

Runoff Estimation and Morphometric Analysis for Hesaraghatta Watershed Using IRS-1D LISS III FCC Satellite Data

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Received: 28 April 2009 / Accepted: 02 June 2010 / Published online: 2 March 2011
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Abstract The study area, Hesaraghatta watershed is located between 77° 20' to 77° 42' E longitude and 13° 10' to 13° 24' N latitude with an area of 600.01 km². Thematic layers such as Land Use/Land Cover, drainage, soil and hydrological soil group were generated from IRS-1D LISS III satellite data (FCC). An attempt was made to estimate runoff using Soil Conservation Service (SCS) curve number model and it was estimated to be 1960, 2066, 1870 and 1810 mm for sub-watersheds 1, 2, 3 and 4 respectively. Quantitative morphometric analysis was carried out for the entire watershed and the four sub-watersheds independently by estimating their (a) linear aspects like stream order, stream length, stream length ratio, bifurcation ratio, length of overland flow, drainage pattern (b) aerial aspects like shape factor, circulatory ratio, elongation ratio and drainage density and (c) relief aspects like basin relief, relief ratio, relative relief and ruggedness number. Drainage

density was estimated to be 1.23 km/km² designating the study area as a very coarse textured watershed.

Keywords Hesaraghatta · Watershed · Soil Conservation Service (SCS) · Antecedent Moisture Conditions (AMC) · Runoff · Morphometric analysis

Introduction

Water of sufficient quantity and quality is an essential resource not only for agriculture, industry, and tourism, but also for everyday life in cities and villages. Water resources distributed in time and space are at the heart of sustainable development in many regions of the world, and their availability varies greatly from time to time and place to place. An abrupt change and an imbalance in the hydrological cycle put forth the necessity to quantify the available water resources with the objective of managing the resources both environmentally as well as ecologically. As such, approach towards management of watershed assures greater importance in recent years. Remote sensing data can be used in conjunction with conventional data for delineation of ridge lines, characterization, priority evaluation, problem identification, assessment of potentials and management needs, identification of erosion prone areas, evolving water conservation strategies, selection of sites for check dams and reservoirs etc., (Dutta et al. 2002). Durbude (2001) estimated surface runoff potential of watershed in semi-arid environment, in Banswara district of

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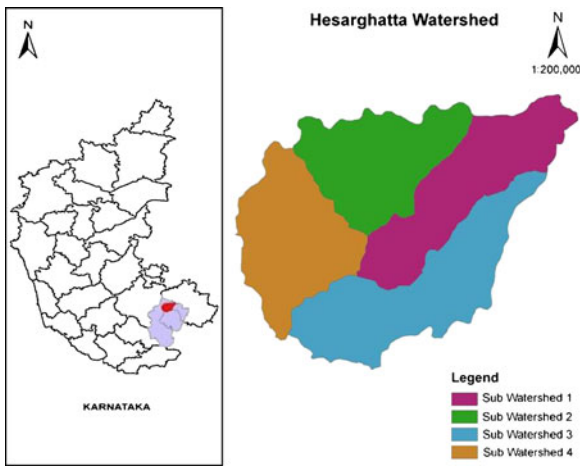
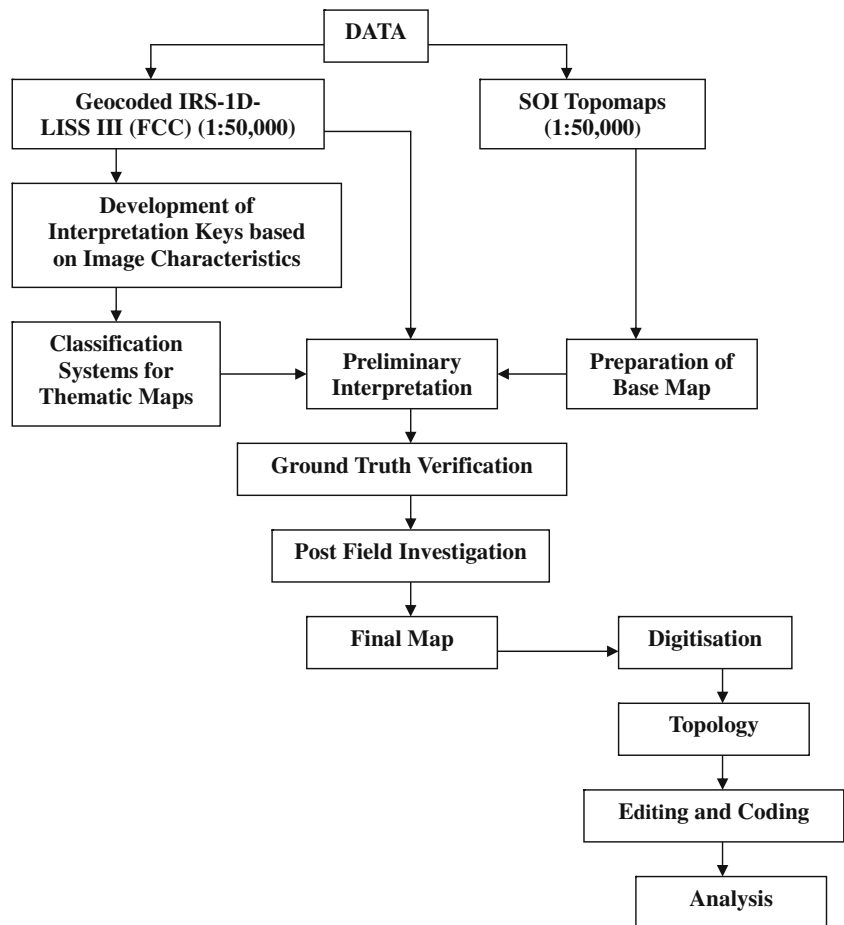


