IOSR Journal of Environmental Science, Toxicology and Food Technology (IOSR-JESTFT)
e-ISSN: 2319-2402,p- ISSN: 2319-2399.Volume 9, Issue 7 Ver. I (July. 2015), PP 41-48
www.iosrjournals.org

Quantitative Morphometric Analysis of AmbilOdha (Rivulet) In Pune, Maharashtra, India.

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Abstract:*Morphometric analysis of a watershed is useful in comprehending the interaction of the operating processes and landform characteristics. In the present paper, an attempt has been made to study the morphometric characteristics of AmbilOdha (rivulet) watershed which is a part of Mutha river basin in Pune. For the detailed analysis of the watershed, Digital Elevation Model (DEM) of the area and Geographical Information System (GIS) were used for the assessment of the linear, areal and relief aspects of morphometric parameters. The aim of the study is to find out the concerned factors which played an important role in formation of the watershed.*

Keywords:*Morphometric analysis, GIS, AmbilOdha, Pune, Land use and Land cover.*

I. Introduction

Morphometry in simple term means the measurement of a shape or geometry (Strahler 1975). Morphometry is not only related to the measurement but also to the mathematical analysis of the earth's surface configuration and dimensions of landforms (Hajam et.al. 2013). Horton (1945) initiated the use of quantitative approaches in fluvial geomorphology to study the stream system of the drainage basin. The entire area that collects the rainwater and contributes it to a particular channel is known as the drainage basin or catchment area (Kale and Gupta 2001). River basin have special relevance to drainage pattern and geomorphology and consist of distinct morphologic regions (Gundekar et.al. 2011). Morphometric parameters comprises the form and structure characteristics of drainage basin and their associated drainage networks (Goudie 2004). The morphometric characteristics of a watershed may reveal information regarding its formation and development because the hydrologic and geomorphic processes take place within the watershed (Pareta and Pareta 2011).

There are several morphometric parameters which are useful in understanding the processes shaping the morphology of the watershed. The most important factor is the basin shape which exerts a control over the geometry of the stream network. Circularity ratio, elongation ratio, form factor ratio and compactness coefficient are used to determine the shape of the basin (Eze and Efiong 2010). GIS is a significant tool, which has the potential to give rapid and accurate analysis of the spatial information and is used to determine the characteristics of the watershed. Morphometric factors represent relatively simple approaches to describe the drainage basin processes and to compare the drainage basin characteristics (Gundekar et.al. 2011). The objective of the present study was to analyse the linear, aerial and relief morphometric parameters of the AmbilOdha (rivulet). It is an attempt to understand the nature of the watershed and to use it as an important tool for further watershed planning.

Study Area

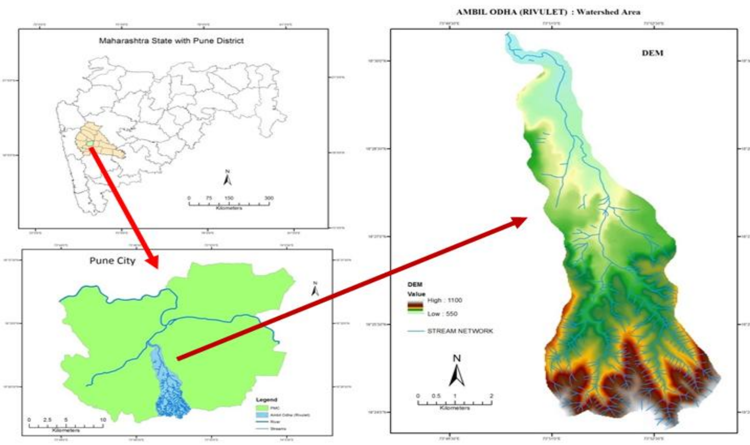

Fig. 1: Location of the study area

The AmbilOdha (rivulet) drains a catchment of 30.02 sq.km. It is located to the south of Pune City between 18°23’40’’N to 18°30’33’’N Latitudes and 73°50’20’’E to 73°53’30’’E Longitudes. The rivulet originates at an elevation of 1100 m above mean sea level (AMSL) near the offshoot Western Ghats and flow towards north north-west direction to join the Muthariver. The physiography in the upper catchment area is hilly and of undulating nature.A dendritic type of drainage pattern is observed as the rivulet flows through the basalt. The water from the upper catchment areas gets accumulated in a reservoir known as Katraj Lake from where the rivulet flows. Joglekar et.al. (2006-07) have reported the presence of a tributary stream (AmbilOdha) which drained during the Holocene period at an elevation of around 549m AMSL. The documentary evidence reveals that the rivulet was diverted during the Peshwa era in 17th century. The need for such construction was to meet the water demand of the areas near Pune city. The overall altitude in the study area ranges between 1100 m and 550 m above MSL. The monsoon season is experienced by the region between June and September. Hence, most of the 722 mm (28.43 in) average annual rainfall in the study areais received in these months, where July is the wettest month of the year (IITM, Pune).

