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Morphmetric Analysis of Randenigala Reservoir catchment using GIS

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ABSTRACT

Morphometric techniques play a major role in addressing the quantitative description of the geometry of the drainage basins and its network. This helps in characterizing the drainage network, comparing the characteristics and examining the effect of lithology, rock structure and rainfall. The study focuses on analysis of morphometric features of Randenigala reservoir catchment based on available digital data using GIS.

River Mahaweli was dammed closer to MinepeAnicut to build Randenigala reservoir with the elevation of 160 m to 240 m (7° 8′ to 7° 14′N and 80° 48′ to 80° 49′ E). The capacity is 861 MCM and catchment comprise of 448 km^2 in the Kandy and Nuwara-Eliya districts. The elevation of the catchment ranges from 240 m to 2500 m. Method of Horton and Strahler (1945) was used to rank the stream segments. The stream numbers were entered into the table and other analyses based on the mathematical formulas. The results indicated that the catchment area was 448.9 km^2, perimeter 111.24 km, mean slope 36.8, axial length 30.5 km, basin width 14.72 km, form factor 0.48, compactness factor 1.48, circulatory ratio 0.46, elongation ratio 0.78, orders of stream network indicated, 1315 of first orders, 314 of 2nd, 72 of 3rd, 15 of 4th, 3 of 5th, 1 of 6th and one seventh order stream. The stream frequency and drainage density were 3.83 (no. of streams /km^2) and 2.43 (km/km^2). Bifurcation ratio was 3.65 and length of overland flow was 0.21 km. These findings are useful in determining the effect of catchment characteristics such as size, shape, slope of the catchment and distribution of stream network.

KEYWORDS: *Morphometric features, GIS, Catchment characteristics*

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1. INTRODUCTION

River Mahaweli was dammed closer to 6 km from the old Minepe Anicut to build Randenigala reservoir and it has the highest capacity out of the other reservoirs within the Upper Mahaweli Catchment reservoir chain namely Kotmale, Victoria and Rantambe. The reservoir storage capacity is 861.4 MCM (Anon, 1986). It is located at an elevation of 160 m to 240 m with a geographical position of 7° 8′ to 7° 14′N and 80° 48′ to 80° 49′ E. The upstream dam site of the reservoir comprises 448 km^2 in the districts of Kandy and Nuwara-Eliya. The elevation of the catchment ranges from 240m to 2500m at Pidurutalagala mountain range.

The tributaries of the left bank are Ma Oya and Kehelella Ela. The Belihul Oya and Kurundu Oya belong to the right bank. Headwaters of the Belihul Oya, originate at the Pidurutalagala mountain range, which is the highest position of the catchment. After generating hydropower, outflow of the Victoria reservoir enters the Randenigala reservoir via River Mahaweli.

The Objective of the study was to analyse the morphometric features of Randenigala reservoir catchment based on available digital data using GIS.

2. MORPHOMETRY OF THE CATCHMENT

The development of morphometric techniques was a major advance in the quantitative description of the geometry of the drainage basins and its network. These parameters are useful in characterizing river basins and comparing their characteristics. For the first time it was proposed by Horton, in 1945. This development helps in characterizing the drainage network, comparing the characteristic of several drainage network and examining the effect of variables such as lithology, rock structure, rainfall etc. on the drainage network (Kale & Gupta, 2001).

The Morphometry parameters could be categorized into two major groups namely; the measured parameters and the calculated parameters (Naithani & Rawat, 1990).

2.2 Measured Parameters

According to Horton, stream order is a dimensionless term because of the extent of order number of streams is directly proportional to the size of watershed, channel dimension and to stream discharge. Therefore, the stream orders of drainage basin plays first step in analysis of drainage basin (Suresh, 2000). Strahler defined streams of different orders. All the un-branched smallest fingertip tributaries are called as first order streams. When two first order streams are joined they form a second order stream. When two second order streams are joined they form third order stream and so on (Waugh, 1995). Basin size is an important factor for the watershed's functions, which can be determined using soil map, contour map, aerial photographs and stream network, and computers with relevant software and other electronic devices (Gregory & Walling 1985). Axial length depends on the shape of the basin, which can be circular, elongated and curved; most of these features are governed by morphological characteristics of the basin (Gupta, 1999).

