Geo-spatial topology based morphometric analysis for soil and water conservation in Dholbaha watershed of Kandi region

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Abstract. Morphometric analysis forms the basis for planning water and soil conservation treatments in a watershed. Geospatial topology based morphometric analysis in Dholbaha watershed, located in the Kandi region of Punjab, was carried out using the IRS data of LISS IV, Cartoset-I merged satellite data, ASTER DEM and ArcGIS-10.2 software. As per topology, Dholbaha watershed is the 5th order watershed. Out of all the 279 streams identified, 213 are of 1st or 2nd order and one 5th order stream. The total stream length is found to be 191.73 kms. The dendritic drainage pattern is found with stream frequency of 4.67 no./km² and mean bifurcation ratio of 3.9. Both length as well as number of streams decrease with the increase in the order of streams. Topological model indicates lesser effect of geological structure on the drainage pattern of the watershed. Drainage density of watershed (3.21 km/km²) reflects the closeness of spacing in channels with permeable sub strata. Fine drainage texture (7.34 no./km) and large length of the overland flow (150 m) in watershed resulted into high peaked hydrographs and high sheet erosion in the watershed. The circularity ratio, form factor and elongation ratio of the watershed 0.412, 0.51 and 0.72, respectively indicate that watershed is less elongated in shape, associated with medium to high relief, having moderately permeable sub-soil conditions resulting in moderate peak discharge, and moderate runoff volume resulting in high soil erosion. The watershed requires urgent conservation measures to control siltation of the reservoir.

1. Introduction
Assessment of the watershed characteristics using morphometric analysis in quantitative form gives the information related with the hydrological nature of the watershed and quantitative form of description of the drainage system. It plays a vital role to understand the hydrological characteristics of the watershed [1]. The morphometric analysis of the watershed provides the important parameters for the demarcation of sites for water resource management, geographic characteristics and water harvesting structures of drainage system. Drainage pattern can be characterized by the measurement of the relief, aerial and linear aspects of watershed. Watershed geometry, topography, bedrock, soil type, vegetation cover and climate influence the run-off and sediment movement in a watershed. Thus to predict approximate behavior of a watershed, morphometric analysis helps in elaborating its hydrological diagnosis.

In accurate prediction of the runoff importance of geomorphic factors cannot be overlooked. Delineating the watershed and stream network is the first step in calculating the hydrologic parameters. Influence of the watershed characteristics on runoff can be studied by the measurement and expression of quantified geomorphic parameters. Hence, simple and useful procedure to simulate the hydrologic behavior of watershed can lead the linkage of the geomorphologic parameters with hydrologic characteristics of the area.

Geospatial techniques are used for the analysis of different morphometric characteristics of the watershed, as these promote a flexible environment and a useful tool for the manipulation of geospatial informations. The greatest advantage of using remotely sensed data for morphological study is its ability to create information in temporal and spatial domains. In current times, satellite data application and
GIS have been successfully explored to create suitable data on the geospatial characteristics of the drainage providing an insight into hydrological characteristics of the watershed [2], [3].

Topology in the GIS framework applies the rules and sets that displays how point, line and polygon(s) share their corresponding geometry. It has been a key prerequisite in GIS for data management and its reliability. Generally, a GIS topological data model realises geospatial relationships by depicting locational (point), linear (line) and areal (polygon) features, as essential representation of topological depictions of knots (nodes), sides (faces) and boundaries (edges). These primitives, (of nodes, faces and edges), along with their association to each other and to their representative features are distinctly defined through graphical geometries of topology elements (fig. 1).

Primarily, topology is used for ensuring data qualities of spatial relationships and aiding data compilation. It is used for spatial analysis and analysing spatial relationships in conditions like boundary dissolution between adjacent polygons with similar traits (attribute values) or crossing along a linear feature or network of components in topological grid.

