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Morphometric Analysis of a Vrishabavathi Sub-watershed Using Remote Sensing and Geographical Information System: A Case Study

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Abstract: The seasonal abrupt flood event in the GaliAnjaneya Temple sub-watershed of Vrishabavathi watershed was the major loss for socio-economic infrastructure. The main objective of this study is to characterize the morphometric parameters of the nine micro-watersheds on the up-stream side of GaliAnjaneya Temple of Vrishabavathiv sub-watershed, located at GaliAnjaneya temple of Bangalore city, Karnataka State, India, which depicted on topo sheets 57/H 9 and 57/H/ 9/1 with scale 1:25,000 were used. The morphometric parameters were delineated through STRM data using ArcGIS-10.1software. The sub- watershed is covering about 38.00 Km2 consists of valleys and plains. The longest flow path was calculated and found to be 9.311 Km. In this study, morphometric parameters such as stream length, bifurcation ratio, drainage density, stream frequency, texture ratio, form factor, circularity ratio, elongation ratio and compactness ratio are studied. The highest bifurcation ratio among all the micro-watersheds is 5.2 (3.647avg. for the entire sub-watershed) which indicates a strong structural control on the drainage. The maximum value of circularity ratio is 45.81for the micro-watershed No.5. The micro-watershed No.9 has the maximum elongation ratio of 1.041. The form factor values are in range of 0.113 to 0.850 which indicates that the Vrishabavathi sub-watershed has moderately high peak flow for shorter duration and has a dendritic drainage pattern

Keywords: Morphometry, Vrishabhavathi sub-basin, Drainage Characteristi, SOI: Survey of India, DEM: Digital Elevation Model, ASTER: Advanced Space-borne, ArcGIS, RS, Spatial analysis, hazards, River basin.

1.Introduction:

Morphometric analysis is refers as the quantitative evaluation of form characteristics of the earth surface and any landform unit. This is the most common technique in basin analysis, as morphometry form an ideal areal unit for interpretation and analysis of alluvially originated landforms where they exhibits and example of open systems of operation. The composition of the stream system of a drainage basin in expressed quantitatively with stream order, drainage density, bifurcation ration and stream length ratio (Horton, 1945). It incorporates quantitative study of the various components such as, stream segments, basin length, basin parameters, basin area, altitude, volume, slope, profiles of the land which indicates the nature of development of the basin.

This modern approach of quantitative analysis of drainage basin morphology was given inputs by Horton (1945) the first pioneer in this field. Horton’s laws were subsequently modified and developed by several geomorphologist, most notably by Strahler (1952, 1957, 1958, and 1964), Schumm (1956) and etc.

For the present study, Remote Sensing (Lillisand Thomas, 2002) and Geographical Information System (GIS) will be used as tools for managing and analyzing the spatially distributed information. ArcGIS a powerfulsoftwares to analyze, visualize, update the geographical information, and create quality presentations that brings the power of interactive mapping and analysis. Many researchers have done morphometric analysis using Remote Sensing and GIS technique. (Shakil Ahmad et al., 2012) has used Geoinformatics for assessing the morphometric control on hydrological response at watershed scale in the upper Indus Basin.

detecting change, and developing databases. Many researchers have developed an integrated approach to combine RS and GIS techniques to elucidate the effects of land-use change on runoff using a simple Soil Conservation Service (SCS) model. In the present study, distributed SCS-CN model in GIS platform has been applied to estimate variations in runoff during significant rainfall events for four different periods, i.e. year 1973, 1992, 2002 and 20014 for the Vrishabhavathi sub catchment in Bangalore south, India. Satellite remote sensing imageries have been used to prepare land use/cover and soils map, which was used to calculate the average Curve Number for the basin.

2.Study Area

Bangalore city is capital of Karnataka State. It is one of the major metropolitan cities of India and it is recognized as Capital of IT city in India. The study area Vrishabavathi sub-watershed upstream side of GaliAnjaneya Temple islies (Latitude 13˚1’11”N and 70˚32’6”E Longitude) in the Southern part of the Bangalore city, Karnataka, India. The study area is, covering a total area of about 38.38 Km2 (Figure1). The mean annual total rainfall is about 880 mm with 60 rainy days/year in last 40-years. The summer temperature ranges from 18°C to 38°C, while the winter temperature range from 12°C to 25°C.The SOI Topo-sheet numbers 57/H 9 and 57/H/ 9/1 are used to delineate the boundary.

