Geospatial approach for morphometric analysis of environs of Jammu (J&K), India

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Abstract

Remote sensing (RS) and Geographical information system (GIS) has emerged as an efficient tool for assessing various terrain and morphometric parameters of the drainage basins and watersheds. Morphometric analysis is an important hydrological investigation used for development and management of drainage basin. The morphometric parameters of basin can address linear, areal and relief aspects. The present study deals mainly with the geometry, more emphasis being placed on the evaluation of morphometric parameters such as stream order (Nu), stream length (Lu), mean stream length (Lsm), stream length ratio (RL), bifurcation ratio (Rb), mean bifurcation ratio (Rbm), drainage density (Dd), stream frequency (Fs), drainage texture (Dt), form factor ratio (Rf), circularity ratio (Rc), elongation ratio (Re), length of overland flow (Lg) and constant channel maintenance (C). Jammu city, the winter capital of the state of Jammu and Kashmir is located on both the banks of the river Tawi and lies between 32° 38" and 32° 48" North latitude and 74° 47" and 74° 50"East latitude. By using Arc GIS 10.5 software, watershed has been delineated using drainage extracted from ASTER Digital Elevation Model (DEM). The study area possesses the dendritic drainage pattern with maximum 5th order of stream which is mainly controlled by physiographic and lithological conditions of the area. These types of studies are useful for rainwater harvesting, ground water recharge and watershed management practices that can be used in reducing rates of environmental degradation in the basins.

Keywords: ***Morphometric analysis, ASTER DEM, Remote sensing and GIS***

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 fluvial 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 law of stream lengths suggested that a geometric relationship existed between the numbers of stream segments in successive stream orders. The law of basin areas indicated that the mean basin area of successive ordered streams formed a linear relationship when graphed. Horton’s laws were subsequently modified and developed by several geomorphologist, most notably by Strahler (1952, 1957), Schumm (1956), Morisawa (1957, 1958), Shreve (1966), Gregory and Walling (1968). Subsequently a number of books by Bloom (2003), Keller and Pinter (1996) have further propagate the Morphometric analysis. Stream profile analysis and stream gradient index by Hack (1973) is another milestone in morphometric analysis. Morphometry is the measurement and mathematical analysis of the configuration of the earth's surface, shape and dimensions of its landforms (Clarke 1996). This analysis can be achieved through measurement of linear, aerial and relief aspects of basins by using remote sensing and GIS. The present study is an attempt to critically evaluate and assess various morphometric parameters of micro-watersheds of Jammu city and its environs.

Remote sensing and GIS based drainage basin assessment has been carried out by number of researchers, scholars and scientists for different landscapes and it is proved to be a very systematic tool for generation of detailed and updated information for characterization of drainage basin parameters (Grohmann 2004; Korkalainen *et al.,* 2007). The recent development in drainage morphometric assessment concluded the utilization of space borne satellite images for extraction of streams and their related features are one the important development in geospatial technology for drainage system mapping and their periodic monitoring in GIS environment (Singh *et al.,* 2013; Saha and Singh, 2017). Geographical Information System (GIS) methods are used now a day for evaluating several terrain and morphometric parameters of the drainage basins and watersheds, as it provide a flexible atmosphere and a efficient tool for the manipulation and study of spatial information (Hajam *et al.,* 2013).

Study area

Jammu city, the winter capital of the state of Jammu and Kashmir is located on both the banks of the river Tawi and lies between 32° 38'' and 32° 48'' North latitude and 74° 47'' and 74° 50''East latitude. Large scale urbanization has given rise to the urban area comprising the old and new cities along with the suburbs. The old city is situated on a hillock, and the northeastern parts of the city are sloping up towards the hills. The city is surrounded by Shivalik range to the north, east and southeast while the Trikuta Range surrounds it in the north-west. The area falls in sub Himalayan region and can be divided into two sub regions, the outer plains, with an average elevation of 280-320m and the outer hills, at an average elevation of 320-400m. The area is sub-tropical and experiences sub tropical monsoon type of climate with three significant seasons: summer, extending from April to July, with average temperature of 35°C and low relative humidity; monsoon, from July to September, with uniformly high temperatures and relative humidity, and winter, with average temperature of 10-15°C and average rainfall of 150 cm.