2. Methods and materials
2.1 Study area
Dholbaha watershed, in the Shivalik foot-hills of Punjab, is located in Bhunga Block 32 km from Hoshiarpur town (Fig.2). It lies between latitude 32°2’12” and 31°32’48” North and longitude 74°48’1” and 76°10’1” East. An earthen dam with reservoir area of 132 hectares has been constructed by the Department of Irrigation, Punjab, in the year 1987 for providing irrigation in the downstream area of 3745 hectares and for controlling floods that were causing heavy loss to the neighbouring villages. However, the capacity of the dam is decreasing at a fast rate due to high siltation rate (65-75t/ha/yr). The temperature in the area varies from 14° C to 47° C in summers and 0° C to 32° C in winter. The south-western monsoon reaches during July and remains till September. The average annual rainfall ranges from 60 to 90 cm. The soil of the watershed varies in texture from sandy loam to loam clay with boulders. Drainage streams of the watershed have been assigned order as per fig.3.
Figure 2. Location of study area

Figure 3. Method for assigning stream order in Dholbaha watershed
2.2 Data sources
Survey of India’s toposheets of 1:50,000 scale with bearing No. 44M/13 and 44M/14 have been put to use for preparing watershed’s drainage map and have been updated through LISS IV and Cartosat-1 merged data of the year 2009. The raw satellite data was rectified using topological geometry and was georeferenced. Ground control points (GCPs) have been taken by using WGS 84 datum and UTM projection.

The present study has been done on the digital data of IRS (Indian Remote Sensing) LISS IV and Cartosat-1 of year 2009 with the spatial resolution of 2.5m. ASTER was used for delineating watershed boundary, slope, flow direction, flow accumulation, aspect, relief and contour map. Drainage study has
been done by on screen digitization using ArcGIS software. After completion of map generation, field verification was done and final theme maps were prepared (fig. 4). Length of the stream, bifurcation ratio and area of the watershed were calculated as morphometric parameters using Arc GIS. Locational points and feature boundaries were stored in main files which were owned and managed by ArcInfo Workstation. The linear or polygon boundary geometry as topological edges, were held as “ARC” file referred as "arcs." Similarly, the point locations were held as "LAB" file, used as “label” points depicting polygon or individual point feature, like wells feature layer. Likewise, other files have been used to define the topological relationships between each of the edges and the polygons and persevering them. Table 1 depicts the computation methodologies of morphometric parameters.

### Table 1. Computation of morphometric parameters

| Morphometric Parameters for analyzing topological characteristics | Formula/Definition | Reference |
|---------------------------------------------------------------|-------------------|-----------|
| Order of the Stream (U)                                      | Horton’s Hierarchical Rank | Horton (1945) [4] |
| Length of the Stream (L_u)                                   | Length of the Stream (in km) | Horton (1945) |
| Mean Length of the Stream (L_{sm})                           | L_{sm} = L_u / N_u, km | Strahler (1964) [5] |
| Bifurcation Ratio (R_b)                                      | R_b = N_u / N_u+1 | Schumm (1956) [6] |
| Mean Bifurcation Ratio (R_{bm})                              | R_{bm} = All orders average bifurcation ratios | Schumm (1956) |
| Over Land Flow Length (L_g)                                  | L_g = 1/ D_d×2 Km | Horton (1945) |
| Drainage Density (D_d)                                       | D_d = Σ(L_u / A_u) km/km^2 | Horton (1945) |
| Drainage Texture(D_t)                                        | D_t = Σ N_u/P | Smith (1954) [7] |
| Stream Frequency (F_s)                                       | F_s = Σ N_u / A_u | Horton (1932) [8] |
| Form Factor (R_l)                                            | R_l = A_u / L_b^2 | Horton (1932) |
| Circularity Ratio (R_c)                                      | R_c = 4πA_u / P^2 | Miller (1953) [9] |
| Elongation Ratio (R_e)                                       | R_e = √A_u/π / L_b | Schumm (1956) |
| Relief (R)                                                    | R = H-h | Hadley and Schumm (1961) [10] |
| Relief Ratio (R_h)                                           | R_h = H / L_b max | Schumm (1956) |

### 3. Results and discussions

Morphometric analysis for proper hydrological characterization of watershed indirectly reflects hydro-geological status of the watershed. Detailed statistical analysis of the morphometric parameters is of vast usefulness in runoff generation and soil erosion and management at watershed scale. The morphometry based analysis of Dholbaha watershed was carried out over measuring its relief, aerial and linear characteristics. Topological features of stream segments with respect to open links of the network systems were analysed. Topology applications in ArcGIS works and scales to very large geo-databases.
Through its multiuser systems it performs well, including good proofing and edit tools for structuring and retaining topologies in geo-databases. It comprises better and flexible data displaying tools which helps its users to amass practical and operational schemes on files for associated geo-databases, and for all number of schemas.