Stratigraphic succession of region (After Godbole et.al. 1996)

The Purandargad formation is the youngest and occurs at an elevation of above 800 m AMSL. The formation comprises of compact, massive plagioclase phyric basalt with mafic microphenocrysts.Diveghat Formation overlies the Karla formation and is observed above 700m AMSL. It comprises mainly of simple flows of ‘Aa’ type that are aphyric. The lava flows of this formation are characterized by presence of vesicular, plagioclase basalt with medium grained groundmass.Karla formation essentially comprises of compound lava flows exhibiting the pahoehoecharacters.The flows are characterized by the presence coarse grained, altered, amygdaloidal basalt and near absence of plagioclase.

II. Methodology

The measurement of linear, aerial and relief aspects of the watershed basin is studied in the morphometric analysis. The morphometric analysis of the watershed was carried out on the Survey of India toposheet no. 47/F/14/3, 47/F/14/6, 47/F/15/NW, 47/F/15/NE on the scale of 1:25000. The topographical map was geo-referenced and the streams were digitized using the ArcGIS software (version 10.1). Different morphometric parameters of the watershed were generated in the GIS environment.

The land use and land cover patterns for 1991 and 2010 were mapped using Landsat-5 satellite imagery. An unsupervised classification was conducted using ERDAS IMAGINE software (Version 13) and the accuracy of the classification was verified by limited field check.

III. Results And Discussion

Based on the Survey of India toposheet, the morphometric analysis results were prepared. The morphometric parameters are classified into Drainage network, Basin Geometry, Drainage texture analysis, and Relief characteristics. In the present study, morphometric attributes like the stream order, stream length, bifurcation ratio, rho coefficient, circularity ratio, wandering ratio, elongation ratio, lemniscate, form factor ratio, drainage texture, drainage density, absolute relief, relative relief were calculated using the formula as given in Table 2.

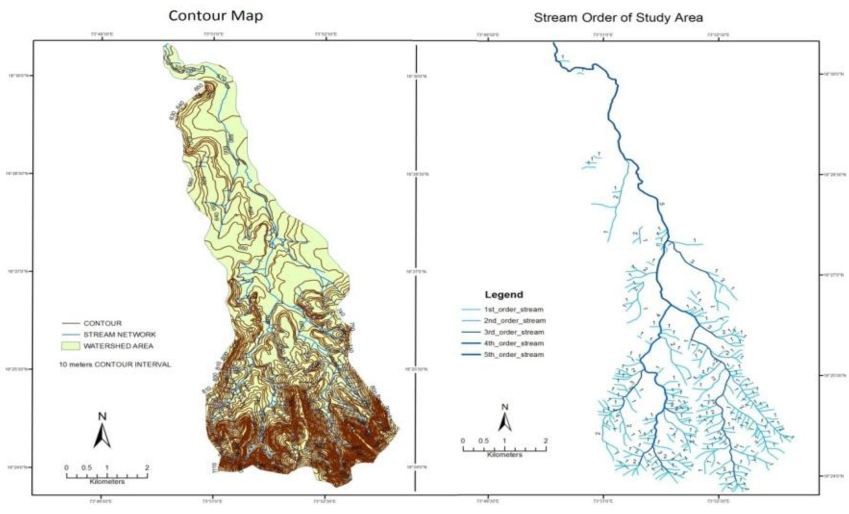

Fig. 2: Contour map and Stream Network Map

A. Drainage Network

Stream Order:

This is the most significant step to carry out the quantitative morphometric analysis of a watershed. Horton (1945) was the first one to advocate the stream ordering system. His system of stream ordering was later modified by Strahler (Pareta and Pareta 2011). Stream ordering is the method of assigning a numeric order to links in a stream network (Das et.al. 2012). In the present study, the stream ordering is based on the method proposed by Strahler and is a 5th order drainage basin (See Table 1).

