Morphometric Analysis of the Walki Watershed, Pune Maharashtra Using GIS

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Introduction

One of the factors that govern the sustainable development of any nation is the availability of the water resource. Although water is omnipresent and abundant since oceans cover about 70 percent surface of the earth, but the fact remains that usable fresh water on land accounts for just about 2.7 per cent. Out of this nearly 2 percent is in the form of glaciers. In essence just about 1percent of water on earth is usable. The ever-increasing population has also increased the demand of water resource for various purposes. A holistic approach to manage water resource is what is known as Watershed Management Programme.

Watershed is a spatial unit with complex relations among its entities and is defined by stream pattern where the rainwater is collected through surface and subsurface run off and culminated at the common point down the stream (Reddy, 2004). In a watershed management programme emphasis is laid on proper utilization of different resources for optimum production and minimum hazard to the environment. The behavior of any watershed is a function of its physiography, geology, climate, geomorphology, social set up, etc.

In the present study an attempt is being made to carry out the Morphometric analysis of Walki watershed using GIS. Morphometric analysis is one of the important elements of any watershed development programme. This paper makes an attempt to show how GIS can be used to measure various morphometric parameters, which would have otherwise required time-consuming and tedious calculations. However the importance of ground surveys is not undermined as such analysis need to be authenticated with the help of such surveys.

Area

The Walki River basin lies between $73^0$30’E to $75^0$35’40’E longitude and 18^0 32’16” N to 20^0 45, 52” N Latitude. It occupies an area 75.75 sq. km. of Toposheet number 47 F/10 in the scale of 1:50,000. The basin is situated in Mushi Taluka of Pune District with its head quarter at Paud.

Climate

The Walki river basin is characterized by monsoon climate. It receives rainfall from the south – west monsoon that begins in early June and lasts until the middle of October. A wide range is experienced depending upon the variation in physiographic setup. The occurrence of rainfall is erratic and uncertain. The components of this variability are changes in aggregated precipitation, the dates of the onset and cessation of the rainy season, the number of rainy days and frequency and duration of dry spells (Thigale, S. S. 1983). The average rainfall of Walki basin is 2300mm.

The winter follows the rains reaching its peak in December and January with minimum temperature of 10^0 C to 12^0 C. Amongst the summer months April and May are the hottest with maximum temperature of about 39^0C. The average yearly maximum and minimum temperatures are 35.27 ^{0}C and 17.55 ^{0}C.

Physiography

The Walki river basin is a fifth order basin, which covers an area of about 75.75 sq.km. There are a number of peaks of more than 1000 m altitude along the peripheral part of the basin, the highest being 1256 m of Mandavi. The lowest point 575m is located at the confluence of Walki River and Mula River.

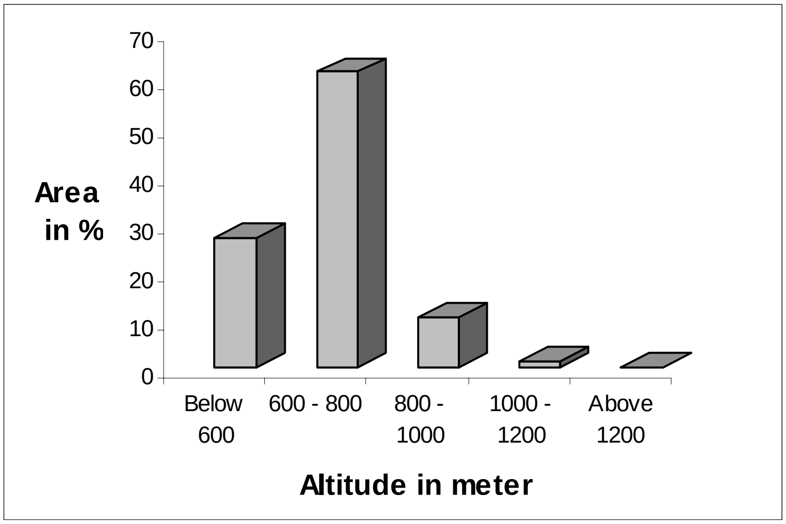

Figure 1: Graph of Altitude vs Percentage of the area for Walki River basin.

The basin is named after the Walki River, which is a fifth order stream. The river flows in the south – east direction and joins the river Mula at Mugavade.

