

Full Length Research Paper

Estimation of sediment production rate of the Umbaniun Micro-watershed, Meghalaya, India

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Conservation of soil and water is essential to sustain any developmental activity carried out on a watershed. Analyzing shape parameters and drainage pattern parameters is known to be very important in watershed management. The Umbaniun micro-watershed with an area of 3951.18 ha located at 25°27'29" to 25°32'34" North latitude and 91°47'10" to 91°52'40" East longitude has an elongated shape with low sediment production rate (SPR) of 0.16218 ha-m/100 sqkm/year. It is under high biotic pressure and no conservation measures have been taken up to maintain its ecological health and stability. In this paper, we highlight a pilot study analyzing soil erosion and sediment production rate with reference to morphometric characteristics of the Umbaniun micro-watershed in Meghalaya.

Key words: Shape parameters, drainage pattern parameters, run-off rate, sediment production rate, Meghalaya, North-eastern India.

INTRODUCTION

A watershed is a natural hydrological entity which allows surface run-off into a defined channel, drain, stream or river at a particular point (Chopra et al., 2005). Physiographic information such as watershed slope, configuration of channel network, location of drainage divide, channel length and geomorphologic parameters namely relative relief, shape factor, circulatory ratio, bifurcation ratio, drainage density and hypsometric integral (HI) are often used in watershed prioritization and implementation of soil and water conservation measures (Sarangi et al., 2003).

Although management of land resources on a watershed is given top-most priority in India, most of the states of North-East India are not managed to conserve soil and nutrient state as per watershed management plan. The state of Meghalaya is one of the seven sister states of North-Eastern India and it has the heaviest rainfall in the world.

The soil erosion rate and rate of sediment production are affected by the shape of the watershed which controls the time taken for run-off to concentrate at the

outlet and the drainage pattern of a micro-watershed.

The present paper highlights a pilot study to analyze soil erosion and sediment production rate with reference to morphometric characteristics of the Umbaniun micro-watershed of Meghalaya.

Study area

The Umbaniun micro-watershed of Meghalaya covers an area of 3951.18 ha, is located at 25°27'29" to 25°32'34" North latitude and 91°47'10" to 91°52'40" East longitude. The elevation ranges from 1600 m at its mouth to above 1960 m at the remotest point (point of origin). The micro-watershed is dissected by 242 streams of different orders and drained by a 5th order stream that merges with Umiew River at 25°27'37" N and 91°47'28" E that finally falls in Bangladesh plain towards the Southern direction (Figure 1).

The average annual rainfall recorded during the survey is 2148.28 mm and the mean maximum temperature is recorded at 21.05°C. Summer (March to June) experiences a maximum temperature of 24°C and a minimum temperature of 15°C. Winter (November to February) is freezing, where snowfall and fog formations are observed. The minimum temperature recorded during

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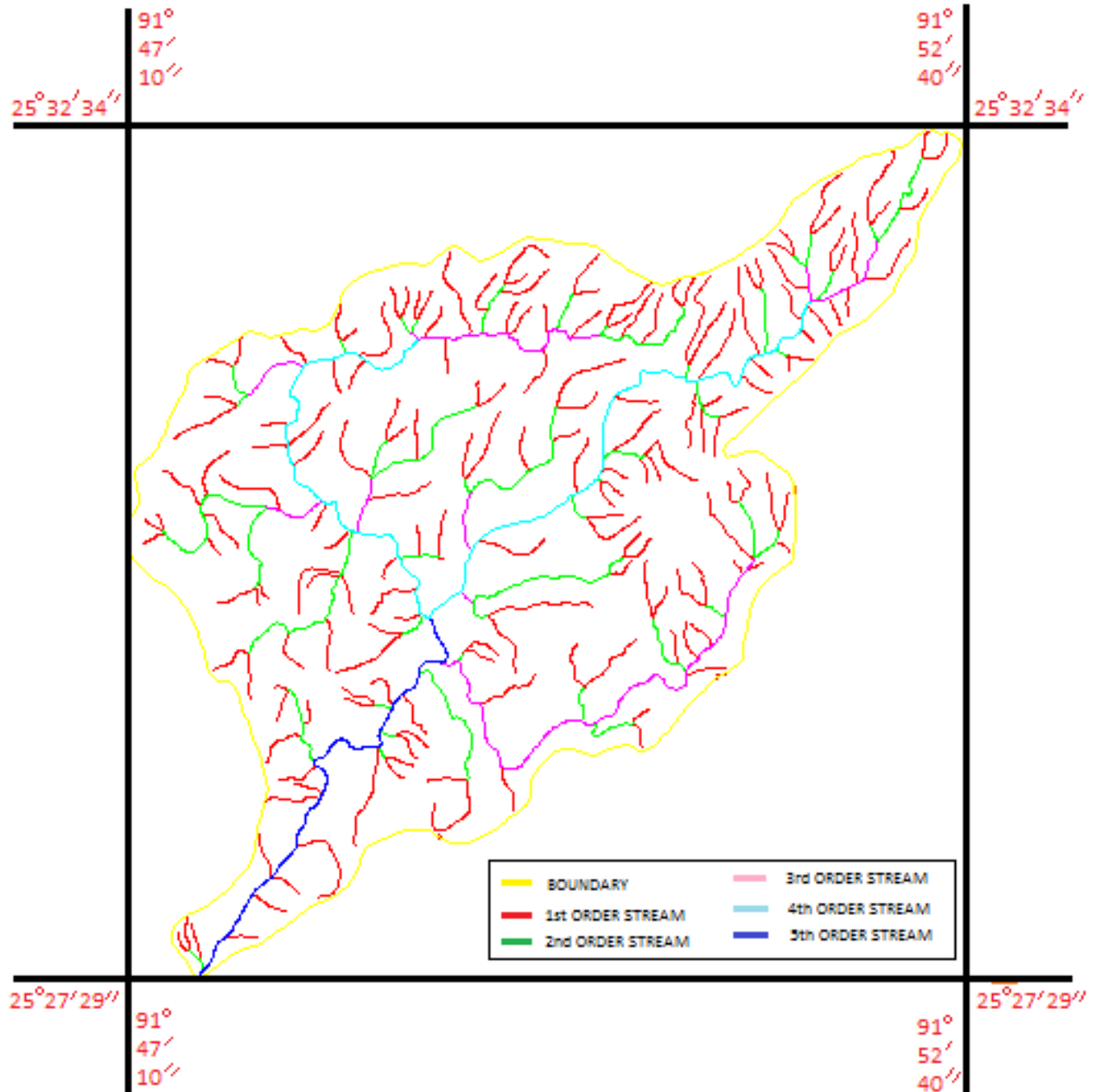