2.1 Calculated Parameters

The major calculated parameters of a basin are the basin shape, Bifurcation ratio, Circulatory ratio, Elongation ratio, Form factor, Compactness factor, Drainage density, Stream frequency, Overland flow and the average slope. Basin shape is referred to as the shape of outline of drainage basin that is determined as shape of projected surface on the horizontal plane of the basin map (Suresh, 2000). Mulder & Syvitsky (1996) have indicated that a majority of rivers have elongated basins. Bifurcation ratio (Rb) was recognized as an important characteristic of the drainage basin by Horton (1932) and was defined as the ratio of the number of streams of order in to the number of streams of the next higher order (n+1).This method therefore, dependent upon the ordering methods of either Horton or Strahler. The Circulatory ratio (Rc), is expressed as the shape of the basins that was used by Miller (1935). The circulatory ratio is dimensionless. Miller found that, Rc remains remarkably uniform in the range of 0.6 to 0.7 for 1st and 2nd order basins in homogeneous shales and dolomites, indicating the tendency of small drainage basins with homogeneous geologic materials to preserve the geometrical similarity (Suresh, 2000). Elongation ratio indicates how the shape of the basin deviates from a circle (Schumm, 1956). It is an index to mark the shape of the drainage basin. Form factor has been introduced by Horton (1932) that shows the shape of the basin. If there is a low form factor in a basin that indicates less intense rainfall simultaneously over its entire area than an area of equal size with a large form factor (Gupta, 1999). According to Gregory & Walling, (1985) the form factor is the governing factor of the water courses which enter the main streams.

Compactness factor is expressed as the shape of the basin that was used by Horton and was devised by Gravelius (Gupta, 1999). Drainage texture includes drainage density and stream frequency. According to Schumm (1956) under a given set of geologic and hydroclimatic conditions, a minimum area is needed for maintaining a river channel of a given length. The minimum area to sustain a channel is largely determined by lithology, climate and average slope and also rock type is an important control on the drainage texture and density. In addition, the vegetation cover, its density and types also play an important role in determining the drainage texture (Kale & Gupta, 2001). Length of overland flow was described by Horton (1933, 1945**)** as a component of total runoff in a drainage basin. When the rainfall intensity exceeds soil infiltration capacity, the excess water flows over the land surface as overland flow (Suresh, 2000)**.** Average slope, which is the inclined surface of a part of the Earth’s crust. The earth surface consist of various angles of slopes that may range from 0° horizontally to 90° vertically, and any land has been assembled of various types of slopes, which usually include the hillcrests, the valley-side slopes and the slope along the drainage lines at the base of the valley.

3. METHODOLOGY

To define the morphometric features of Randenigala catchment, the digital data on 1:50000 scaled hydrology and 20m interval contours were obtained from the Survey Department of Sri Lanka. ArcGIS 9.x software was used in the analysis of digital data for this purpose.

Catchment area (boundary line) was drawn through the centre of highest elevation's saddles and closed contour lines. Axial length of the catchment is expressed as "the distance from the outlet to the most remote point on the basin". Length of the basin was measured according to the above rule in the present study. Perimeter of the catchment was obtained from the created outline of the basin, which is dependent upon the topography of the area. Perimeter of the catchment was measured using ArcGIS 10.x software. Stream order; the method of Horton and Strahler was used to rank the stream. The relevant numbers of the streams were entered into the attribute table using ArcGIS software package.

Form factor defined as the ratio of basin area to the square of the basin length, using the following equation.
Where:

$$R_f = \frac{A_u}{L_b^2} \quad (1)$$

$A_u =$ Basin area (km^2)

$L_b =$ Basin length (km)

Compactness factor; the compactness factor was obtained from the ratio of the perimeter of the watershed to the circumference of a circle whose area is equal to that of the drainage basin (Gupta, 1999).