Fig. 1 Location map of the study area

Rajasthan. The analysis was done using IRS-1B-LISS II satellite images in the form of FCC using SCS curve number method. Jasrotia et al. (2002) computed a mathematical model to estimate rainfall and runoff in conjunction with remote sensing data and GIS using SCS method and runoff potential map. Tripathi et al. (2002) used weighted average runoff curve number and developed an empirical model to predict the runoff for the available events of a small agricultural watershed- Nagwan, Hazari bagh, Bihar. Similarly, Anand (2004) demonstrated the use of remote sensing and geographic information system for runoff estimation by SCS curve number method and also to suggest alternate land use classification, while Ashwini (2007) explained the potential use of remote sensing and geographic information system for runoff estimation for identifying the land suitability for different crops based on available natural resources within the watershed.

Flow Chart 1 Methodology for the preparation of thematic maps



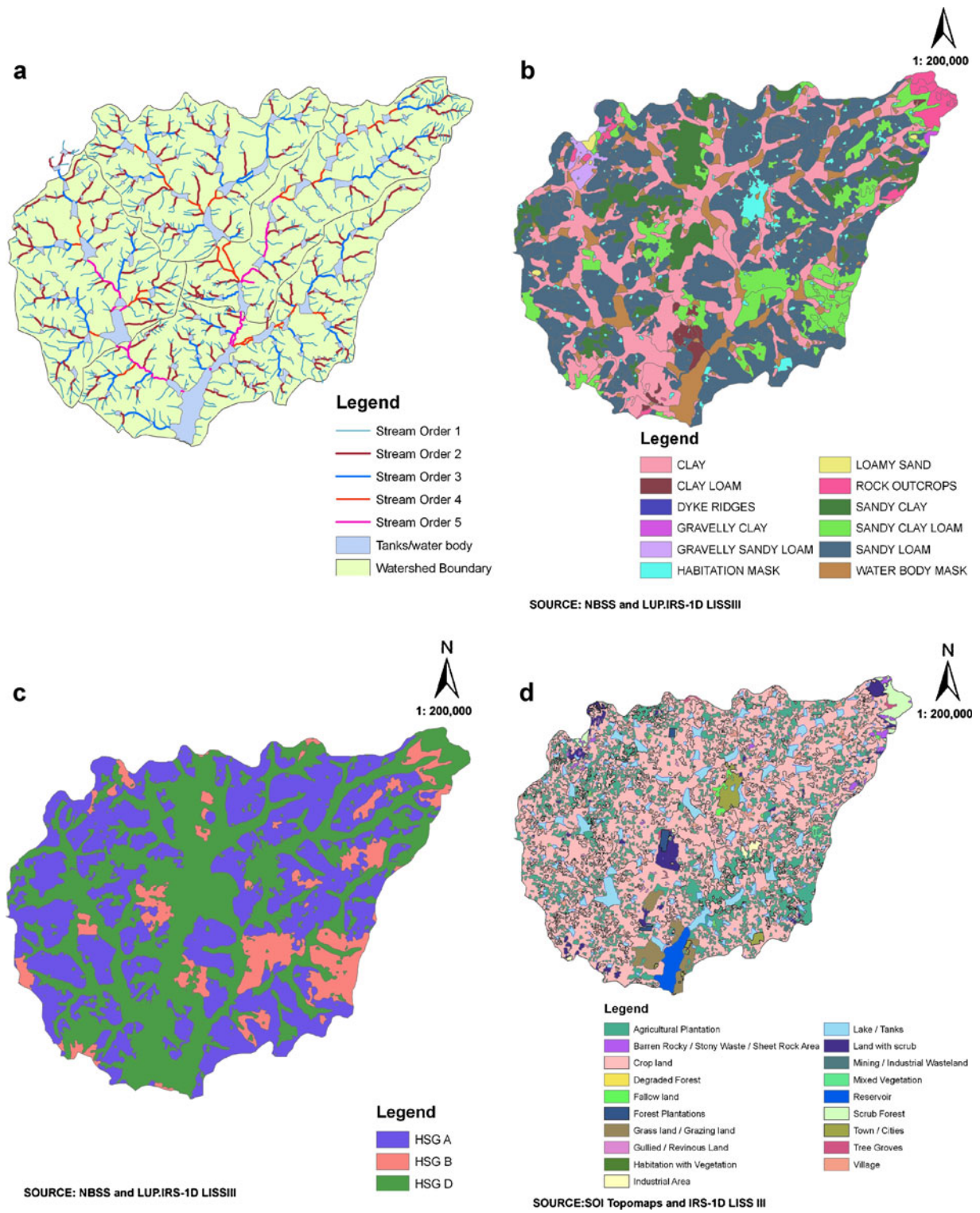


Fig. 2 a Drainage map b soil map c hydrological soil group map d land use/land cover map of Hesaraghatta watershed

The Study Area

The study area, Hesaraghatta watershed is located in Bangalore Rural District, stretching geographically between 77° 20' and 77°42' E longitude and 13°10' and 13° 24'N Latitude. The catchment area of the watershed is about 600.00 km² with a length of 33.36 km and width of 27.28 km (Fig. 1). The watershed is divided into 4 sub-watersheds based on topography and drainage system to understand the hydrological processes. The study area is covered in the survey of India (SOI) toposheets 57 G/7, 57 G/8, 57 G/11 and 57 G/12 and characterized by large number of tanks, which intersect the flow from their receptive command area. Most of these tanks are old and partially silted and the status of the bunds, sluice and