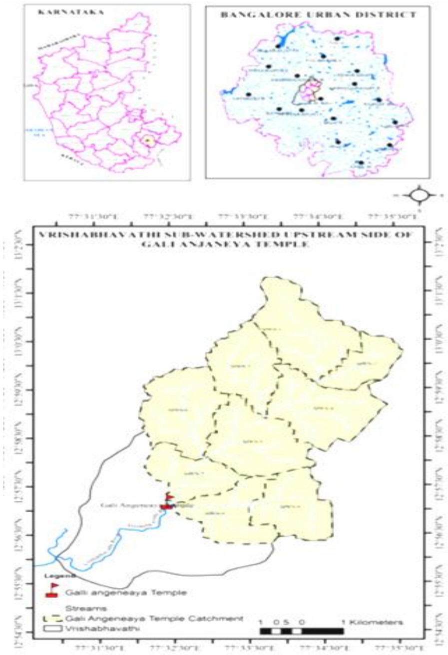


Figure 1: Location Map of Study Area & prominent features include the 9 sub basins

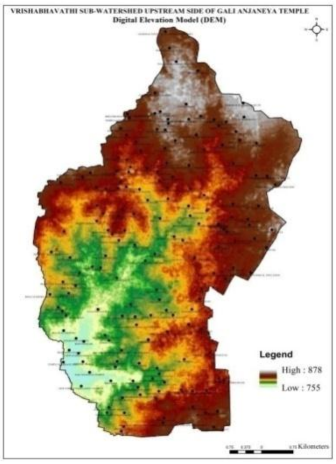
2.1.Data used and Methodology:

This work is based on map analysis carried out onscreen digitization. Toposheet number 57H/9 and 57H/9/1 with the scale of 1:25,000. (Survey of India) were mosaic to subset the study region. The subset image is geometrically corrected through the process of rectification. Strahler's, Horton's and Schumm's methods have been employed to assess the fluvial characteristics of the study region. The maps were georeferenced and digitized in ArcGIS-10.1 and Erdas Imagine-10 software's and attributes were assigned to create the digital database. The map showing drainage pattern in the study area (Figure 1) was draped over SRTM 10m resolution DEM data for further clarification. Morphometric analysis was carried out at sub-basin level in the GIS System (ArcGIS-10.1). Based on the drainage order, the drainage channels were classified into different orders [6]. In GIS, drainage channel segments were ordered numerically as order number 1 from a stream's headwaters to a point downstream. The stream segment that results from the joining of two first order streams was assigned order 2.
data were used to calculate the runoff using SCS-CN method.

3. Results and Discussions:

3.1. LinearAspect:
The parameters representing length were considered in linearaspects.Drainage basin analyses begin by designation of stream orders. The channel segment of the drainage basin has been ranked according to Strahler stream ordering system usingArcGIS-10.1.

3.1.1.Stream Order (U):
The designation of stream order is the first step in the drainage basin analysis. The primary step in drainage basin analysis is to designate stream orders. The study area is a 6th order drainage basin (Figure 3). The total number of 1,287 streams identified from 9 micro- watershed of which 990 are 1st order which is 76.92%, 232 are 2nd order which amounts 18.026%, 45 are 3rd order which is 3.496%, 13 in 4th order which is 1.01%, 6 in 5th order which amounts 0.466% and 1 in 6th order (Table 3). The study reveals that the development of 1st order streams is maximum in the hilly area and minimum in the alluvial plains (Figure 3 & Table3). Similarly the numbers 2nd and 3rd order streams are gradually high from alluvial to highly dissected hills from north to south (Figure 3 & Table 3).