Stream Number:

It is the number of stream segments for each order. There are a total of 284 streams in the watershed (See Table 1).

Stream length:

Stream length is measured from the mouth to the drainage divide. Horton's law of stream length suggest a geometric relationship between the number of stream segments in successive stream orders and landforms (Horton 1945). In the present study, stream length has been calculated by using the Survey of India (SoI) toposheet. The total length of stream is maximum in the first order and decreases with the higher order streams (See Table 1).

Table 1: Stream order, stream number, stream length and bifurcation ratio

Stream Order	Stream Number	Stream Length (km)	Bifurcation ratio (Rb)
1st Order	235	67.38	5.88
2nd Order	40	21.05	6.67
3rd Order	6	10.41	3
4th Order	2	5.62	2
5th Order	1	9.55	
Total Streams	**284**	**114.01**	**Mean Rb = 4.39**

Stream Length Ratio:

It is the ratio of the mean length of the one order to the next lower order of the stream segments (Das et.al. 2012). Changes in the stream length ratio from one order to another order indicates the development of the late youth stage of streams. The mean length of a stream of any given order is always greater than the mean length of a stream of the next lower order (Gundekar et.al.2011). The stream length ratio in the study area varies from 0.59 to 3.20.

Bifurcation Ratio:

It is the ratio of the number of stream segments of given order to the number of streams in the next higher order (Goudie 2004). The bifurcation ratio varies with the irregularities in the geological development of the drainage basin. It shows the degree of integration prevailing between the streams of various orders in a drainage basin (Selvan et.al. 2011). According to Kale and Gupta (2001), the bifurcation ratio ranging between 3 and 5 indicate the natural drainage system within a homogenous rock. The lower value of bifurcation ratio are characteristics of the watershed which have flat or rolling watersheds while the higher values of bifurcation ratio indicate strong structural control on the drainage pattern and have well-dissected drainage basins (Horton 1945; Fryirs and Brierley 2013). The higher bifurcation ratio leads to less chances of risk of flooding (Eze and Efiong 2010). The mean bifurcation ratio of the area is 4.39 (See Table 1).

Length of main channel:

This is the length along the upper limit of the watershed boundary to the outflow point. The length of the main channel is 15.96 km.

Rho coefficient:

This is a parameter which can be identified from the relation of the drainage density with the physiographic development of the concerned watershed. Combined influences of climatic, geologic, geomorphic, biologic and anthropogenic factors determine the change in this parameter (Pareta and Pareta 2011). Rho value of the study area is 0.44, which indicate moderate hydrologic storage during floods.

B. Basin Geometry

Length of the basin:

Pareta and Pareta (2011) defined the basin length as the longest dimension of the basin parallel to the principal drainage line. The length of the basin is 9.06 km.

Area of the basin:

The area of the basin was considered between the divide and the mouth of the basin. The area of the basin is 30.02 sq.km.

Basin perimeter:

In general, it can be defined as the total length of the outer boundary of basin. Basin perimeter is measured along the divides between the watersheds and is one of the important factor that determines the shape and size of the watershed basin. The basin perimeter of the watershed is 33.56 km.

Lemniscate:

The slope of the watershed basin can be determined by the Lemniscate values (Pareta and Pareta 2011). In the formula $k = Lb^2/4 * A$, Lb is the basin length and A is the area of the basin. The lemniscate value for the study area is 2.73 which shows that maximum area is occupied in its region of inception with large number of streams of higher order.

Form Factor ratio:

Form factor may be defined as the ratio of basin area to the square of the basin length. The form factor provides a measure of relationship between catchment area and catchment length and effects on hydrology (Fryirs and Brierley 2013). The value of form factor for a perfectly circular watershed is 0.754 (Pareta and Pareta 2011). The elongated watershed basins have small value of form factor while the higher value indicate a basin which is nearly circular. The elongated nature of the study area can be determined by the value of form factor ratio which is 0.37. In the elongated basin, the flow of water is distributed over a longer period of time as compared with the circular basin (Eze and Efiong 2010).

Elongation ratio:

According to Pareta and Pareta(2011), elongation ratio is defined as the ratio of diameter of a circle of the same area as the basin to the maximum basin length and have classified the watershed with the help of the index of elongation ratio, i.e.circular (0.9-0.10), oval (0.8-0.9), less elongated (0.7-0.8), elongated (0.5-0.7), and moreelongated (< 0.5). Catchments with elongation ratio around 0.6 are relatively elongated (Fryirs and Brierley 2013). The elongation ratio of the study area is 0.68. Hence, it is clear that the watershed basin is elongated.