Where:

$$Comfactnessfactor = \frac{P}{2\sqrt{\Pi A}} \quad (2)$$

$P =$ Perimeter of the basin (km)

$A =$ Area of basin (km^2)

Average slope of the catchment was calculated using the contour length, its interval and the basin area using the following equation:

$$S = \frac{MN}{A} \times 100 \quad (3)$$

$M =$ Total length of contours within the watershed (m)

$N =$ Contour interval (m)

$A =$ Size of the watershed (m^2)

Circulatory ratio obtained from the ratio of basin area (Au) to the area of a circle (Ac) having equal perimeter as the perimeter of drainage basin.

Where:

$$R_c = \frac{A_u}{A_c} \quad (4)$$

Elongation ratio was defined as the ratio of diameter of a circle which has same area as the basin to the maximum basin length.

Where:

$$R_l = \frac{D_c}{L_{bm}} \quad (5)$$

$D_c =$ Diameter of circle having same area

$L_{bm} =$ Maximum length (km)

To define the drainage density, length of all stream channels in the basin were calculated using GIS and their lengths were divided by the area of the basin.
Where:

$$D_d = \frac{L_s}{A} \quad (6)$$

$L_s =$ Total length of all stream channels in the basin

$A =$ Area of the basin

To obtain the Stream frequency of the drainage basin; total length of all stream channels in the basin were divided by the area of the basin.

Where:

$$Ds = \frac{Ns}{A} \tag{7}$$

$Ns =$ Number of streams

$A =$ Area of basin

Length of overland flow was calculated as one-half of the reciprocal of the drainage density.

Where:

$$L_g = \frac{1}{2D_d} \tag{8}$$

$D_d =$ Drainage density

Bifurcation ratio for the catchment was defined as the ratio of number stream segments of a given order *u* divided by the number of stream segments of next higher order (*u*+1),

Where:

$$R_b = \frac{N_u}{N_{u+1}} \tag{9}$$

4. RESULTS AND DISCUSSIONS

Certain morphometric features of the catchment as well as the morphometry of reservoirs could collectively contribute to the degradation of water quality in the reservoir. Size, shape, slope of the catchment and distribution of stream network within the catchment, the capacity of the reservoir, could collectively contribute to the reservoir water quality degradation by increasing the productivity or by nutrient loading effects.

The catchment area of Randenigala was 448 km^2. The catchment areais land areas that drain elements into the Hydro Network. According to Gregory & Walling (1985) almost every watershed characteristics are correlated with the catchment area.

Kale & Gupta, (2001) have stated that the larger basins have large average discharge. The axial length also indicates the lag time taken for the water to reach the reservoir from its longest distance in the catchment after the rainfall. Together with mean slope, the axial length of the catchment affects the runoff to interact with the catchment. In the present study, the value of 30.5 km was indicated for the catchment.

Perimeter of the catchment was 111.24 km; it varies with its irregularity, which is based on the morphology of the area.

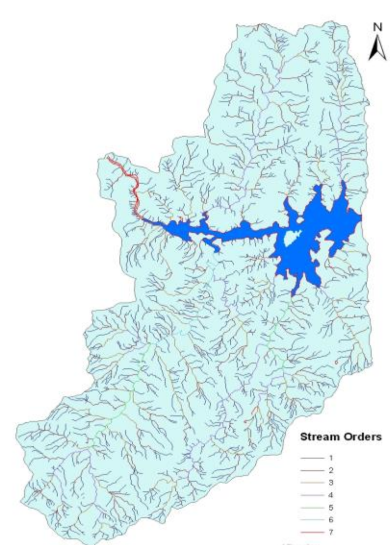

Figure1. Stream network of Randenigala reservoir

Bifurcation ratio of Randenigala catchment was 3.65 which indicate whether a basin is elongated or circular. Suresh (2000) has shown the high bifurcation ratio (Rb) is expected in the regions of steeply dipping rock strata, where narrow strike valleys are confined between the ridges.