channels are poor. The study area falls in the southern maidan region, characterized by undulating landscape with rather broad based valleys. The land forms are considered ancient and have undergone an extensive pediplantation, leading to the present landscape. The highest relief is found at 1460 m above mean sea level and lowest relief at 860 m above MSL. The slope of the land is from northeast to southwest. The overall relief for the basin is 0.630 km with shallow valleys and few inselberg. The area comprises of granite in the form of intrusives in the gneissic complex and vary in color, structure and

texture. It is rich in red loamy soils, which are bright red to pale red rather sticky when moist. The soils represent one of the oldest soils, derived from igneous rocks, principally granitic gneisses. The depth varies from 50 cm to several meters depending on the undulating terrain. Soils are moderate to well drained with infiltration rates ranging from 8 to 12 mm/h (NBSS and LUP, 1998). Ragi (*Eleusine coracana*) is the major and important crop grown in the taluk in addition to Paddy (*Oryza sativa*), Maize (*Zea mays*) and Cereals along with Wheat (*Triticum* spp.), Jowar (*Sorghum bicolor*) and Millets. Pulses comprise of field bean, groundnut, etc.

The present study was undertaken with an aim to prepare different thematic layers using Survey of India (SOI) topomaps and remote sensed data on 1:50000 scale by visual interpretation technique. Runoff estimation was carried out by using information on various aspects pertaining to rainfall, topography of the study area, etc. using hydrological models (e.g., SCS Curve Number model). Additionally, morphometric analysis of the watershed has been done to find out stream properties from the measurement of various stream attributes to quantify the effects of watershed characteristics in order to understand the hydrological process and predict the hydrologic behavior.