In the last few decades, there has been stupendous growth in the urban population of the city due to migration of people from small towns. The population of Jammu city according to 2011 census is 503,690 (Municipality) and 951,373 (Urban agglomeration) with the density of 5,697 persons/km2 (14,760 persons/sq mile). The increasing urban population has consequently resulted in the encroachments of agricultural lands, drainage networks and seasonal *nallahs*. Due to the illegal encroachments a huge change in land use and land cover has been witnessed. The prime agricultural lands and drainage/ river beds have been transformed and diverted for varied purposes such as residential, commercial, agriculture, *etc*. The changing drainage pattern and decreased capacity of the drains/*nallahs/sewers* to accommodate the runoff during rains, some areas are witnessing floods every year and is expected many more areas to be affected by it, posing threat to life and property.

Methodology

The study is based on the secondary data. The Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) DEM has been downloaded from USGS website. The Arc GIS 10.5 software has been used for morphometric analysis of the study area. The DEM has been corrected using FILL tool (which removes the errors such as sinks and eliminates discontinuities) in Arc GIS Hydrology toolset. Flow Direction (Creates a raster of flow direction from each cell to its steepest downslope neighbor), Flow Accumulation (Creates a raster of accumulated flow into each cell. A weight factor can optionally be applied, Stream Order tool in Strahler method (Assigns a numeric order to segments of a raster representing branches of a linear network) and Stream to feature tools have been used to find out pattern of stream in study area. Number of stream orders has been calculated using raster file itself and length of each stream have been calculated using the feature (.shp) file in Arc GIS. The length, perimeter and area of micro-watersheds delineated using drainage network have been calculated using suitable tools in software. When the necessary data have been collected from the software the Linear and Arial properties of various micro-watersheds have been analyzed using the method shown in table 1.

Table:1 Methods of Calculating Morphometric parameters of basin

Morphometric Parameters	Formula	Reference
Stream Order (Nu)	Hierarchial rank	Strahler (1964)
Stream Length (Lu)	Length of the stream	Horton (1945)
Mean Stream Length (Lsm)	Lsm= Lu/Nu where, Lsm= Mean stream length Lu= Total stream length of order 'u' Nu= Total no. of stream segments of order 'u'	Strahler (1964)
Stream Length Ratio (RL)	RL= Lu/Lu-1 where, RL= Stream length ratio Lu= The total stream length of order 'u' Lu-1= The total stream length of its next lower order	Horton (1945)
Bifurcation Ratio (Rb)	Rb= Nu/Nu+1 Where, Rb= Bifurcation ratio Nu= Total no. ofstream segments of order 'u' Nu+1= Number of segments of the next higher level	Schumm (1956)
Mean Bifurcation Ratio (Rbm)	Rbm= Average of bifurcation ratios of all orders	Strahler (1957)
Drainage Density (D)	D= Lu/A Where, D= Drainage density Lu= Total stream length of all orders A= Area of the basin (km^2)	Horton (1932)
Stream Frequency (Fs)	Fs= Mu/A Where, Fs= Stream frequency Mu= Total no. of streams of all orders A= Area of the basin (km^2)	Horton (1932)
Drainage Texture (Rt)	Rt= Nu/P Where, Rt= Drainage texture Nu= Total no. of streams of all orders P= Perimeter (km)	Horton (1945)
Form Factor (Rf)	Rf= A/Lb^2 Where, Rf= Form factor A= Area of the basin (km^2) Lb^2= Square of basin length	Horton (1932)
Circularity Ratio (Rc)	Rc= 4*Pi8A/P^2 Where, Rc= Circularity ratio Pi= 'Pi' value i.e. 3.14 A= Area of the basin (km^2) P= Perimeter (km)	Miller (1953)
Elongation Ratio (Re)	Re= 2v(A/Pi/Lb) Where, Re= Elongation ratio A= Area of the basin (km^2) Pi= 'Pi' value i.e. 3.14	Schumm (1956)

	Lb= Basin length	
Length of Overland Flow (Lg)	Lg= 1/D*2 Where, Lg= Length of overland flow D= Drainage density	Horton (1945)
Constant Channel Maintenance (C)	C=1/D Where, C= Constant channel maintenance D= Drainage density	Schumm (1956)

Morphometric analysis of watershed

The following paragraphs describe the physical meaning of various morphometric parameters. Further values of these parameters are obtained as per methods proposed by various researchers for the study area and indicated in respective descriptions.