Figure 1. Umbaniani micro-watershed.

winter is 2°C. Agriculture occupies the major portion of the micro-watershed which is being practiced on the hill slopes and in the valleys, without any measure being taken to prevent soil erosion.

METHODS

To define the morphometric features of the Umbaniani micro-watershed, the digital data on hydrology and elevation contours were obtained from the Survey of India top sheet with a 1:50,000 scale and 20 m contour interval. Micro station Software was used to analyze the digital data.

The shape index, S_i is the ratio of the length of the basin along the main stream to the area of the watershed. The following equation was used for calculating the shape index, S_i (Horton, 1932).

$$S_i = L_s^2/A \tag{1}$$

Where L_s is the length of the main stream; A is the area of the basin. The form factor, F_r , has been introduced by Horton (1932), and it describes the shape of the basin. It was defined as the ratio of basin area to the square of the basin length, using the following equation:

$$F_r = A/L_b^2 \tag{2}$$

Where A is the area of the basin; L_b is the length of the basin.

The compactness coefficient, C_c , was obtained from the ratio of the perimeter of the watershed to the area of the basin (Gravelius, 1914).

$$C_c = 0.282L_p/A^{0.5} \quad (3)$$

Where L_p is the perimeter of the basin; A is the area of the basin.

The elongation ratio, R_e , 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 and it was calculated using the following equation:

$$R_e = 1.128A^{0.5}/L_b \quad (4)$$

Where A is the area of the basin; L_b is the length of the watershed. The circulatory ratio, R_c , was used by Miller (1953) to describe the shape of the basins. The circulatory ratio is dimensionless. This was obtained from the ratio of the area of the basin to the basin perimeter using the following equation:

$$R_c = 4\pi A/L_p^2 \quad (5)$$

Where A is the basin area; L_p is the perimeter of the watershed.

The rotundity factor, R_f , is defined as the ratio of the length of the basin to the basin area (Chorley et al., 1957). It was calculated using the following equation:

$$R_f = L_b^2/4A \quad (6)$$

Where L_b is the length of the basin; A is the basin area.

The bifurcation ratio, R_b , was recognized as an important characteristic of the drainage basin by Horton (1932). It was defined as the ratio of the number of stream segments of a given order u divided by the number of stream segments of the next higher order ($u+1$).

$$R_b = N_u/N_{u+1} \quad (7)$$

The drainage density, D_d , was calculated using the following equation (Horton, 1932):

$$D_d = L_s/A \quad (8)$$

Where L_s is the total length of all stream channels in the basin; A is the area of the basin.

The stream frequency, S_f , is a measure of the stream per unit drainage area. The higher values of S_f indicate more intense erosion (Horton, 1945). It was calculated using the following equation:

$$S_f = N_s/A \quad (9)$$

Where N_s is the number of streams; A is the area of the basin.