Flow Chart 2 Methodology to estimate surface runoff by SCS curve number model

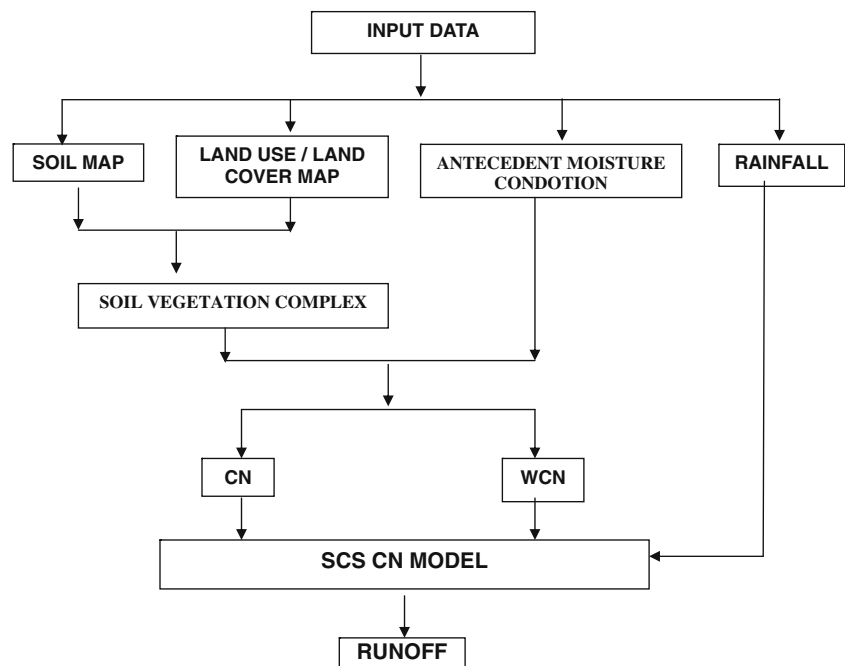


Table 1 Morphometric characteristics of Hesaraghatta watershed

Stream order	No. of segments	Total length (N _u) (km)	Bifurcation ratio (R _b)	Mean length (L _u) (km)	Cumulative length (km)	Length ratio (R _L)	Drainage density (km/km ²)
1	768	439.02	–	0.57	439.02	–	1.23
2	372	167.55	2.06	0.45	606.57	0.79	
3	144	71.63	2.59	0.50	678.20	1.11	
4	63	36.15	2.29	0.57	714.35	1.14	
5	39	21.65	1.62	0.56	736.00	0.98	

Table 2 Sub watershed-wise Morphometric characteristics of Hesaraghatta watershed

Watershed number	Area (km ²)	Stream order 1		Stream order 2		Stream order 3		Stream order 4		Stream order 5		Total no. of stream segments	Total stream length (km)
		No	Length (km)	No	Length (km)	No	Length (km)	No	Length (km)	No	Length (km)		
1	147.68	165	104.23	38	40.22	7	18.15	2	9.37	1	8.26	213	180.24
2	136.65	156	98.46	33	35.01	8	15.36	2	6.52	0	0	199	155.30
3	142.62	176	105.74	38	43.84	7	15.44	3	4.21	1	4.92	225	174.15
4	173.06	212	130.49	36	48.88	11	22.43	2	6.56	2	6.113	263	214.48

Table 3 Description of soil series and the hydrological soil group assigned

Sl. No	Description of major soils	Class assigned	Area (km ²)	% area
01	High infiltration rates. Soils are deep, well drained to excessively drained sands and gravels.	Group A	260.58	43.43
02	Moderately deep, well drained, gravelly clay soils with low average water content, strongly gravelly in the sub soil on rolling lands with slight erosion; associated with deep, somewhat excessively drained, clayed soils, severely eroded	Group B	60.71	10.12
03	Very deep, moderately well drained clayey soils of valleys with problems of drainage and slight salinity in patches; associated with moderately deep, well drained loamy soils.	Group D	278.71	46.45
	Total		600.00	100.00

Table 4 Land use/land cover classification

Sl. No.	Level I	Level II
1	Built up land	Settlements
2	Agricultural land	Kharif Rabi Double (Kharif+Rabi) Fallow land Agricultural plantations
3	Wasteland	Land with/without scrub Stony waste/Sheet Rock/Barren land
4	Forest	Forest (Degraded) Forest (Plantation)
5	Water bodies	Tank with water and without water

Materials and Methods

Survey of India (SOI) Topomaps 57 G/7, 57 G/8, 57 G/11 and 57 G/12 on scale 1: 50,000 were scanned,

georeferenced and mosaiced. Multispectral satellite data of IRS-1D LISS III (geocoded FCC) of date January, 20, 2000 pertaining to path-row 100–64 was used for the current study. Visual interpretation of satellite imagery was carried out to delineate various geomorphic units and landform features. Flow Chart 1 depicts the methodology followed for the preparation of various thematic maps. The toposheets were used as ancillary source of information in addition to satellite data to delineate the watershed and to prepare Base, Drainage (Fig. 2a), Soil (Fig. 2b), Hydrologic Soil group (Fig. 2c), Land Use/Land Cover (Fig. 2d) maps necessary for runoff estimation. The ground truth verification was carried out before finalization of the thematic maps.