3.1 Basic watershed parameters

For the quantitative study of the morphology, area and perimeter of the watershed are very important components. Watershed area is also of hydrological importance, as it directly influence the base of the magnitudes of mean and peak runoff with the storm hydrograph. The area of Dholbaha watershed was found to be 5967 ha having perimeter of 38 km. The watershed length (Lb) as defined by Horton (1932) as the straight-line distance from watershed outlet to the point on the watershed divide intersection and the projection of line’s direction through the source of the chief stream is arrived at 12.03 km (fig. 4).

3.2. Morphometric analysis

3.2.1. Linear aspect

3.2.1.1. Order of the Stream (U)

Dholbaha watershed is the fifth order drainage basin. In the watershed, total number of 279 streams have been identified, out of which 213 are of 1st order streams, 52 of 2nd order, 10 of 3rd order, 3 of 4th order and 1 stream of fifth order (main stream). Number of streams decreases as the order of the stream increases, in the Dholbaha watershed (Fig. 5) and (Fig. 6). The relationship is represented by the following regression equation:

\[ Nu = 746.4 e^{-1.35U} \quad (R^2 = 0.994) \]  

Where \( Nu \) = Number of streams of the U order in the watershed

3.2.1.2. Length of the Stream (Lu)

Stream length is the sum of the whole length of stream(s) in the defined order. It is the utmost important feature of watershed as it indicates the characteristics of the surface runoff. Bigger slopes with finer texture are characteristics of relatively smaller length streams. Flatter gradients are generally indicators of longer lengths of streams. This result brings out the strong assumption that watershed is subjected to soil erosion and also that some areas of basin are characterized by variation in topography and lithology [3].

The total length of the 1st order streams is 105.56 km. It is 50.73 km for 2nd order, 25.39 km for 3rd order, 9.16 km for 4th order, and 2.99 km for 5th order. The mean stream length for all streams in the watershed is 0.6876 km. The first order streams are having largest whole length of stream segments and length of streams decreases as the stream order increases (Fig. 7).

3.2.1.3. Mean Length of the Stream (Lsm)

The mean length of the stream is directly proportional to the order of the stream (Fig. 8) and (Fig. 9). The relationship is represented by the following regression equation:

\[ Lsm = 0.708U - 0.158 \quad (R^2 = 0.907) \]

Characteristic size of drainage network components is resulted by the mean length of the stream and it is a dimension which is contributing watershed surface. The stream length ratio decreases with the increases in stream order in Dholbaha watershed. The study watershed stream order wise mean stream length (table 2) varies from 0.49 to 3.05 km. Mean stream length of a given order is higher than its lower order, but in this watershed 5th order mean length stream is less than that of 4th order due to the changes in topography and soil.
Figure 4. Drainage map of Dholbaha watershed

Figure 5. Variation of stream numbers with stream order in Dholbaha watershed
Figure 6. Association between stream order and stream numbers in Dholbaha watershed

\[ y = 746.44e^{-1.338x} \]
\[ R^2 = 0.9942 \]

Figure 7. Variation of stream length with stream order in Dholbaha watershed

Table 2. Mean stream length of different order streams in Dholbaha watershed

| Order of Stream | Total length of stream (km) | Stream length Ratio | Mean stream length (km) |
|-----------------|-----------------------------|---------------------|-------------------------|
| 1               | 105.56                      | -                   | 0.49                    |
| 2               | 50.73                       | 0.48                | 0.97                    |
| 3               | 23.29                       | 0.46                | 2.33                    |
| 4               | 9.16                        | 0.39                | 3.05                    |
| 5               | 2.99                        | 0.32                | 2.99                    |
3.2.1.4. Bifurcation Ratio (Rb)
Bifurcation ratios ranged from 3.0 to 5.2 in Dholbaha watershed, where geologic structures did not distort its drainage pattern. Greater values of bifurcation ratio show stronger structural control in drainage pattern (Table 3). Structural disturbances have not been found in the lower values [1]. The mean bifurcation ratio (Rbm) of Dholbaha watershed is found to be 3.9, which specifies pattern of drainage to be less affected by geological structures. Also, the watershed is less elongated and may result in high runoff peak [5].
3.2.1.5. Length of overland flow (Lo)
The value of the length of overland flow in Dholbaha watershed is 150 m. The value is above the standard length of around 100 meters. It means that it has the potential to cause surface sheet erosion owing the longer distance travelled by surface run-off before it reaches a stream.