From the figure it is evident that 11.4% area occurring over 800 m altitude above mean sea level is a rugged terrain.61.54% area between 600m and 800m is gently rolling, while remaining area below 600 m contributes to about 26.92% of the total area of the Walki Basin. The Walki basin exhibits more or less flat topography.

Geology

The area of the present study is dominantly constituted of basaltic flow. These basaltic flows belong to the Deccan Volcanic Province represented by horizontally disposed basaltic flows. The basaltic flows in the study area on the hill slopes are covered by residual and / or colluvial soils. The alluvial soils are seen to be developed along the banks of Walki River.

The criteria adopted by Shrock (1948), Mc Donald (1967) and others have been adopted to demarcate flow boundaries. The basaltic flows were marked between 575m and 1100 along the divide separating the Walki and the Rihe stream basins.

Godbole et al. (1986) made an attempt to evolve the lithostratigraphy of Deccan basalts from Western Maharashtra. As per the classification suggest by them the basaltic flows of the study area comes under the Karla formation of Lonavala sub-group belonging to north Sahyadri Group of Deccan Trap Super group. According to Subbarao and Hooper (1988) the present study area falls in the Bushe Formation of the Lonavala sub-group belonging to Deccan Basalt group. As per the two fold Hawaiian classification, which has been adopted by the Geological Survey of India both pahoehoe and aa flows are present in the study area. These flows are brief described below:

Pahoehoe flows – These flows are of the compound type and characteristically display three units: a basal section with pipe amygdales, a middle section of dense rock, and an upper, highly vesicular / amygdaloidal section. The middle of numerous flow units vary considerably in size, form and petrographic characters. Ropy surfaces are seen on the surface of some flow units. The tops of some individual flows were found to be reddened Vesicles are usually concentrated in the upper part: Coalescence of two or more vesicles has given rise to irregular cavities, which are subsequently filled by zeolites or other secondary minerals including silica. Within the massive part of the flows units lenticular to tabular zones of highly vesicular rocks are seen.

AA flows: The aa flows are simple or multiple in nature, though compound flows with a few, largely tabular, flow units are recorded. The aa flows consist of a dominant, dark homogenous section. The weathered tops of the AA flows form rubble of fragmentary rocks, the spaces between larger fragments being filled by smaller pieces. The fragments possess angular edges. The aa flows often exhibit characteristic spheroidal weathering. Weathering of this type sometimes give rise to smooth surfaced rectangular blocks. The slopes developed due to aa flows are found to be gentle. At places they give rise to 'steps' corresponding to different flows.

At few places the volcanic breccia often occurs as a capping on the aa flows. The breccias possess purple, dark gray or greenish grey colour and is composed of highly altered angular fragments of basaltic material. The matter surrounding the angular fragment may show fairly extensive zeolitization.

Red horizons: -Red horizons referred as red boles (Kanegaonkar, 1977; Kshirsagar, 1982) show two types of field relationship with the basalt flows.

Red boles are thin layers constituted of clayey material. They vary in thickness from a few centimeters to more than one meter and can be traceable discontinuously for considerable distances. These beds characteristically display a close spaced prismatic jointing. At places they may be highly zeolitised. Red bole occurs as a horizon at the top of the zeolitised basaltic flow, which exhibit a gradational relationship with underlying basalts.

Petrology

The basaltic rocks occurring in the area can be megascopically grouped into the following categories:

1. Non-vesicular basalts, which are hard and compact, dark to greenish gray in colour and medium to fine grained in texture.
2. Vesicular and amygdaloidal basalts which are comparatively soft, greenish gray to greenish or pinkish in colour. The vesicles are filed with secondary material like green earth, zeolite, calcite, etc.
3. Prophyritic basalts with phenocrysts generally of plagioclase crystals only in appearance.

In thin sections the basalts are seen to be fine to medium grained rocks exhibiting an equigranular texture. Plagioclase phenocrysts are commonly seen to occur either singly or in glomerophorphiritic aggregates. Pyroxenes (augite), iddingite and olivine are occasionally present.

Sub ophitic relationship is common between plagioclase and augite. The ground mass is usually hypocrystalline consisting of sub-hedral grains of augite, laths of plagioclase, irregular shaped opaque minerals and some interstitial glass. The modal analysis of basalts of Mulshi area (Saxena, 1986) revealed that the plagioclase and augite respectively constitute 44.2% and 35.2% and opaque minerals, glass and olivine respectively 3%, 7% and 6% of the total volume.