Runoff was estimated indirectly with the aid of hydrological models using USDA (United States Department for Agriculture) methodology for estimation of surface runoff using SCS (Soil Conservation Service) Curve Number Model (Flow Chart 2). To estimate the curve numbers and runoff depth for the watershed, vector coverage of land use/land cover, soil

Table 5 Land use/land cover classification for Hesera-ghatta watershed

Sl. No	Land use/land cover classification	Area (km ²)	% area
1	Agricultural Plantation	115.14	19.1
2	Barren Ricky/Stony waste/Sheet Rock area	3.505	0.6
3	Degraded Forest	0.0398	0.01
4	Dense grass land/Grazing land	10.754	1.8
5	Fallow land	2.099	0.34
6	Forest Plantation	1.91	0.32
7	Gullied/Revinos land	0.882	0.2
8	Habitation with vegetation	0.197	0.03
9	Industrial area	2.066	0.33
10	Kharif+Rabi (Double crop)	115.26	19.2
11	Kharif crop	261.06	43.5
12	Lake/Tanks	39.623	6.6
13	Land with scrub	12.648	2.11
14	Mining/Industrial waste land	0.96	0.2
15	Mixed Vegetation	0.655	0.11
16	Rabi crop	0.817	0.14
17	Reservoir	7.073	1.2
18	Scrub forest	5.953	0.99
19	Town/Cities	6.24	1.03
20	Tree groves	1.034	0.18
21	Village	12.08	2.01
	Total	600.00	100

Table 6 Watershed shape ratio and its interface

Watershed	Shape ratio
Circular	0.9
Oval	0.8–0.9
Less elongated	0.7–0.8
Elongated	0.5–0.7
More elongated	0.5

map showing clayey soil and loamy soil series and HSG map showing hydrological soil group prepared from IRS satellite data were integrated. CN values were determined from hydrological soil group and antecedent moisture conditions in the watershed. The Curve Number values for AMC-I and AMC-II were obtained from AMC-II (Chow et al. 1988) by the method of conservation. The Quantitative Morphometric Analysis of the drainage basin is considered to be the most satisfactory method because it enables understanding of the relationship between different aspects of the drainage pattern of the same basin. Hence, the drainage details derived from Survey of India (SOI) topomaps on 1:50000 scale, updated with IRS 1D LISS III, FCC remote sensed data was used to carry out morphometric analysis and to estimate dimensional parameters using ArcGIS 9.2 software. It included

a) *Linear aspects* include the measurements of linear features of drainage basin such as stream order (u), stream length (L_u), stream length ratio (R_L), bifurcation ratio (R_b), length of overland flow (L_o) and drainage pattern (Strahler 1952) etc. Additionally, total number of streams in an order was determined by numbering of segments for each order.

b) *Areal aspects* (A_u) of a watershed of given order ‘u’ is defined as the total area projected upon a horizontal plane contributing overland flow to the channel segment of the given order and includes all tributaries of lower order. It comprises of watershed shape factor (S_f), form factor (R_f), circulatory ratio (R_C), elongation ratio (Re) and drainage density (D_d).

c) *Relief aspects* is an indicator of flow direction of water as it is an important factor in understanding the extent of denudational process that have undergone within the watershed. It comprises of Basin relief (H), Relief Ratio (R_r), Relative relief (R_R) (Melton 1957), Ruggedness number (R_n) (Strahler 1964).

Results and Discussion

Based on the drainage details derived from Survey of India (SOI) topomaps on 1:50000 scale and remote sensed data (IRS 1D LISS III, Jan 2000), morphometric analysis for the present study can be classified into linear, areal and relief aspects (Table 1). The *drainage pattern* is dendritic for the study area, indicating that soil is semi-pervious in nature. The drainage pattern showed a well integrated pattern formed by the main stream with its tributaries branching and rebranching freely in all directions and, occurs on relatively homogeneous material such as granitic terrain. The total length of all stream segments (N_u) in a stream order, total stream length (L_u) in stream order (u), cumulative stream length of all stream strength of the all stream orders, mean stream length for the watershed was calculated. It is evident from Table 1 that *mean length of channel segments* of a given order is more

Table 7 Classification of textures

Drainage density (D_d) (km/km ²)	Textures
<1.24	Very coarse
1.24–2.49	Coarse
2.49–3.73	Moderate
3.73–4.97	Fine
>4.97	Very fine

Table 8 Stream frequency for no. of streams/km²

Stream frequency (Sf)	No. of streams/km ²
Low	0–5
Moderate	5–10
Moderate high	10–15
High	15–20
Very high	20–25