Texture ratio:

Texture ratio is an important factor in the drainage morphometric analysis which is dependent on the underlying lithology, infiltration capacity and relief aspect of the terrain(Pareta and Pareta2011). In the present study, thetexture ratio of the watershed is 7.00 and can be categorized as moderate in nature.

Circularity ratio:

Circularity ratio is defined as the ratio of watershed area to the area of a circle having the same perimeter as the watershed and it is pretentious by the lithological character of the watershed (Pareta and Pareta 2011). Catchments with low circularity ratios are elongated in shape and controlled primarily by the geologic structure (Fryirs and Brierley 2013). The circularity ratio of the study area is 0.34, which indicates that the basin is not circular.

Drainage texture:

Drainage texture is the total number of stream segments of all orders per perimeter of that area (Das et.al. 2012).Pareta and Pareta (2011) have classified drainage texture intofive different textures i.e., very coarse (<2), coarse (2 to 4), moderate (4 to 6), fine (6 to 8) and very fine (>8). The areas having low drainage density have coarse texture while high drainage density leads to fine drainage texture. The value of drainage texture in study area is 8.46 which indicates that the texture is very fine.

Compactness coefficient:

Compactness coefficient of a watershed is the ratio of perimeter of watershed to circumference of circular area, which equals the area of the watershed(Pareta and Pareta 2011). The compactness coefficient of study area is 1.74.

Fitness ratio:

The ratio of main channel length to the length of the watershed perimeter is fitness ratio, which is a measure of topographic fitness (Pareta and Pareta 2011; Hajam et.al. 2013).The fitness ratio for the study area is 0.48.

Wandering ratio:

Wandering ratio is defined as the ratio of the mainstream length to the valley length (Pareta and Pareta 2011; Hajam et.al. 2013). Valley length is the straight-line distance between outlet of the basin and the farthest point on the ridge. In the present study, the wandering ratio of the watershed is 1.76.

C. Drainage Texture Analysis

Stream Frequency:

The total number of stream segments of all orders per unit area is known as stream frequency (Selvan et.al. 2011; Das et.al. 2012). It provides additional information concerning the response of drainage basin to runoff process (Selvan et.al. 2011). It mainly depends on the lithology of the basin. The stream frequency for the study area is 9.46.

Drainage density:

The degree of dissection of the terrain can be quantitatively characterised by the drainage density (Dingman 2009). Drainage density is the stream length per unit area in region of watershed (Horton 1945; Goudie 2004; Selvan et.al. 2011) is another element of drainage analysis. Drainage density determines the spacing of channel, length of hillslope and reflects the processes governing landscape dissection (Goudie 2004). High drainage density reflects highly dissected drainage basin and rapid hydrological response to the rainfall events while low drainage density means slow hydrological response (Selvan 2011; Hajam et.al. 2013). The low value of drainage density is one of the characteristics of the humid region (Dingman 2009). The study area has moderate drainage density with a value of 3.80 km/km^2 or 3.80/km.

Constant of channel maintenance:

The inverse of drainage density can be described as the constant of channel maintenance. The constant of channel maintenanceindicates the relative size of landform units in a drainage basin and has a specific genetic connotation. The constant of channel maintenance for the study area is 0.26 km^2/km or 0.26 km.

Drainage intensity:

Drainage intensity is the ratio of the stream frequency to the drainage density. The high value of drainage intensity indicates that together the drainage density and stream frequency have more effect on the surface denudation. This study shows a moderate drainage intensity of 2.49 for the basin.

D. Relief Characteristics

Relief ratio:

The relative relief of a basin is the difference in the elevation between the highest pointand the lowest point onthe valley floor. The relief ratio is a dimensionless number which provides a measure of the average drop in elevation per unit length of river (Fryirs and Brierley 2013). If the relative relief is more, the degree of dissection is maximum. In the study area, the value of relief ratio is 0.061. It has been observed that areas with moderate relief and slope are characterized by moderate value of relief ratios.

Absolute relief:

It is the highest elevation of a given location in a river basin. According to Selvan et.al. (2011) absolute relief gives the elevation of any area above the sea level in exact figure. The absolute relief of the area is 1100m.