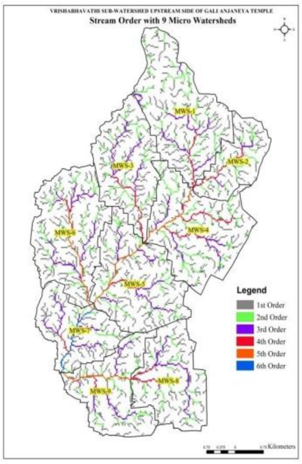


Figure 2: DEM of study area**Figure 3:** Stream order

3.1.2. Stream number (Nu):

The quantity Nu represents total number of all streams, counted as the stream segments, having the order 'U' present in the watershed. The number of streams of each order was an important concept in hydrologic synthesis. It is inversely proportional to the stream order. In the present the total number of stream segments is found to decrease as the stream order increases in all the micro watersheds. The high number of streams found in the micro- watersheds of KempapuraAgrahar 183 (MWS-5) and Kempegowda Bus station 180 (MWS-4), indicates mature stage of topography. In the mature stage, river widens its valley. The lowest streams are found in Palace Grounds 86 (MWS-2).

As per the Strahler's (1964) ordering scheme the study area ending with sixth order drainage basin. The minimum length of the sixth order is 2.0 km.

3.1.3. Stream length (Lu):

Stream length measured from mouth of the river to drainage divided, the stream length of different order has been delineated from ArcGIS software. Horton's law of stream length supports the theory that geometrical similarity is preserved generally in the basin in theincreasing order. The mean length of channel Lu of order 'U' is the ratio of total length to the number of stream of the given order. Mean length of channel is the given order greater than that of the next lower order but less than that of the next higher order (Table 3).

3.1.4. Mean stream length (Lsm):

This is the length along the longest water course from outflow point of designated micro-watershed to the upper limit of micro-watershed boundary. Mean stream length of a stream channel segment of order 'u' is a dimensional property revealing the characteristic size of components of a drainage network and its contributing basin surface (Strahler, 1964). The lengths of stream segments of up to 6th order are measured and the total length as well as Mean Stream Length (Lsm) of each order is computed.

The mean stream lengths of stream increase with the increase of the order. But in some micro- watersheds shows opposite relation, higher order stream has a small mean length. In micro- watershed No. 2 (MWS-1) to micro-watershed No.9 (MWS-9) the length of 2nd orders stream is extremely short. These micro-watershed shows variable lithology with asymmetry in nature and these micro-watersheds are found along the major structural lineament. The micro-watersheds shows high hypsometric integral value and high relative up liftment, reveals the tectonic control on these sub basins

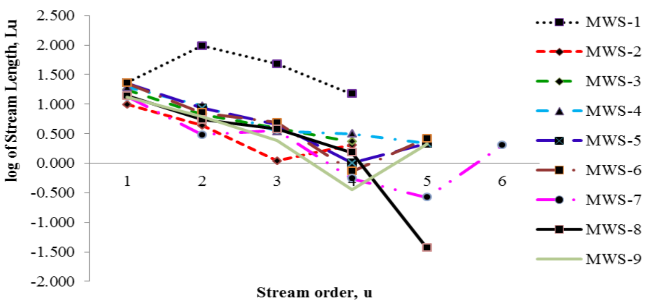


Figure 4: Stream Length versus Stream Order

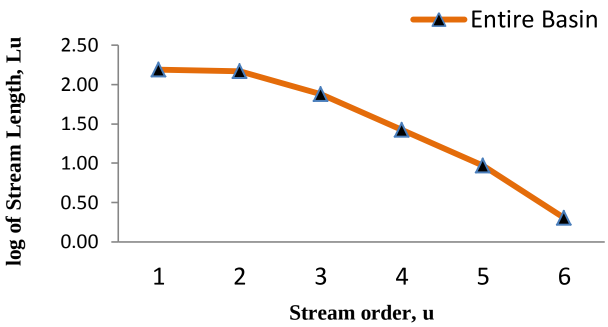


Figure 5.10: Logarithm of Stream Length versus Stream Order for the Entire Basin

3.1.5.Basin length (Lb):

Basin length was calculated as the distance between outlet and farthest point on the basin boundary. It is indicative of the contributing area of the basin of that order. Basin length is the longest dimension of a basin to its principal drainage channel. Micro-watershed having index 1, 3, 5 and 6 has the longest basin length of 7.05, 4.41, 3.74 and 3.62 km accordingly and the micro-watersheds having index 2, 7 and 9 has the shortest basin length of 3.078, , 2.06 and 1.917 km respectively. Watershed length and the watershed area of the alluvial river are maximum and in the dissected hill it is minimum. Micro-watershed lengths for the sub-watershed are tabulated in the given Table 5.