Table 9 Morphometric parameters of Hesaraghatta watershed

Sl no	Watershed/morphometric parameters	Units	Entire watershed	Sub-watershed number			
				1	2	3	4
1	Watershed Area	km ²	600.01	147.68	136.65	142.62	173.06
2	Perimeter of the watershed	km	116.45	68.36	56.5	55.76	80.2
3	Watershed stream highest order	No.	5	–	–	–	–
4	Maximum length of watershed	km	33.36	–	–	–	–
5	Maximum width of watershed	km	27.28	–	–	–	–
6	Cumulative stream length	km	736	–	–	–	–
7	Stream length	km	–	180.237	155.305	174.144	214.478
8	Drainage density (D _d)	km/km ²	1.23	1.22	1.13	1.22	1.23
9	Constant of channel Maintenance (C)	km ² /km	0.81	–	–	–	–
10	Stream frequency (S _f)	No./km ²	2.31	1.44	1.45	1.57	1.52
11	Bifurcation ratio (R _b)	–	4.357	3.815	4.281	3.847	3.925
12	Length ratio (R _L)	–	1.005	1.923	1.728	1.959	1.561
13	Form factor (R _f)	–	0.54	0.223	0.503	0.358	0.235
14	Shape factor (S _f)	–	1.855	4.49	1.98	2.79	4.25
15	Circularity ratio (R _C)	–	0.56	0.397	0.537	0.576	0.339
16	Elongation ratio (R _e)	–	0.83	0.53	0.8	0.67	0.55
17	Compactness coefficient	–	1.34	1.58	1.36	1.31	1.72
19	Total watershed relief (H)	km	0.630	–	–	–	–
20	Relief Ratio (R _f)	–	0.018	–	–	–	–
21	Relative Relief (R _R)	–	0.0054	0.006	0.003	0.0007	0.002
22	Ruggedness number (R _n)	–	0.775	0.48	0.187	0.051	0.233
23	No. of Stream segments	–	–	213	199	225	263

Table 10 Runoff curve numbers for (AMC II) hydrologic soil cover complex

Sl No	Land use	Hydrologic soil group			
		A	B	C	D
1	Agricultural land without conservation (Kharif)	72	81	88	91
2	Double crop	62	71	88	91
3	Agriculture Plantation	45	53	67	72
4	Land with scrub	36	60	73	79
5	Land without scrub (Stony waste/rock Out crops)	45	66	77	83
6	Forest (degraded)	45	66	77	83
7	Forest Plantation	25	55	70	77
8	Grass land/pasture	39	61	74	80
9	Settlement	57	72	81	86
10	Road/railway line	98	98	98	98
11	River/Stream	97	97	97	97
12	Tanks without water	96	96	96	96
13	Tank with water	100	100	100	100

(Source: Chow et al. 1988)

Table 11 Soil group classification (Mc. Cuen 1982)

Soil group	Description	Min. infiltration rate (mm/h)
A	Soils in this group have a low runoff potential (high-infiltration rates) even when thoroughly wetted. They consist of deep, well to excessively well-drained sands or gravels with high rate of water transmission	7.62–11.43
B	Soils in this group have moderate infiltration rates when thoroughly wetted and consists chiefly of moderately deep to deep, well-drained to moderately well-drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission.	3.81–7.62
C	Soils have slow infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes the downward movement of water, or soils with moderately fine-to fine texture. These soils have a slow rate of water transmission.	1.27–3.81
D	Soils have a high runoff potential (very slow infiltration rates) when thoroughly wetted. These soils consist chiefly of clay soils with high swelling potential, soils with a permanent high-water table, soils with a clay layer near the surface, and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.	0–1.27

than that of next higher order as L_u increases with increase of order number.

According to Strahler’s method of ordering, the watershed forms the *fifth order* and hence designated as fifth order watershed (Table 2).

Soil map and hydrological soil group prepared for the present study illustrates clayey soil and loamy soil series and three different hydrological soil groups (A, B and D) based on soil series within the watershed (Table 3).

Land Use and Land Cover Map indicates that the main crops during the Kharif season are ragi, pulses and oil seeds where as paddy is grown in the command area of tanks. New crops have replaced the traditional crops as a result of increase in

irrigation potential by bore wells. Land use/land cover of Hesaraghatta watershed has been classified into five major classes in Level I and 12 major classes in Level II (Table 4). Further, Land Use/Land Cover has been classified into 21 sub-classes according to the SNRIS norms and their extent and proportion to the total geographical area of the watershed has been summarized (Table 5).

The *shape of the basin* has a profound influence on the runoff and sediment transport process and it governs the rate at which water enter the stream, being dependent on circulatory and elongation ratio. The *circularity ratio* (R_c) for Hesaraghatta watershed is 0.56, signifying mature nature of topography, The

Table 12 Classification of Antecedent Moisture Condition (AMC)

AMC class	Description of soil conditions	Total five day antecedent rainfall (mm)	
		Dormant season	Growing season
I	Soils are dry but not to the wilting point; satisfactory cultivation has taken place	<12.7 mm	<35.56 mm
II	Average conditions	12.7–27.94 mm	35.56–53.34 mm
III	Heavy rainfall or light rainfall and low temperatures have occurred within last 5 days; Saturated soils	> 27.94 mm	53.34 mm

Table 13 Weighted curve numbers for the subwatershed

Sub-watershed no	Area (km ²)	CN II	CN I	CN III
1	147.68	76.04	58.18	88.22
2	136.65	77.45	60.09	88.94
3	142.62	75.13	56.98	87.62
4	173.06	74.24	55.82	87.09

elongation ratio (Re) was found to be 0.83 indicating that the watershed is oval in shape (Table 6) and the values varied from 0.53 to 0.8 among sub-watersheds.