Dissection index:

Dissection index is the ratio of maximum relative relief to maximum absolute relief (Selvan et.al. 2011). It is an important morphometric indicator which explains the nature and magnitude of the dissection in a terrain. On average, the values of dissection index vary between‘0’ (complete absence of vertical dissection/erosion and hence dominance of flat surface) and‘1’ (it may be at vertical escarpment of hill slope or atseashore) (Pareta and Pareta 2011). Dissection index of the watershed is 0.5 which indicate that the watershed is moderately dissected.

Table 2: Morphometric parameters of AmbilOdha

Sr. No.	Parameters	Abbreviation	Formula	Result
	DRAINAGE NETWORK			
1	Stream Order			1 to 5
2	Stream Number	Nu	Nu=N1+N2+...Nn	284
3	Stream Length	Lu		114.01 km
4	Stream Length Ratio	Lur	Lur=Lu/Lu-1	0.59 – 3.20
5	Bifurcation Ratio	Rb		2 - 6.67
6	Mean bifurcation ratio			4.39
7	Length of main channel	Cl		15.96 km
8	Rho coefficient	ρ	ρ=Lur/Rb	0.44
B	**BASIN GEOMETRY**			
9	Length of the basin	Lb	Lb=1.312*A^0.568	9.06 km
10	Basin Area	A		30.02 sq. km
11	Basin Perimeter	P		33.56 km
12	Lemniscate	k	k=Lb^2/A	2.73
13	Form Factor Ratio	Ff	Ff=A/Lb^2	0.37
14	Elongation Ratio	Re	Re=(2/Lb)*(A/π)^0.5	0.68
15	Texture Ratio	Rt	Rt=N1/P	7.00
16	Circularity Ratio	Rc	Rc=12.57*(A/P^2)	0.34
17	Drainage Texture	Dt	Dt=Nu/P	8.46
18	Compactness Coefficient	Cc	Cc=0.2841*P/A^0.5	1.74
19	Fitness Ratio	Rf	Rf=Cl/P	0.48
20	Wandering Ratio	Rw	Rw=Cl/Lb	1.76
C	**DRAINAGE TEXTURE ANALYSIS**			
21	Stream Frequency	Fs	Fs=Nu/A	9.46
22	Drainage Density	Dd	Dd=Lu/A	3.80 km/km^2
23	Constant of channel maintenance	C	C=1/Dd	0.26 km^2/km
24	Drainage Intensity	Di	Di=Fs/Dd	2.49
D	**RELIEF CHARACTERISTICS**			
25	Maximum height of the watershed	Z		1100 m
26	Minimum height of the watershed	z		550 m
27	Total basin relief	H	H=Z-z	550 m
28	Relief Ratio	Rh	Rh=H/Lb	0.061
29	Absolute Relief	Ra		1100 m
30	Dissection Index	Dis	Dis=H/Ra	0.5