3.2.2. Aerial Aspects:
3.2.2.1 Drainage density (Dd)
Spacing of stream’s closeness is represented by its drainage density. Coarse drainage texture resulted in low drainage density, while fine drainage texture resulted in high drainage density. Low drainage density is favored in such regions, where highly permeable subsoil is present underneath dense cover of vegetation. Drainage density of 3.21 is found in the Dholbaha watershed.

3.2.2.2. Drainage texture (Dt)
The texture of drainage of Dholbaha watershed is 7.34 no./km. Drainage texture provides information on the spacing of the drainage streams. Drainage texture is affected by natural factors and developmental stage of a watershed. Smith (1954) has classified drainage texture (where < 2 specifies very coarse texture; 2 to 4 as coarse texture; 4 to 6 as moderate texture; 6 to 8 as fine texture and > 8 as very fine drainage texture). Hence, Dholbaha watershed with Dt 7.34 no./km falls in the category of fine texture.

3.2.2.3. Stream frequency (F_s)
Dholbaha watershed has the stream frequency of 4.67 no./km². The stream frequency (F_s) value indicates the increasing stream numbers with increasing drainage density. High frequency of stream occurrence indicates that the topography of the watershed is not plain.

3.2.2.4. Form Factor (R_f)
The result value of the form factor in Dholbaha watershed is 0.412. Form factor is equal to unity when the basin shape is a square and decreases according to the extent of elongation. Form factor, defined by Horton (1932), would never exceed 0.754 for a perfectly circular basin. The value of form factor (0.412) in Dholbaha watershed display that watershed is less elongated.

3.2.2.5. Circularity Ratio (R_c)
In the Dholbaha watershed, the circulatory ratio value is 0.51, indicating that watershed is less elongated having moderate discharge of runoff and moderate permeability of sub soil conditions. Such drainage systems cause problem of soil erosion to some extent.

3.2.2.6. Elongation Ratio (R_e)
Dholbaha watershed’s elongation ratio has been computed to be 0.72. Generally, the R_e values vary between 0.6 and 1.0. The elongation ratio of Dholbaha watershed (0.72) indicates less elongation, but oval shaped watershed having medium to high relief and slope. These types of watershed result in high peaked hydrographs causing problem of soil erosion.

3.2.3. Relief Aspects:

Table 3. Bifurcation ratio in the Dholbaha watershed

| Stream Order | No of streams | Bifurcation ratio (R_b) |
|--------------|---------------|-------------------------|
| 1            | 213           | 4.09                    |
| 2            | 52            | 5.2                     |
| 3            | 10            | 3.33                    |
| 4            | 3             | 3                       |
| 5            | 1             | -                       |
| Mean Bifurcation Ratio | – | 3.9 |
3.2.3.1. Relief
The average value of relief of the Dholbaha watershed is 285 m. The relief is not very high as basin length is 12.03 km.

3.2.3.2. Relief Ratio
The value of relief ratio is 0.029 in the Dholbaha watershed, which is quite low. All the morphometric parameters of Dholbaha watershed have been summarized in Table 4. These parameters indicate moderate volume of runoff and high sheet erosion in the watershed.

| S. N. | Parameter                  | Result                |
|-------|----------------------------|-----------------------|
| 1     | Area (km$^2$)              | 59.67 (5967 ha)       |
| 2     | Perimeter (km)             | 38                    |
| 3     | Length of Overland flow (m)| 150                   |
| 4     | Drainage density (km/km$^2$)| 3.21                  |
| 5     | Stream frequency (no./km$^2$)| 4.67                  |
| 6     | Drainage Texture (no./km)  | 7.34                  |
| 7     | Form factor                | 0.412                 |
| 8     | Circularity ratio          | 0.51                  |
| 9     | Elongation ratio           | 0.72                  |
| 10    | Basin length (km)          | 12.03                 |
| 11    | Relief (m)                 | 285                   |
| 12    | Relief Ratio               | 0.029                 |

3.3. Digital Elevation Model (DEM)
Digital Elevation Model of the Dholbaha watershed is shown in Fig. 10. Topography in GIS is usually named as DEM, which indicates a digital description of the terrain relief. DEM formed the basis for generation of elevation of the spatial units with relief, slope and aspect maps.

