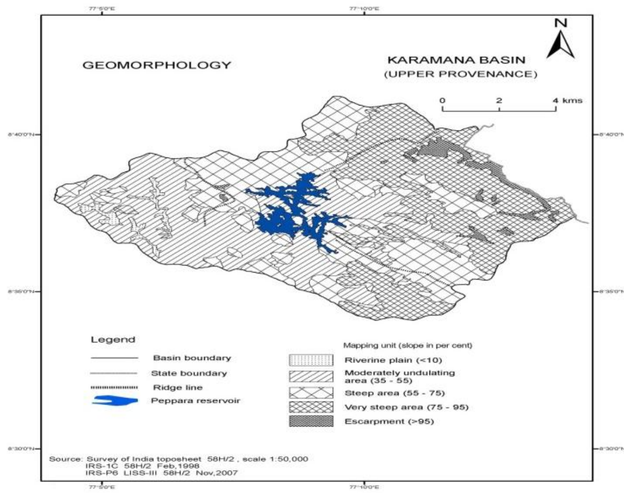


Figure.5-Digital Terrain Model (DTM) for the Karamana basin.

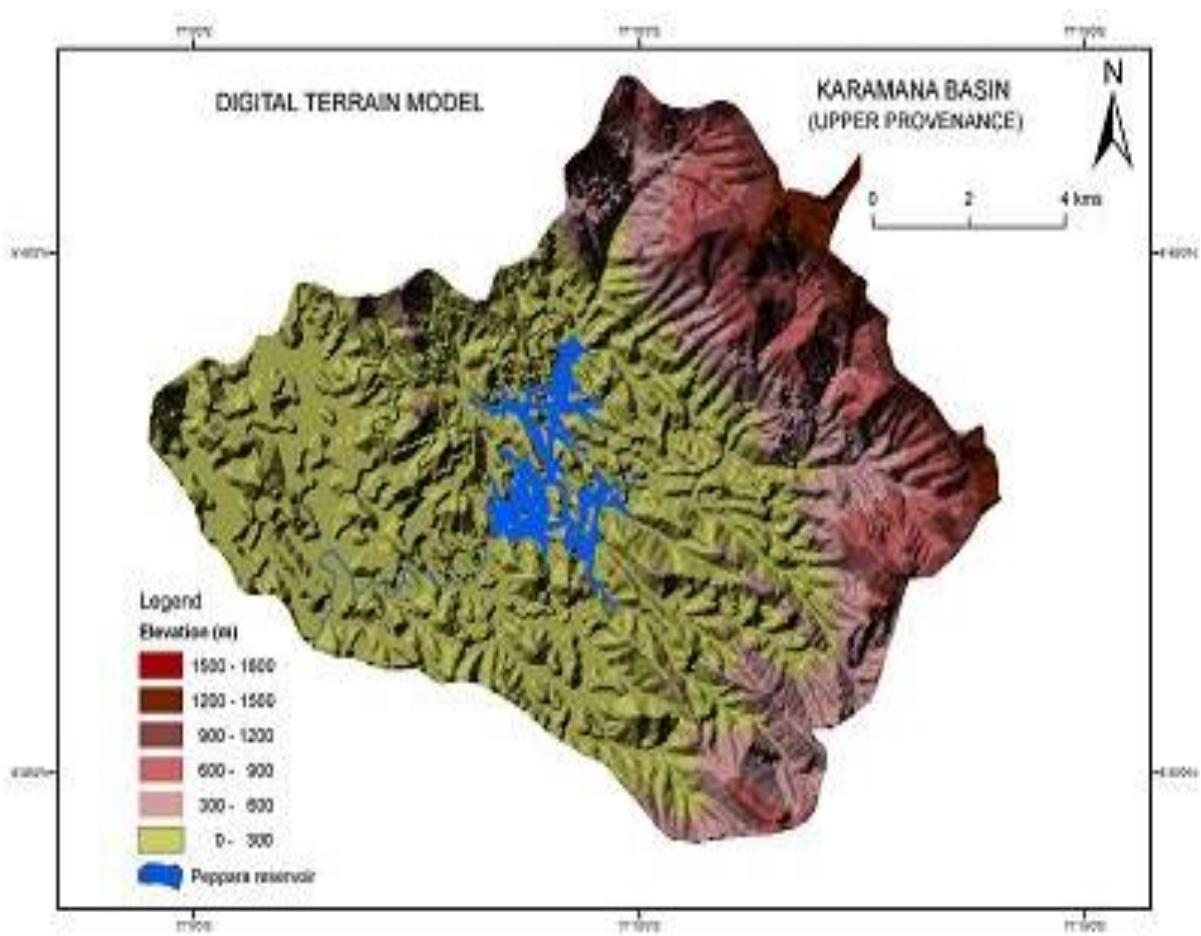


Fig.6-Geomorphology of Karamana basin.

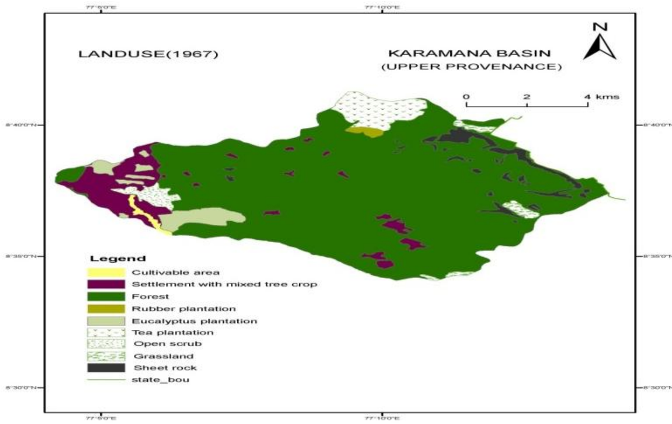


Figure.7-Landuse map of Karamana basin in 1967.