Stream Order (Nu)

There are four different system of ordering streams that are available [Gravelius (1914), Horton (1945), Strahler (1964) and Schideggar (1965)]. Strahler's system, which is a slightly modified of Hortons system, has been followed because of its simplicity, where the smallest, un-branched fingertip streams are designated as 1st order, the confluence of two 1st order channels give a channels segments of 2nd order, two 2nd order streams join to form a segment of 3rd order and so on. When two channel of different order join then the higher order is maintained. The trunk stream is the stream segment of highest order. It is found that highest drainage is of 5th order. Drainage patterns of stream network from the watershed have been observed as mainly of dendritic type which indicates the homogeneity in texture and lack of structural control. The properties of the stream networks are very important to study basin characteristics.

Stream Length (Lu)

The stream length (Lu) has been computed based on the law proposed by Horton (1945). Stream length is one of the most significant hydrological features of the basin as it reveals surface runoff characteristics. The stream of relatively smaller length is characteristics of areas with larger slopes and finer textures. Longer lengths of streams are generally indicative of flatter gradient. Generally, the total length of stream segments is maximum in first order stream and decreases as stream order increases. The numbers of streams are of various orders in a watershed are counted and their lengths from mouth to drainage divide are measured with the help of ARC-GIS software. The length of first order stream is 388.68 Km, second order stream is 232.15 Km, third order stream is 100.89 Km, fourth order stream is 28.15 Km and fifth order stream is 16.84 Km. The observation of stream order verifies the Horton's law of stream number i.e. the number of stream segment of each order forms an inverse geometric sequence with order number.

Mean Stream Length (Lsm)

The mean stream length is a characteristic property related to the drainage network and its associated surfaces (Strahler, 1964). The mean stream length (Lsm) has been calculated by dividing the total stream length of order by the number of stream. The mean stream length of study area is 0.84 Km for first order, 1.86 Km for second order, 2.82 Km for third order, 3.48 Km for fourth order and 4.21 Km for fifth order. The mean stream length of stream increases with increase of the order.

Stream Length Ratio (RL)

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and has an important relationship with surface flow and discharge (Horton, 1945). The RL values between streams of different order in the basin reveal that there are variations in slope and topography.

Bifurcation Ratio (Rb)

Bifurcation ratio (Rb) may be defined as the ratio of the number of stream segments of given order to the number of segments of the next higher order (Schumm, 1956). It is observed that Rb is not the same from one order to its next order. In the study area mean Rb varies from 3.4 to 11.9; the mean Rb of the entire basin is 8.04. Usually these values are common in the areas where geologic structures do not exercise a dominant influence on the drainage pattern. It is seen that higher is the bifurcation ratio as the basin area increases.

Drainage density (Dd)

Horton (1932), introduced the drainage density (Dd) is an important indicator of the linear scale of land form elements in stream eroded topography. It is the ratio of total channel segment length cumulated for all order within a basin to the basin area, which is expressed in terms of Km/Km2. The drainage density indicates the closeness of spacing of channels, thus providing a quantitative measure of the average length of stream channel for the whole basin. The drainage density (Dd) of study area is 1.86 Km/Km2 indicating moderate drainage densities. The Moderate drainage density indicates the basin is highly permeable subsoil and vegetative cover (Nag, 1998).

Stream Frequency (Fs)

Stream frequency (Fs), is expressed as the total number of stream segments of all orders per unit area. It exhibits positive correlation with drainage density in the watershed indicating an increase in stream population with respect to increase in drainage density. The Fs for the basin is 1.59 Km^2.