The values of *bifurcation ratio (R_b)* for the Hesaraghatta watershed was 4.357, remained less than five even for subwatersheds, indicating that watershed has suffered less structural disturbance with undistorted drainage density pattern and the watershed may be regarded as the elongated one. The *drainage density* reflects land use and affects the infiltration and the watershed response time between the precipitation and discharge. The value was 1.23 km/km² suggesting very coarse nature of area (Table 7). It varied from 1.13 km/km² to 1.23 km/km² among subwatersheds. This low value is an indication that the area has highly resistant or highly permeable sub-soil material and less undulated. This low value of drainage density influence greater infiltration and hence the wells in this region will

have specific capacity and the region appear to possess good water potential. The watershed exhibits impermeable subsurface material, which is evident from the presence of narrow stream coarse, while the watershed no.1 and 2 exhibited highly permeable subsoil materials, which are broad and wide valley fill zones with dense vegetation cover. The length of overland flow suggests that surface runoff reaches the streams faster.

The *constant of channel maintenance 'C'* (Schumm 1956) value for the study area is 0.81 km²/Km, which indicates the number of square kilometer of watershed required to sustain one linear km of the channel. The *Stream frequency (Sf)* (Horton 1945) obtained for the study area is 2.3 No. of streams/km² and its classification has been presented in Table 8 and the values for subwatershed level is given in Table 9.

The highest watershed relief is formed by Nandi Hills at the northern tip of the watershed where river Arkavati originates at an elevation of 1460 m above MSL. The lowest relief is obtained at 860 m above MSL. The *overall watershed relief* calculated for the basin is 0.630 km (630 m).

Based on the minimum infiltration rate, SCS developed a soil classification system consisting of four *hydrologic Soil group (HSG)*, namely A, B, C, and D (Table 10) and the soil characteristics associated with each of this group are given in the Table 11.

Table 14 Watershed and sub-watershed runoff (mm) estimated using SCS curve number model along with annual rainfall (mm)

Year	Rainfall (P)	Runoff (Q)				
		Hesaraghatta watershed		Sub watershed		
				1	2	3
1995	609.90	37.99	39.175	42.23	37.029	35.201
1996	908.20	147.46	152.263	163.816	143.713	136.446
1997	757.00	146.72	149.838	156.754	144.37	139.716
1998	1101.30	280.48	287.614	304.018	275.01	264.264
1999	691.60	139.37	142.315	149.884	136.93	132.213
2000	1166.20	353.19	359.641	374.406	348.209	338.359
2001	771.40	202.56	207.617	219.436	198.617	190.859
2002	462.40	87.21	88.893	92.925	85.879	83.275
2003	382.80	17.89	18.801	20.962	17.206	15.888
2004	773.50	173.79	178.191	188.071	170.458	163.871
2005	817.80	142.21	146.123	155.608	139.106	133.061
2006	590.50	185.79	189.66	198.339	182.832	176.951
Total	9032.80	1914.66	1960.13	2066.45	1879.36	1810.1

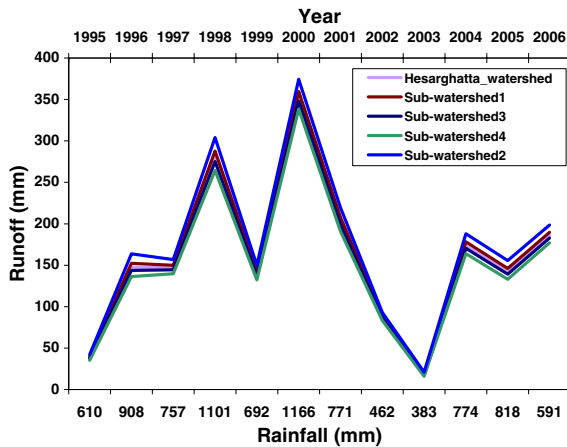


Fig. 3 Relationship between rainfall and runoff for Hesaraghatta watershed and four subwatersheds for the year 1995 to 2006

The SCS developed three Antecedent Moisture Conditions (AMC), labeled as I, II, III (Table 12) based on the water content of the soil at a given time. It is intended to reflect the effect of infiltration on both the volume and rate of runoff according to the infiltration curve.