Morphometric Analysis

Landforms are the most common features on the earth's surface. If properly interpreted they throw light upon the geologic history, structure and lithology of the region. (Jagtap. H. B. 2001). Hydrogeological problems in the Deccan volcanic province are best understood if the geomorphology of such rock types is fully comprehended. Such understanding of any area can be achieved by carrying out morphometric analysis or fluvial morphometry.

Fluvial morphometry is the quantitative investigation of geometric properties of rivers and their basins. (Bryant, R. H. 1990). Procedures in fluvial morphometry were originally proposed by Horton and subsequently amended by Strahler. Study of parameters such as stream order and numbering, type of drainage, stream frequency, stream length and length ratio, drainage density, altitude distribution etc are undertaken.

According to Bryant (1990) the examination of large number of systems have shown that if the number of streams in each order is counted then that number decreases with increasing order in a regular manner. This is known as the ' Law of Stream Numbers'. Stream order is related to stream numbers on a semi-logarithmic scale, and a straight line emerges. Similar straight-line plots can be obtained if stream order is plotted against the area drained by each order – ' Law of Stream Lengths', and if stream order is plotted against the total stream lengths per order – ' Law of Basin Areas'. Bifurcation ratio is used to express the number of streams in a given order to the number of streams in the next order.

These various geometric properties show that in a given river basin, downstream changes are regular and determinable, so that laws of growth and development can be formulated, relating river length, number of tributaries, basin area, river gradient and relief to the order of river. (Bryant, 1990, pp 54).

These laws are sometimes collectively referred to ' Laws of Drainage Composition'. Underlying them is a fundamental growth principle, which in biological sciences is known as the 'Law of Allometric Growth'. This law when applied to an animal, states that the relative growth of an organ is a constant fraction of the relative growth of the whole individual. The same applies to the component part of a river system in relation to the total growth of the system. (Bryant, 1990).

In the present study an attempt has been made to calculate the above mentioned morphometric parameters using GIS.

Application of Geographical Information System in Fluvial Morphometry

A GIS is a computer system for capturing, storing, querying, analyzing and displaying geographic data (Chang 2002). Tools in GIS can be used effectively to carry out a study of the above-mentioned morphometric parameters. Morphometric analysis of Walki Basin was carried out using various GIS softwares such as AutoCAD Map 2000i, ArcGIS 9 and Arc View 3.2a.

The steps involved are as follows:

- Raster Map Creation /Scanning
- Geometric Transformation / Georeferencing
- Spatial Data Editing
- Topology Creation
- Analysis and results

Raster Map Creation /Scanning: Scanning is a digitizing method that converts an analog map into a scanned file, which is converted back to vector format through tracing (Verbyla and Chang 1997). Scanning converts the map into a binary scanned file in raster format; each pixel has a value of either 1(map feature) or 0 (background). In the present study, scanning of the analog map was done with the help of a drum scanner.

Geometric Transformation/Georeferencing: A map must be converted to real world coordinates before tracing of the map is undertaken in order to get real world measurements between the points of vector data.
Georeferencing is the process of converting a digital map or an image from one coordinate system to another, using a set of control points and transformation equations (Chang, 2002). In the present study, four control points (Ground Control Points) with known longitude and latitude values were digitized. Georeferencing was carried out in ArcGIS 9. Since the GCPs used were in degrees – minutes – seconds, they were converted into degrees – decimal units.

Digitization: This process converts Raster data into vector format. In the present study, various entities like watershed boundary, streams of various orders, etc. were digitized on separate layers. For digitization the software used was AutoCAD Map 2000i.

Spatial Data Editing: this refers to the removal of errors from digital maps (Chang 2002). Spatial data editing covers two types of errors. Location errors such as missing polygons or distorted lines relate to inaccuracies of map features, while others such as dangling arcs and unclosed polygons relate to logical inconsistencies among map features (Chang 2002). In the present study spatial data editing was carried out using AutoCAD Map2000i.

Topology Creation: Topology is the term given to the spatial relationships between features having similar properties. The relationship can be between two lines meeting at a point or a directed line, which has a left and right side (ArcInfo 3.5.2 user manual).
Once topology is created the system generates spatial attribute data, which corresponds to the real world measurements of the entities concerned.
In the present study, topology was created for the stream orders first-, second-, third-, fourth-, and fifth- order streams. Topology was also created for the boundary of Walki Watershed (Polygon topology) and for representative second-, third-, fourth- order basin.
The attribute data table which is generated by the system (in this case AutoCAD Map 2000i) consists of ID, area, perimeter and links _quantity fields. On the other hand attribute data for network topology consists of ID, start_node, end _node, direction, direct _ resistance, reverse _ resistance, left _polygon and right_ polygon.