3.1.6.Stream Length ratio (RL):

Stream length ratio (RL) is ratio of the mean length of the one order to the next lower order of the stream segment. Horton postulated that, the length ratio tends to be constant throughout the successive orders of the stream. Elongated micro-watersheds (MWS-6,7 and 9) shows high length ration (up to7.62 in case of MWS-7) in the higher order whereas the basin (MWS-1,3,4 and 8) with comparatively high circularity ratio shows the low length ratio (<1). The variations in length ratio, attributed to variation in slope of topography indicate youth stage of geomorphic development in the streams of the study area (Singh and Singh, 1997, Vittala et al., 2004).

3.1.7. Basin perimeter (P):

Basin perimeter was taken as the lengths of watershed divide which surrounds the basin.

3.1.8. Mean Bifurcation ratio (Rmb):

The mean bifurcation ratio (Rbm) may be defined as the average of bifurcation ratios of all order. In the present case, Rbm varies from 3.065 (MWS7- Bapujinagar) to 5.190 (MWS1-Sanket Tank) and all micro-watersheds fall under normal basin category Table 4. In the present study, the higher bifurcation ratio indicates there may be some structural distortion in that basin area.

3.1.9. Length of Overland Flow (Lg):

It is the length of water over the ground before it gets concentrated in to definite streams channels 3. This factor depends on the rock type, permeability, climatic regime, vegetation cover and relief as well as duration of erosion4. The length of overland flow approximately equals to half of the reciprocal of drainage density(Horton1932). The length of overland flow ranges between 0.0154 - 0.0782

In the study area length of overland flow has a low value. These basins have a drainage density and runoff is more but they have short course of flow. Smaller the value of overland flow the quicker surface runoff will enter the streams represents well developed drainage network with higher slope.

3.2. Aerialaspects:

The areal aspect is the two dimensional properties of a basin. It is possible to delineate the area of the basin which contributes water to each stream segment. The watershed can be traced from where the stream has its confluence with the higher order stream along hillcrests to pass upslope of the source and return to the junction. This line separates slopes which feed water towards the streams from those which drain in to other streams. Different shape parameters like Form Factor (R_f), Circularity Ratio (R_c), Elongation Ratio (R_e) and Compactness Coefficient (C_c) have beendiscussed.

3.2.1Drainage area (A):

Drainage area (A) was represented by the area enclosed within the boundary of the watershed divide. It is the most important characteristic for hydrologic design. The drainage area calculated for the watershed is 38.00 km^2.

3.2.2.Drainage density (D_d):

It was estimated as the ratio of total length of channels of all orders in the basin to the drainage area of the basin. D_d is a measure of the texture of the network, and indicates the balance between the erosive power of overland flow and the resistance of surface soils androcks.

The micro-watersheds in the catchment show comparatively high drainage density (6.395-32.3869 km−1) which exhibits high impermeable subsurface material. Which is evident from fracture-controlled narrow drainage/stream courses, sparse vegetation and mountainous relief, with the presence of built up, paved roads, etc. geologically, the area is composed of residual capping is indicates that less permeable material are found. The entire basin is very fine-textured.

3.2.3. Stream frequency/channel frequency (Fs):

Drainage frequency may be directly related to the lithological characteristics. The number of stream segments per unit area is termed Stream Frequency or Channel Frequency or Drainage Frequency (Fs) Horton (1945). The drainage frequency of the entire sub-watershed ranges from 5.917 – 8.995 km-2. Micro-watershed having index 3 (MWS3) has the high stream frequency and the micro-watershed of alluvial has the low stream frequency (5.917 km- 2). The watersheds of the structural hills have higher stream frequency, drainage density while the watersheds of alluvial has minimum.