Drainage texture (Dt)

Drainage texture (Dt) is the total number of stream segments of all orders per perimeter of that area (Horton, 1945). It depends upon a number of natural factors such as climate, rainfall, vegetation, rock and soil type, infiltration capacity, relief and stage of development. In the present study the texture ratio of the basin is 1.10 Km and categorized as moderate in the nature.

Form Factor (Rf)

Form factor (Rf) is defined as the ratio of the basin area to the square of the basin length. This factor indicates the flow intensity of a basin of a defined area (Horton, 1932). The smaller the value of the form factor, the more elongated will be the basin. Basins with high form factors experience larger peak flows of shorter duration, whereas elongated watersheds with low form factors experience lower peak flows of longer duration. The Rf value for study area is 0.25.

Circularity Ratio (Rc)

Circularity Ratio is the ratio of the area of a basin to the area of circle having the same circumference as the perimeter of the basin (Miller, 1953). It is influenced by the length and frequency of streams, geological structures, land use/ land cover, climate and slope of the basin. The Rc value of basin is 0.40. Higher the value represents more circularity in shape of the basin and vice versa. Value of Rc varies from 0 to 1.

Elongation Ratio (Re)

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the same area as the drainage basin and the maximum length of the basin. Values of Re generally vary from 0.6 to 1.0 over a wide variety of climatic and geologic types. The Re values in the study area is 0.6 (more elongated) indicating high relief and steep ground slope. Circular basins are more efficient in runoff discharge than an elongated basin.

Length of overland flow (Lg)

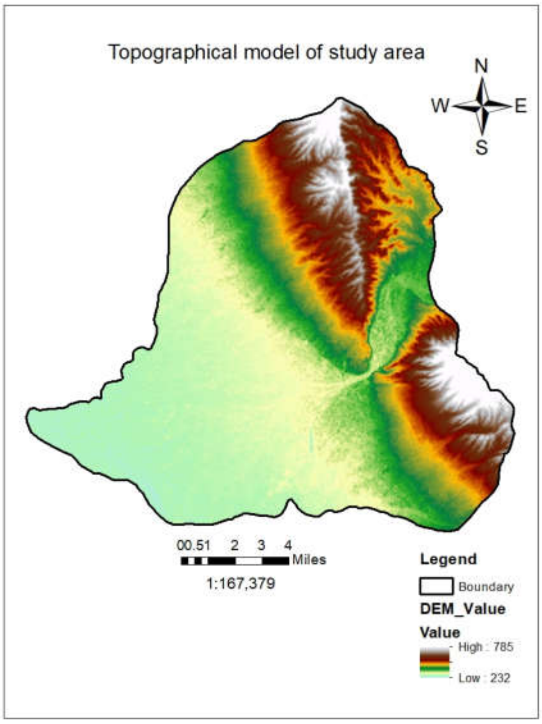
The Length of Overland Flow (Lg) is the length of water over the ground surface before it gets concentrated into definite stream channel (Horton, 1945). Lg is one of the most important independent variables affecting hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density. The Lg value of study area is 1.11Km.

Constant channel maintenance (C)

Schumm (1956) used the inverse of drainage density as a property termed constant of stream maintenance C. This constant, in units of square feet per foot, has the dimension of length and therefore increases in magnitude as the scale of the land-form unit increases. Specifically, the constant C provides information of the number of square feet of watershed surface required to sustain one linear foot of stream. The value C of basin is 0.55 Km. It means that on an average 0.55 sq.ft surface is needed in basin for creation of one linear foot of the stream channel.