The weighted curve numbers used for the four subwatersheds of Hesaraghatta watershed is given in Table 13. All the three AMC conditions are considered for the estimation of runoff from watershed.

According to Drought Monitoring Cell (DMC), Bangalore, the mean annual rainfall of the study area for the period between 1995 and 2006 is 925 mm, with a maximum of 1166.2 mm in 2000 and 2005 with 120 rainy days and a minimum of 382.8 mm in 2003 with 62 rainy days (Table 14). From the SCS curve number model for the present study, the minimum runoff for subwatershed 1, 2,3 and 4 estimated to be 18.80, 20.96, 17.20 and 15.89 mm respectively in 2003 and the maximum runoff is

Table 15 Correlation between rainfall and runoff for watershed and subwatersheds

	Rainfall (P)	Watershed / subwatershed
Runoff (Q)	.872	Hesaraghatta watershed
	.874	Sub watershed 1
	.879	Sub watershed 2
	.870	Sub watershed 3
	.867	Sub watershed 4
± .576	critical value 0.05 (two-tail)	
± .708	critical value 0.01 (two-tail)	

estimated as 359.64, 374.40, 348.21 and 338.36 mm respectively in 2000 (Table 14). Relationship has been established between rainfall and runoff for the entire watershed as well as for the four subwatershed (Fig. 3) and it is evident that in all five cases, rainfall and runoff are strongly correlated with coefficient of correlation (r) value being 0.87 (Table 15).

Conclusion

Hesaraghatta watershed is basically a low rainfall area and is characterised by erratic and irregular pattern of rainfall. No perennial source of water is available for the watershed other than the tanks fed by rainwater. Hesaraghatta watershed can be designated as very coarse textured and fifth order watershed, with low drainage density, leading to higher bifurcation ratio into the soil. The watershed has suffered less structural disturbance and the oval shaped watershed is of elongated nature. The dendritic pattern of drainage indicates that soil of the study area is semi-pervious in nature. Various harvesting structures such as Check dams, Nala bunds, farm pond besides desilting of tanks can be suggested at various locations based on the above evaluation to facilitate groundwater recharge.

References

Anand, B. K. (2004). Integrated approach for watershed development using remote sensing and geographic information system, M.E. Thesis Department of Civil Engineering, accepted by Bangalore University, Bangalore.

Ashwini. (2007). Analysis of land use classification using remote sensing and geographic information system, M.E. Thesis, accepted by Department of Civil Engineering, Bangalore University.

Chow, V. T., Maidment, D. R., & Mayse, W. (1988). *Applied hydrology*. New York: Mc Graw Hill.

Dutta, D., Sharma, J. R., & Adiga, S. (2002). *Watershed characterization, prioritization, development planning and monitoring—remote sensing approach, technical report, ISRO-NNRMS-TR-103-2002*. Bangalore: ISRO.

Durbude, D. G. (2001). *Journal of the Indian Society of Remote Sensing*, 29(1&2), 111–210.

Horton, R. E. (1945). Erosional development of streams and their drainage basins: Quantitative Morphology. *Bulletin of the Geological Society Of America*, 56, 275–361.

Jasrotia, A. S., Dhiman, S. D., & Aggarwal, S. P. (2002). Rainfall-runoff and soil erosion modeling using remote sensing and GIS technique – A case study on tons

- watershed. 'Photonirvachak' *Journal of Indian Society of Remote Sensing*, 30(3), 167–180.
- Mc. Cuen, R. H. (1982). *A guide to hydrologic analysis using SCS methods*. Englewood Cliffs: Prentice Hall Inc.
- Melton, M. A. (1957). *An analysis of the relations among elements of climate, surface properties, and geomorphology. Technical Report 11*. New York: Department of Geology, Columbia University.
- National Bureau of Soil Survey and Land Use Planning (NBSS and LUP). (1998). Soil of Karnataka for optimization land use—executive summary in Co-operation with Government of Karnataka, pp 33–35.
- Schumm, S. A. (1956). Evolution of drainage system and slopes in bad lands at poeth Ambry, New Jersey. *Journal of Hydrology*, 240, 45–61.
- Strahler, A. N. (1952). Hypsometric (area–altitude) analysis of erosional topography. *Geological Society of American Bull*, 63, 1117–1142.
- Strahler, A. N. (1964). Quantitative geomorphology of drainage basin and channel networks. In V. T. Chow (Ed.), *Handbook of Hydrology*. Mc Graw Hill, Section 4–11.
- Tripathi, M. P. (2002). Runoff modelling of a small watershed using satellite remote data & GIS. *Journal of the Indian Society of Remote Sensing*, 30(1&2), 40–52.