3.2.4. Drainage texture or Texture ratio (R_t):

Drainage texture is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It is one of the important concepts of geomorphology which means that the relative spacing of drainage lines. Drainage lines are numerous over impermeable areas than permeable areas. Smith (1950) has classified drainage texture into 5 different textures i.e., very coarse (<2), coarse(2to 4), moderate (4 to 6), fine (6 to 8) and very fine(>8).

The drainage texture of entire 9 micro watersheds is of very fine. Hilly micro-watersheds show very finetexture.

3.2.5. Elongation ratio (Re):

Schumm's 1956 used an elongation ratio (Re) defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length. The value of Re varies from 0 (in highly elongated shape) to unity i.e. 1.0 (in the circular shape).Thus higher the value of elongation ratio more circular shape of the basin and vice-versa. Values close to 1.0 are typical of regions of very low relief, whereas that of 0.6 to 0.8 are usually associated with high relief and steep ground slope (Strahler, 1964).

The elongation ratio values of the different micro- watersheds are varies between 0.378 and 1 (Table 6). The micro-watersheds of the alluvial region shows low values (0.4-0.5) represent the elongated basin with low relief. More number of micro- watersheds in the central area shows oval and circular shape. The circular basin is more efficient in run-off discharge than an elongated basin (Singh and Singh, 1997).

3.2.6. Circularity ratio (Rc):

The circularity ratio is mainly concentrated with the length and frequency of streams, geological structures, land use/land cover, climate, relief and slope of the basin. It is the ratio of the area of the basins to the area of circle having the same circumstance as the perimeter of the basin. The Circulatory ratio for all micro-watersheds is in the range of 2.093 to 7.095. The micro-watershed 8 (MWS-8) shows the lowest value, whereas the micro-watershed 3 (MWS-3) shows the high value of 7.095. Higher the value represents more circularity in the shape of the basin and vice-versa. Naturally all micro-watersheds have a tendency to become elongated to get the mature stage.

3.2.7. Form factor (Rf):

Form factor may be defined as the ratio of the area of the basin and square of basin length (Horton, 1932). The value of form factor is in between 0.113-0.850. Smaller the value of form factor, more elongated will be the watershed. The micro- watersheds with high form factors 0.8, have high peak flows of shorter duration, whereas, elongated drainage micro-watershed with lowform factors have lower peak flow of longer duration. The alluvial watersheds shows low form factor value represent elongated in nature of the watersheds. The micro-watershed 9 (MWS9) shows high values of form factor 0.850 is ideal circular watershed. The values indicate the drainage central and western part of the study area shows medium to high values of form factor. The drainage development in these parts is moderate to high and the area has a structural control.

Table 2: Elongation ratio and Shape of river

Elongation Ratio	Shape of the basin
< 0.7	Elongated
0.7 to 0.8	Less elongated
0.8 to 0.9	Oval
> 0.9	Circular

3.2.8. Constant of Channel Maintenance (Ccm):

This parameter indicates the requirement of units of watershed surface to bear one unit of channel length. Schumn (1956) has used the inverse of the drainage density having the dimension of length as a property termed constant of channel maintenance. All the values are computed and shown in the Table. Micro-watershed No.8 (MWS-8) shows highest value of 0.156 km-2 which has the least drainage density, while the micro-watershed No.1 (MWS-1) has lowest constant channel maintenance of 0.030 km-2 , and these two watersheds has the lowest and highest drainage density of 6.395 km-1 and 32.386 km-1.

Lower value of constant channel Maintenance reveals strong control of lithology with a surface of high impermeability.

3.3.Relief Aspect:

In basin relief aspects, the parameters were evaluated are given below in brief.