Result of morphometric analysis

S.No.	Parameter	Value
1	Basin Area (Km)2	444.43
2	Perimeter (Km)	94.38
3	Basin order	5
4	Drainage density(Dd) (Km/Km2)	1.88
5	Stream frequency (Fs) (Km)2	1.59
6	Drainage Texture(Dt) (Km)	1.10
7	Mean Bifurcation ratio (Rb)	8.04
8	Form Factor (Rf)	0.25
9	Circularity ratio (Rc)	0.40
10	Elongation Ratio (Re)	0.6
11	Length of overland flow (Lg) (Km)	1.11
12	Constant channel maintenance (C) (Km)	0.55


Topographical model of study area
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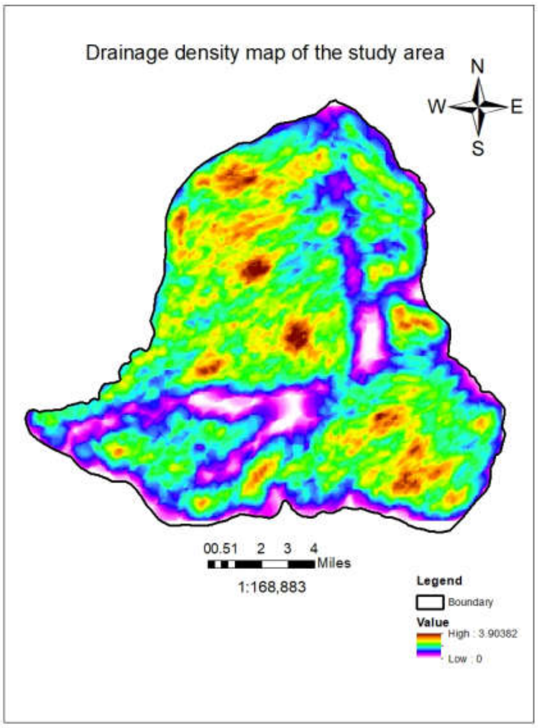
Drainage density map of the study area
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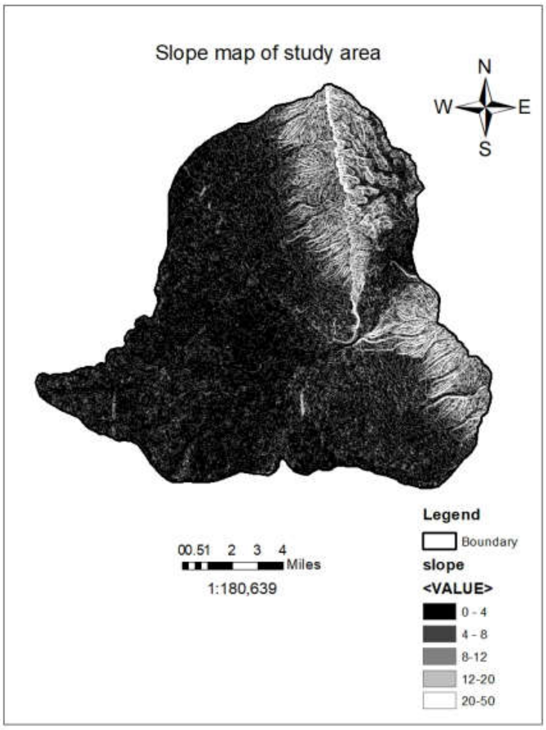
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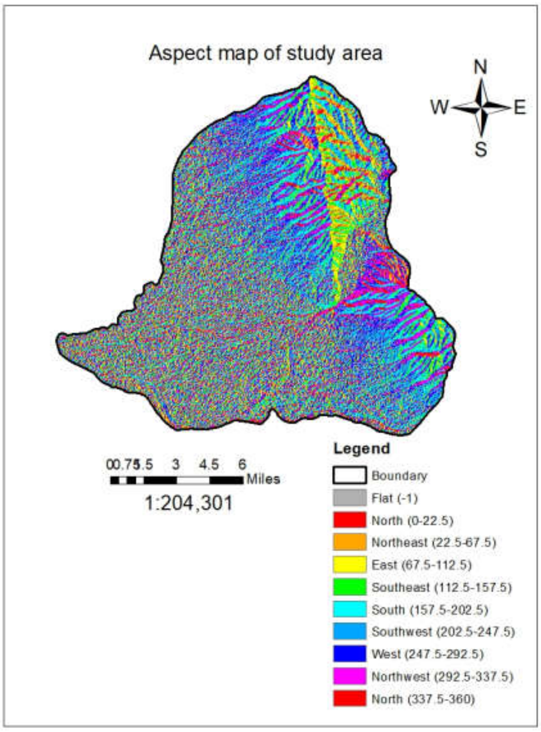
Aspect map of study area
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Northeast (22.5-67.5)
East (67.5-112.5)
Southeast (112.5-157.5)
South (157.5-202.5)
Southwest (202.5-247.5)
West (247.5-292.5)
Northwest (292.5-337.5)
North (337.5-360)