According to Kale & Gupta (2001), the results of the present study ranged from 3 to 5 for the catchment indicating natural drainage system characteristics. Unusually high bifurcation ratio values (>10) are characteristics of drainage systems developed over easily erodible rocks and in areas underlain by heavily jointed rocks (Kale & Gupta, 2001).

Circulatory ratio of the present study was 0.46 which indicates shape of the catchment, the value, which deviate from 1, indicate highly irregular basins. According to Waugh (1995), shape of a basin has long been accepted that a circular basin is more likely to have a shorter lag time and a higher peak flow than an elongated basin.

Suresh (2000) has shown Elongation ratio ranges between 0.6 and 1.0 over a wide variation of climate and geologic types, for the regions of very low relief, the value of elongation ratio is found very close to 1.0, while for the areas involving strong relief and steep ground slope, the elongation ratio ranges from 0.6 to 0.8. The results of the present study indicated 0.78 which falls within 0.6 to 0.8 indicating strong relief and steep ground slope.

Form factor which expresses the shape of the basin. If the basin is wider, the form factor will be comparatively higher. Consequently, much narrower basins have low form factor values. The low form factor is indicated in the elongated basin and high form factor is indicated in the wider basin (Gregory & Walling, 1985). The calculated value of form factor for the catchment was 0.48. The value falls in-between narrower and wider.

Compactness factor of the basin is used to express the basin shape, which is indicated by the deviation of the basin area from a circle having an equal area (Gupta, 1999). The result of the catchment was indicated at 1.48, which reveals the in-between value for the catchment.
Stream network exhibits the main or trunk stream and its tributary streams that drain the basin area collectively form the stream network. The spatial arrangement of a river and its tributary streams in a drainage net work is referred to as the drainage pattern of a basin (Gregory & Walling, 1985).

Figure 1 illustrates the stream network of Randenigala catchment, the stream orders varied from 1 to 7 and the total number of stream segments of all orders recorded was 1721. Orders of stream network indicated, 1315 of first orders, 314 of 2^{nd}, 72 of 3^{rd}, 15 of 4^{th}, 3 of 5^{th}, 1 of 6^{th} and one seventh order streams.

Stream frequency and drainage density of the catchment were 3.83 (no. of streams per km^2) and 2.43 (km per km^2). According to Kale & Gupta, (2001) greater the drainage density and stream frequency in a basin, the runoff is faster, and therefore, flooding is more likely in basins with a high drainage and stream frequency. In addition, Smith (1950) and Strahler (1957) have described drainage density values less than 5.00 as a course, between 5 –

13.7 as medium, between 13.7 – 155.3 as fine, and greater than 155.3 as ultra fine. In Britain values are usually well below 5 and on Dartmoor average 2.14 (Chorley & Morgan, 1962).

Length of overland flow is referred to as the distance of flow of the precipitated water, over the land surface to reach the stream. The results obtained for Randenigala catchment was 0.21 km. The overland flow is higher in the semi arid regions than in the humid and humid temperate regions; in addition, absence of vegetation cover in the semi arid regions is primarily responsible for lower infiltration rates and for the generation of higher surface flow (Kale & Gupta, 2001).

The mean slope of the catchment is resulted from the morphology of the area.The effect of high slope result in high velocity of flow. Therefore it takes much lesser time for the catchment runoff to reach the stream. Mean slope of Randenigala catchment was 36.8%. Gupta (1999) has stated that the slope of the catchment is high which result in high peak flow after rainfall.

4.1 Conclusion

It is easy to analyze the morphometric features of a catchment using GIS. The catchment indicates high peak flow & strong relief after rainfall due to the steep ground slope. Further, it shows that in between elongated and circular shape. These results are useful to protect the reservoirs and apply proper catchment management practices.

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