3.3.1.Basin relief (H):

Total relief (H) is the maximum vertical distance between the lowest (outlet) and the highest (divide) points in the watershed. Relief is an indicative of the potential energy of a given watershed above a specified datum available to move water and sediment down slope. The micro-watershed relief range from 61 to 123m. Micro-watersheds in the southern part of basin shows comparatively high relief than northern part of the study area. Micro- watershed N0.9 (MWS-9) has high relief about 92m. Computed basin relief are tabulated in the Table 5.11

3.3.2.Relief ratio (Rh):

The relief ratio (Rh) was estimated as the ratio between the relief and the distance over which the relief measured (Schumn, 1956). It is an indicator of erosion process operating on the slopes of the basin. It measures the overall steepness of the watershed and can be related to its hydrologic characteristics. The overall relief calculated for the watershed was 0.0161.

In the study area watershed shows high relief ratio. The southern part of basin in micro-watershed No.7 (sixth order watershed) shows high relief ratio than the eastern part sub basins. In the micro-watershed No.1 (MWS-1) in the northern part has a low relief ratio because of high erodability of the rock type. The high values of Relief Ratio in the western part can be explained by the presence of highly resistant rocks underlying the watershed. The high values of Rh indicate steep slope and high relief and vice- versa. Relief controls the rate of conversion of potential to kinetic energy of water draining through the watershed. Run-off is generally faster in steeper basins, producing more peaked basin discharges and greater erosive power.

4.Conclusions:

Following is a summary of the results and a discussion of the inferences from the results.

- GIS and Remote sensing techniques have proved to be accurate and efficient tool in drainage delineation and their updation.
- The Horton’s law of stream orders holds good for the catchment under study.
- Study area satisfies Horton’s law of stream length. States that “streams of smaller lengths are characteristics of areas with larger slopes”, it seems to be in geometric progression.
- The relationship between stream order with log of stream length and stream order was examined (Figures 4 & 5), it seems to be in geometric progression and agree with Horton’s law of stream length. The study shows the total length of stream decreases with increasing order of stream.
- The micro-watersheds in the catchment show comparatively high drainage density (6.395- 32.3869 km−1) which exhibits high impermeable subsurface material, lower maximum basin relief over the flat plain surfaces and fine to very fine drainage texture. It is a reflection of magnitude of surface runoff which leads to formation trellis drainage pattern.

- The mean bifurcation ratio (Rbm) varies from 3.065 to 5.190 in micro-watersheds fall under normal basin category. In the present study all micro- watersheds fall under normal basin category, the higher bifurcation ratio indicates there may be some structural distortion in that basin area.
- Circularity ratio in the range of in the range of
- 2.093 to 7.095. Higher the value represents more circularity in the shape of the basin and vice-versa. Naturally all micro-watersheds have a tendency to become elongated to get the mature stage.
- The elongation ratio values of the different micro- watersheds are varies between 0.378 and 1. The micro-watersheds of the alluvial region shows low values (0.4-0.5) represent the elongated basin with low relief. The circular basin is more efficient in run-off discharge than an elongated basin
- The catchment is largely circular (Rc = 0.639) and largely coarse in texture (Drainage density Dd = 2.6476 Km/Km2) with high Stream frequency (Fs = 5.52). The Circularity ratio is s 0.639 indicating that basin largely circular in shape.
- As reflected by the values of relief ratio, the catchment consists of land area with moderate to high slope (Rr = 5.615) characteristics.
- The further work in the study area is being carried out to quantify the effect of land use and land cover on hydrologic characteristics which in turn effect the flood peak in the Vrishabhavathi Watershed in Bangalore suburb area.

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Table3: Summary of drainage basin parameters in the study area.

Sl.No.	Micro-watershedNo.	Stream order (Nu)											
		1		2		3		4		5		6	
		No.	L_u, km.	No.	L_u, km.	No.	L_u,km.	No.	L_u, km.	No.	L_u, km	No.	L_u,km.
1	MWS-1	125	22.91	35	96.14	7	47.50	1	14.81				
2	MWS-2	62	9.804	19	4.340	4	1.098	1	2.032				
3	MWS-3	115	17.471	25	6.715	4	3.960	1	2.300				
4	MWS-4	139	19.515	31	9.366	7	3.474	2	3.139	1	2.145		
5	MWS-5	140	22.717	35	8.557	5	4.478	2	1.003	1	2.169		
6	MWS-6	141	22.815	27	7.165	6	4.872	2	0.732	1	2.620		
7	MWS-7	86	13.477	19	3.007	5	3.609	1	0.552	1	0.265	1	2.020
8	MWS-8	85	13.803	22	5.479	4	3.779	2	1.526	1	0.037		
9	MWS-9	97	13.175	19	6.080	3	2.454	1	0.358	1	2.098		
Entire Basin		990	155.68	232	146.84	45	75.22	13	26.452	6	9.334	1	3.01