Conclusion

GIS and Remote sensing based morphometric analysis techniques have proved to be accurate and efficient tool in drainage delineation and hydrological evaluation of watershed. Thus, determination of stream networks behavior and their interrelation with each other is of great importance in many water resource studies. The hydrological investigation carried out for the watershed which is delineated using drainage extracted from DEM confirms that the watershed is having low relief and elongated shape. Drainage network of the watershed displays as mainly dendritic type which specifies the homogeneity in texture and helps to study various terrain parameters such as nature of the runoff, infiltration rate, etc. Satellite data also helps in different geological and climatic conditions for better understanding the status of landforms and other parameters like urban planning, transportation planning, flooding, environmental issues, water resources management etc.

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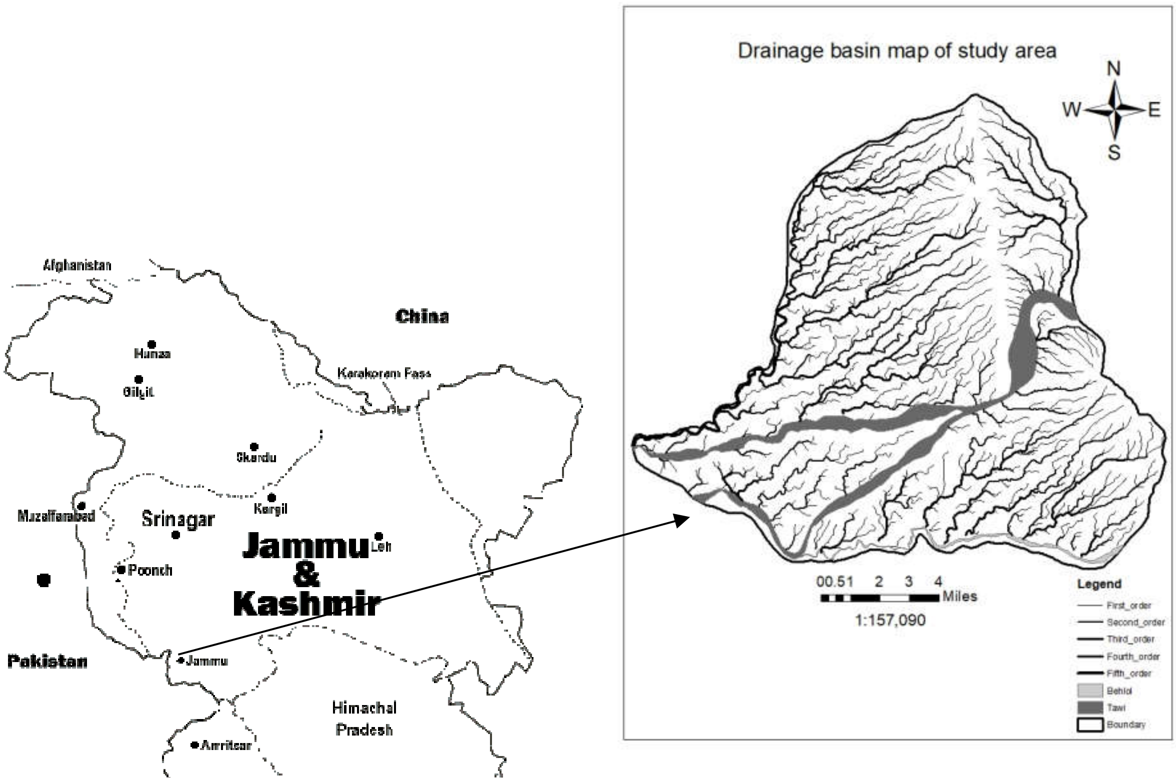

Study area map of Jammu city and its environs

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