Analysis and results
Stream ordering and numbering was carried out according to 'Hortonian Concept'. Streams of first-, second-, third-, fourth-, and fifth- order were digitized on corresponding layers. The number of streams present in a particular order can be calculated by selecting all the objects present in that particular layer. (Table 1)

Stream Order	Number of Streams	Percentage of Streams	Bifurcation ratio
First	265	77.03	4.38
Second	61	17.73	
Third	15	04.36	4.07
Fourth	02	00.58	7.50
Fifth	01	00.29	2.00
	Total = 344	Total = 99.99	Avg.= 4.48

Table 1: Stream order, numbers, percentages and bifurcation ratio of Walki River basin.

By dividing the number of streams of any order the number of streams in the next lower order gives the bifurcation ratio (Horton, 1945). (Table 1)
The stream length of any particular steam can be obtained from its topology attribute data wherein it corresponds to direct resistance in the attribute data table. Similarly total stream length of a particular order was calculated by adding individual steam lengths of number of streams of that particular order**. (**Table 2)

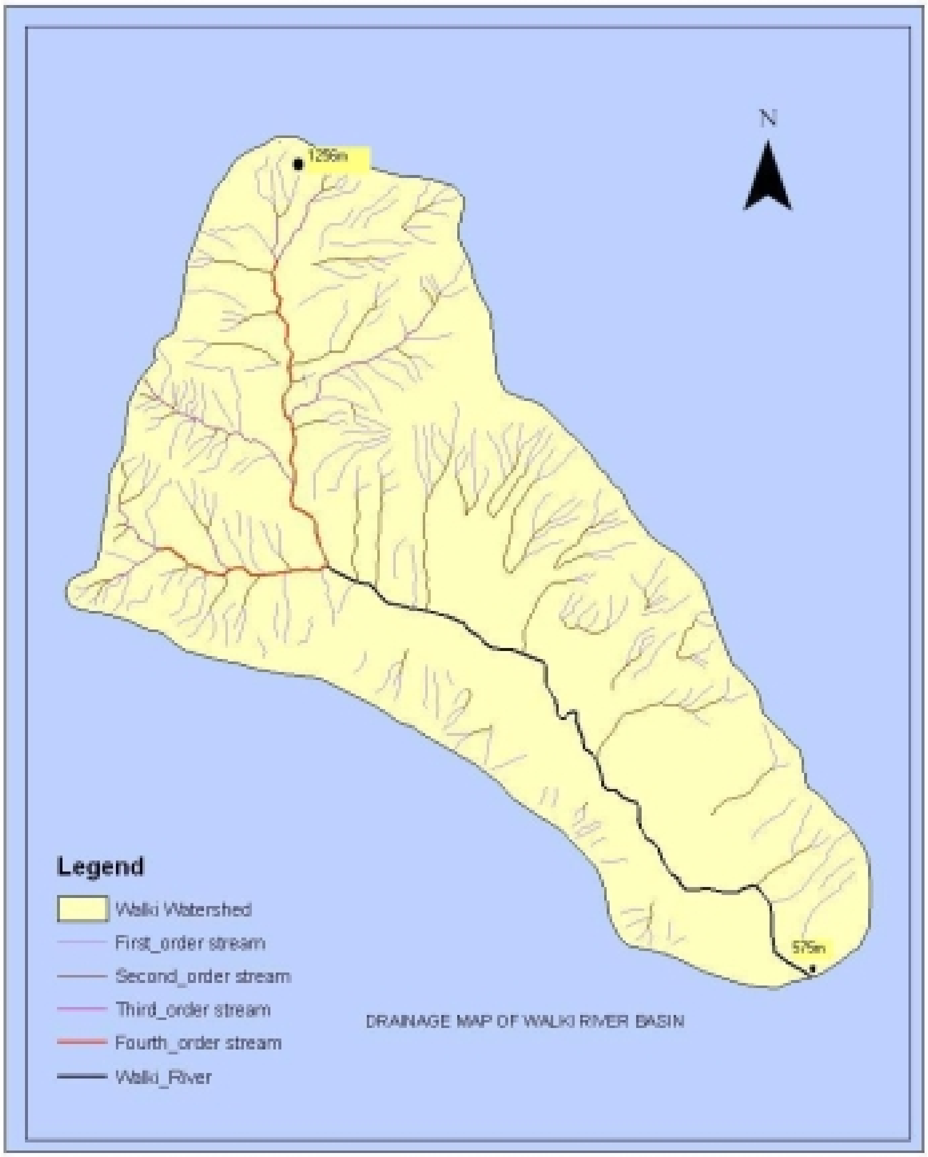

Figure 2: Drainage Map of the Walki River Basin

Type of Drainage: From the drainage map it is evident that three types of drainage patterns are present in the Walki watershed.
The dendritic type, which indicates erosional streams. This pattern is normally observed in the lower order streams, particularly along the periphery of the basin.
Parallel to sub-parallel drainage in the middle reaches of the basin, the direction of parallel streams being NNW-SSE. This direction corresponds to the western ghat scarp and the west coast.
The rectilinear type of drainage indicative of structural control (Jagtap, H.B. 2001).

Stream Order	Number of Streams	Total stream length in Km
First	265	137.80
Second	61	33.50
Third	15	19.5
Fourth	02	8.5
Fifth	01	10.95

Table 2: Stream Length of the Walki River basin.

Drainage Density: Horton (1932) defined drainage density as sum of the channel length divided by the area of the basin. Strahler (1957, 1964) stated that drainage density depends upon the geologic and climatic factor and it increases as the individual drainage unit proportionately decreases. (Table 3)

Order of Basin	Total area in sq. km. (A)	Total channel length in sq. km (B)	Drainage density A/B
Second	1.06	4.80	4.53
Third	4.38	12.30	2.81
Fourth	17.31	57.65	3.33
Fifth	75.75	191.78	2.53

Table 3: Drainage density of the Walki River basin

Stream Frequency: Horton (1945) referred to stream frequency as number of streams per unit area. It is derived by dividing total number of streams by total drainage area.
From table 4 it is evident that the Walki River basin includes 344 streams whereas total area of the Walki basin is 75.75 sq. km. hence stream frequency is 4.54.

Order of Basin	Number of streams in the basin	Area of the basin	Stream frequency