Land Use and Land Cover

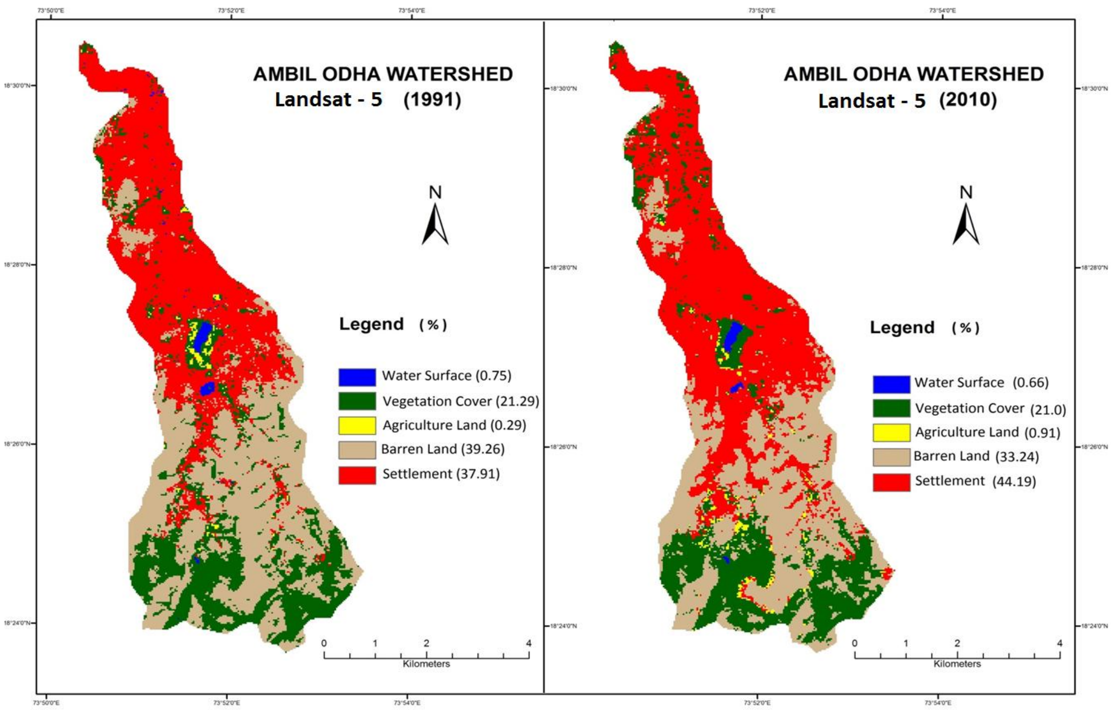

Fig. 3: Land use and Land cover of the study area

An unsupervised classification was used to classify Landsat-5 images for the year 1991 and 2010. The unsupervised image classification method was adopted to classify the images into 5 categories: water surface, vegetation cover, agriculture land, barren landand settlements. A change detection approach was used to study the land use and land cover classification from the Landsat satellite imagery. Table 3 depicts the change in the categories (in percentage) in 1991 and 2010.

Table 3: Land use and Land Cover of the study area from Landsat-5 data.

Sr. no.	Class	1991 (%)	2010 (%)
1	Water Surface	0.75	0.66
2	Vegetation Cover	21.29	21.0
3	Agriculture Land	0.79	0.91
4	Barren Land	39.26	33.24
5	Settlements	37.91	44.19

IV. Conclusion

Various stream properties can be evaluated with the help of morphometric studies. The morphometric analysis of drainage basin play an important role in understanding the geo-hydrological behaviour of drainage basin (Hajam et.al. 2013). The assessment of present condition of water resource in an area can be investigated with the study of drainage basin.

The study area is a 5^{th} order drainage basin. The mean bifurcation ratio indicates that the area is having homogenous rock type and have structural control on the drainage pattern. The drainage density, stream frequency and the drainage intensity are correlated with the degree of dissection in the area. Hence it is clear that intensity of dissection is moderate in the study area and this can also be determined by the moderate dissection index value. Drainage density indicates that the study area is in humid region.

The elongated basins have low to moderate drainage density, low stream frequency and high value of drainage texture (Hajam et.al. 2013). From the Form Factor ratio, Circularity ratio and Elongation ratio it is clear that the basin is elongated in shape. This fact emphasises that there is low and delayed discharge of runoff. From the present study, it is clear that the area is not susceptible to flooding. The study area is having fine drainage texture which is an indication of fine grained rocks with lesser permeability. The drainage density and stream frequency have a moderate effect on the surface denudation in the present area.

Vegetation cover and land use influence drainage density. Sparse vegetation cover leaves the landscape exposed to intense rainfall that induces high rate of erosion and landscape dissection increasing drainage density (Fryirs and Brierley 2013). From the satellite images, it is observed that the percentage of vegetation is gradually decreasing while that of agriculture is gradually increasing. In future, this will consequently lead to the high rate of erosion in the form of hillslope instability and increase in the sediment discharge.

From the satellite images (1991 and 2010) and Table 3, it is clear that in the southern part of the study area, there is a rise in settlements as it has increased by around 7% in the 20 year period. This has made significant impact on the natural land by increasing the impervious surface. Impervious surface tends to affect the infiltration capacity of the land and increases the flow transmission in the streams. Thus, direct human impact in the area will modify the character and behaviour of the streams. It may either expand or suppress the capacity of the river to adjust.

In order to study the transformation of the stream, it is necessary to study the human disturbances in the context of past and present. Further assessment of the channel geometry and hydraulic characteristics will reveal the overall transformation made by human.

The drainage basin is a primary landscape unit for hydrological, water supply and land management activities (Goudie 2004). From the study, it is clear that GIS is an important tool for the geomorphometric analysis of a drainage basin. Such studies can be used for the future planning and management of drainage basin.

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