Table 4: Bifurcation ratio of micro-watersheds in Vrishabavathi sub-watershed

Sl.No.	Micro-watershed	Bifurcation ratio, Rb.					Mean bifurcation ratio, R_{bm}	Highest Elevation, H,m.	Lowest Elevation, L, m.
		I/II	II/III	III/IV	VI/V	V/VI			
1	MWS-1	3.571	5.000	7.000			5.190	878	817
2	MWS-2	3.260	4.750	4.000			3.002	864	817
3	MWS-3	4.602	6.200	4.03			4.945	865	795
4	MWS-4	4.489	4.409	3.52	2.005		3.606	868	795
5	MWS-5	4.001	7.000	2.500	2.002		3.875	834	781
6	MWS-6	5.222	4.499	3.005	2.005		3.683	857	781
7	MWS-7	4.526	3.800	5.00	1.000	1.000	3.065	816	755
8	MWS-8	3.865	5.544	1.984	1.996		3.347	854	794
9	MWS-9	5.105	6.337	3.059	1.000		3.875	848	756
Entire basin		4.293	5.282	3.788	1.668	1.000	3.843		

Table5: Summary of drainage basin parameters in the study area

Sl.No.	Micro-watershedNo.	A (km^2)	P (km)	N_u	L_u (km)	R_t	R_h	L_g km/km2	L, km.	B km.
1.	MWS-1	5.60	5.568	168	171.36	4.318	8.652	0.0154	7.050	2.270
2.	MWS-2	2.32	2.757	86	17.274	0.900	15.269	0.0672	3.078	1.213
3.	MWS-3	4.03	2.671	145	30.446	0.839	15.866	0.0662	4.412	1.597
4.	MWS-4	5.32	4.358	180	37.639	1.045	19.751	0.0706	3.696	3.325
5.	MWS-5	5.07	1.179	183	38.924	1.064	14.155	0.0651	3.744	3.044
6.	MWS-6	5.08	5.265	177	38.204	1.079	20.959	0.0665	3.626	1.747
7.	MWS-7	3.07	2.929	114	20.91	1.217	31.821	0.0669	1.917	1.141
8.	MWS-8	3.85	4.807	114	24.621	1.081	17.162	0.0782	3.496	1.979
9.	MWS-9	3.63	4.272	121	24.165	1.000	44.53	0.0751	2.066	2.017

Table 6: Linear and aerial parameters of sub-watersheds.

Sl.No.	Micro-watershed	Linear parameters						Aerial parameters			
		F_s	D_d	R_{bm}	R_t	L_g	R_f	R_c	R_e	C_{cm}	C_c
1	MWS-1	7.499	32.386	5.190	4.318	0.0154	0.794	2.268	0.378	0.030	0.050
2	MWS-2	8.267	7.445	3.002	0.900	0.0672	0.754	3.834	0.558	0.134	0.144
3	MWS-3	8.995	7.555	4.945	0.839	0.0662	0.913	7.095	0.514	0.132	0.045
4	MWS-4	6.7668	7.075	3.606	1.045	0.0706	1.439	3.518	0.704	0.142	0.043
5	MWS-5	7.217	7.677	3.875	1.064	0.0651	1.354	45.81	0.678	0.130	0.012
6	MWS-6	6.966	7.520	3.683	1.079	0.0665	1.400	2.302	0.702	0.133	0.057
7	MWS-7	7.360	6.811	3.455	0.925	0.0734	1.601	4.495	1.032	0.146	0.087
8	MWS-8	5.917	6.395	3.347	1.081	0.0782	1.101	2.093	0.633	0.156	0.091
9	MWS-9	6.664	6.657	3.875	1.000	0.0751	1.757	2.498	1.041	0.150	0.091