Forest	101.61	78.79	77.44	60.05	-23.79
Settlement with mixed tree crop	9.62	7.46	12.16	9.43	26.40
Eucalyptus	4.92	3.82	5.63	4.37	14.43
Grassland	1.51	1.17	2.64	2.05	74.83
Rubber	0.55	0.43	6.47	5.02	1076.36
Tea	5.07	3.93	4.99	3.87	-1.58
Sheet Rock	4.08	3.16	4.93	3.82	20.83
Degraded forest	-	-	9.44	7.32	-
Water body	-	-	5.25	4.07	-

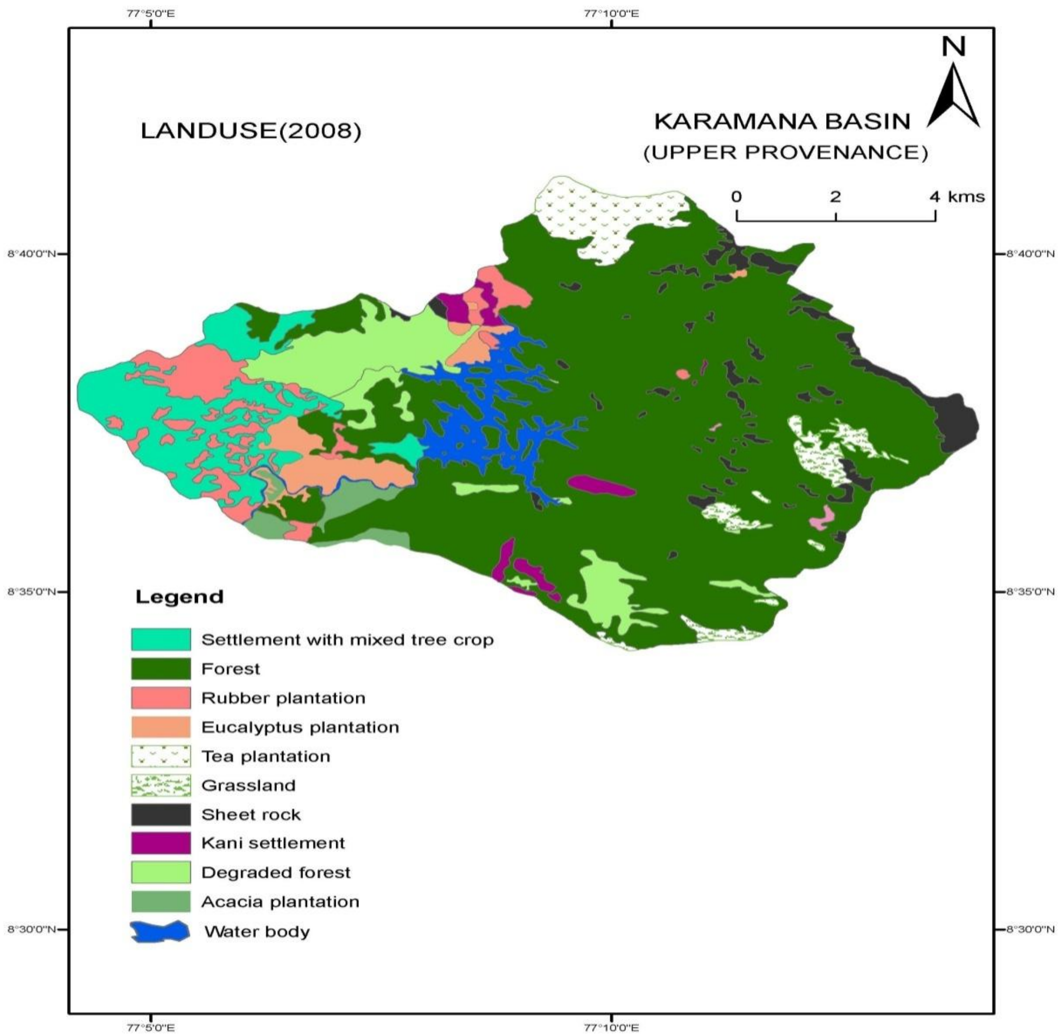


Figure.8-Landuse map of Karamana basin in 2008.

Table-1. Sinuosity of a major stream in Karamana basin.

Segments	Channel length (km) (a)	Valley length (km) (b)	Sinuosity (a/b)
A	**3.00**	**2.00**	**1.50**
B	**3.50**	**3.25**	**1.08**
C	**3.25**	**2.75**	**1.18**
D	**3.00**	**2.25**	**1.33**
E	**5.00**	**3.50**	**1.43**

Table-2 Comparison of landuse changes in Karamana basin.

Land use category	1967		2008		% change in Land use
	Area (sq.km.)	Area (%)	Area (sq.km.)	Area (%)	
Forest	101.61	78.79	77.44	60.05	-23.79
Settlement with mixed tree crop	9.62	7.46	12.16	9.43	26.40
Eucalyptus	4.92	3.82	5.63	4.37	14.43
Grassland	1.51	1.17	2.64	2.05	74.83
Rubber	0.55	0.43	6.47	5.02	1076.36
Tea	5.07	3.93	4.99	3.87	-1.58
Sheet Rock	4.08	3.16	4.93	3.82	20.83
Degraded forest	-	-	9.44	7.32	-
Water body	-	-	5.25	4.07	-