Second	05	1.06	4.72
Third	21	4.38	4.79
Fourth	82	17.31	4.74
Fifth	344	75.75	4.54

Table 4: Stream frequency of representative sub- basins of the Walki River basin

Conclusion

Following the Hortonian concept, various morphometric parameters were computed using GIS. The scope of GIS as a complete solution provider for watershed management coupled with ground surveys/fieldwork is vast. The present paper touches upon a small yet an important use of GIS in watershed management. Morphometric analysis involves measurement of parameters such as number of streams, stream length, stream frequency, bifurcation ratio etc. In the present study network topology was created for the streams of first-, second-, third-, fourth- and fifth order streams. The total stream length of first-, second-, third-, fourth- and fifth order streams in km is 137.80, 33.50,19.50,8.50 and 10.95 respectively. On creating polygon topology the area of the basin in km, of second, third, fourth and fifth order was calculated to be 1.06,4.38,17.31 and 75.75 respectively.

The Walki River is a fifth order stream; the elevation difference of the basin is 661m, out of the total basinal area 11.54% area occurring over 800m altitude is a rugged terrain. 61.51% area between 600 and 800m is a rolling terrain, whereas remaining 26.92% below 600m altitude exhibits more or less flat topography.

Three distinct types of drainage have been observed

- Dendtritic type observed along the periphery of the basin.
- Sub parallel to parallel type in the central part where the streams meet the major tributaries at right angles and
- The rectilinear pattern developed mostly in the NW-SE direction.

Of theses types, the dentritic type is indicative of erosional streams developed over homogeneous formations. The other two types on the other hand are a result of structural disturbance.

The bifurcation ratios obtained after numbering the streams also support the above-mentioned observation. The bifurcation ratio upto third order stream is around 4 indicating that there is no structural control over development of drainage. The bifurcation ratio for the third - and fourth order and fourth – and fifth order streams are 7.25 and 2 respectively. These values, since do not fall in the range of 3 to 5, indicate structurally controlled higher order streams.

The data of stream length analysis suggests that the average length of stream increases with the order of stream in direct proportion. The data of drainage basin area analysis also supports this fact since average area of different order basins increases proportionately. The data of drainage density show decrease from lower to higher order streams but increase in length of overland flow from lower to higher order streams. The value obtained for stream frequency is 4.54.

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