3.3.1. Slope Map of the Watershed
Slope of the watershed is vital for land capability assessment and the estimation of soil loss. The slope in the Dholbaha watershed was classified into nine slope classes (0-1, 1-3, 3-5, 5-10, 10-15, 15-25, 25-33, 33-50, and >50 percent), based on Anon (1970) [11]. Most of the area in the watershed (70%) is moderately sloping to moderately steep sloping i.e. having slope from 5% to 25% (Fig. 11) and (Table 5).

3.3.2. Aspect
The aspect map of the Dholbaha watershed is depicted through Fig. 12. More than 60% of the watershed area is having South-West aspect.
Figure 10. DEM of the Dholbaha watershed, 2009

Figure 11. Slope map of Dholbaha watershed

Figure 12. Aspect map of Dholbaha watershed

Figure 13. Land use map of Dholbaha watershed
### Table 5: Percent area under different slope ranges

| S. N. | Slope Class              | Slope Range (%) | Slope Area (%) |
|-------|--------------------------|-----------------|----------------|
| 1     | Nearly Level             | 0-1             | 1.32           |
| 2     | Very Gentle Slope        | 1-3             | 6.4            |
| 3     | Gentle Sloping           | 3-5             | 10.5           |
| 4     | Moderate sloping         | 5-10            | 26.96          |
| 5     | Strongly sloping         | 10-15           | 20.4           |
| 6     | Moderately Steep to Steep Sloping | 15-25 | 23.12 |
| 7     | Steep sloping            | 25-33           | 6.9            |
| 8     | Very Steep Sloping       | 33-50           | 3.7            |
| 9     | Extremely Steep Sloping  | > 50            | 0.7            |

#### 3.3.2.1. Land Use

Land use/land cover map of Dholbaha as on March, 2009 was prepared by on-screen visual interpretation (Fig. 13). Major portion of the land in Dholbaha watershed is under forest (78.31%) followed by scrub land (13.6%). The area under agriculture crop is only 4.2% of the total area of the watershed (Table 6). The length of all the roads in the watershed is 38.77 km. The area under the roads within the watershed is only 0.18% of the total area. The prevailing land use of the watershed indicates generation of small quantities of runoff.

### Table 6. Percent area under different land uses in Dholbaha watershed (2009)

| S. N. | Land use        | Area (sq km) | Area (%) |
|-------|-----------------|--------------|----------|
| 1     | Forest Land     | 46.73        | 78.31    |
| 2     | Scrub Land      | 8.12         | 13.6     |
| 3     | Agriculture Land| 2.51         | 4.2      |
| 4     | Water bodies    | 1.8          | 3.03     |
| 5     | Built Up        | 0.38         | 0.64     |
| 6     | Roads           | 0.11         | 0.18     |
| 7     | Barren rocky    | 0.02         | 0.03     |
| **Total** |          | **59.67**   | **100**  |

#### 4. Conclusion

After the study, following specific conclusions have been drawn:

- Geospatial topology based techniques have proved to be powerful tools to find out morphometric analysis.

- Drainage density of the watershed (3.21 km/km2) indicates the close relation of channels with permeable sub strata, drainage texture (7.34 no./km) categorize the watershed as fine drainage texture with large length of overland flow (150 m) may result into high peaked hydrographs and high sheet erosion in the watershed.

- The form factor, circularity ratio and the elongation ratio of the watershed 0.412, 0.51 and 0.72, respectively indicate that watershed is less elongated in shape, associated with medium to high relief, having moderately permeable sub-soil conditions resulting in moderate peak discharge, and moderate runoff volume, thus high soil erosion.

- The watershed has 5th order of streams, dendritic in nature with stream frequency of 4.67 no./km² and mean bifurcation ratio of 3.9. Both length as well as number of streams decreases with the
increase in order. These parameters indicate that geological structure is less disturbing/affecting the drainage pattern of the watershed.

- The slope of around 70% of the watershed area is moderate (5-25%); 78.31% and 4.2% areas of the watershed have been categorized as forest land and agricultural land, respectively, the runoff potential of the watershed seems to be low as corroborated by the low value of the watershed relief ratio (0.029).

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