Run-off and sediment production rate were estimated based on the geomorphic, drainage and topographic parameters as suggested by Jose and Das (1982). The following equations were used:

$$\log Q = 2238.43 + 22.12 \log (100 + R_f) - 608.28 \log (100 + R_c) - 530.02 \log (100 + C_c) \quad (10)$$

Where, Q = Run-off in Sqkm-cm/Sqkm, R_f = Rotundity factor, R_c = Circulatory ratio, C_c = Compactness coefficient.

$$\log SPR = 4919.80 + 48.64 \log (100 + R_f) - 1337.77 \log (100 + R_c) - 1166.64 \log (100 + C_c) \quad (11)$$

Where, SPR = Sediment production rate in ha-m/100 Sqkm/year, R_f = Rotundity factor, R_c = Circulatory ratio, C_c = Compactness coefficient.

RESULTS AND DISCUSSION

Shape parameters of micro-watershed

Hydrologically, the shape of the watershed is important because it controls the time taken for the runoff to concentrate at the outlet (Jain, 2004). Watersheds have a variety of shapes, and the shape reflects the way that runoff will "bunch up" at the outlet.

A circular watershed would result in runoff from various parts of the watershed reaching the outlet at the same time. An elliptical watershed that has the outlet at one end of the major axis and the same area as the circular watershed would cause the runoff to be spread out over time, thus producing a smaller flood peak than that of the circular watershed (Northcott, 2000).

Morisawa has shown that Schumm's elongation ratio and Miller's circulatory ratio are the two most successful shape parameters in correlation procedures with runoff data (Ongley, 2008).

Shape index (S_i)

When S_i approaches unity, erosion tends to be maximum, with higher values of S_i , erosion decreases. The shape index of the Umbaniun micro-watershed is found to be 4.79 (Table 1) indicating that the basin studied is elongated in shape.

Form factor (F_f)

The value of form factor would always be less than 0.7854 (Table 1) (for a perfectly circular basin). The smaller the value of the form factor, the more elongated will be the basin. In the present study, the F_f is found to be 0.26 (Table 1) indicating that the micro-watershed is elongated in shape and has lower peak flow of longer duration as suggested by Chopra et al. (2005).

Compactness coefficient (C_c)

When a watershed is a perfect circle, C_c will equal to 1. The closer a compactness coefficient is to 1, the greater the likelihood that precipitation will be quickly concentrated in the main channel, resulting in peak flows (Avery, 1975). The compactness coefficient of the studied basin is found to be higher than unity (1.48) which suggests that the shape of the basin is elongated (Table 1).

Elongation ratio (R_e)

The value of the elongation ratio, R_e , generally varies from

Table 1. Shape parameters of Umbaniun micro-watershed.

| Shape parameters | Values |
|------------------------------------|--------|
| Shape index (S_i) | 4.79 |
| Form factor (F_f) | 0.26 |
| Compactness co-efficient (C_c) | 1.48 |
| Elongation ratio (R_e) | 0.57 |
| Circulatory ratio (R_c) | 0.46 |
| Rotundity factor (R_t) | 3.04 |

Table 2. Stream orders and Bifurcation ratio of Umbaniun micro-watershed.

| Stream order | Number of streams | R_b | Average R_b |
|--------------|-------------------|-------|---------------|
| I | 184 | 4.09 | |
| II | 45 | 4.5 | |
| III | 10 | 5 | 3.898 |
| IV | 2 | 2 | |
| V | 1 | - | |

0.6 to 1.0 and is associated with a wide variety of climate and geology (Chopra et al., 2005). The elongation ratio of the Umbaniun micro-watershed is found to be 0.57 (Table 1). According to Chopra et al. (2005), this R_e value indicates that the basin is elongated and is associated with high relief and steep slope.

Bifurcation ratio (R_b)

Horton (1945) considered the bifurcation ratio, R_b , as an index of relief and dissections. In the present study, the bifurcation ratio is found to be 3.898 (Table 2) indicating a disturbed nature of a landscape.

Drainage pattern of the micro-watershed

The drainage system of an area is strictly dependent on the slope, the nature and attitude of bedrock and on the regional and local fracture pattern. Drainage is studied according to its pattern type and its texture, or density of dissection (Way, 1973). Whilst the first parameter is associated with the nature and structure of the substratum, the second is related to rock/soil permeability (and, thus, also to rock type).

Actually, the less permeable a rock is, the less the infiltration of rainfall, which conversely tends to be concentrated in surface runoff. This gives origin to a well-developed and fine drainage system. In addition to the pattern characterization, drainage can also be described in terms of texture or density of dissection. On this basis, three types can be identified: (1) fine, which is indicative of high levels of runoff, suggesting impervious bedrock and/or fine textured soils scarcely permeable; (2)

medium, which can be related to a medium runoff and mixed lithology, and (3) coarse, which indicates little runoff and consequently resistant, permeable bedrock and coarse, permeable soil materials (Travaglia and Dainelli, 2003).

The drainage density is the ratio of the total length of streams within a watershed to the total area of the watershed. A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response. Values typically range from 1.5 to 6 mi/mi^2 (Northcott, 2000).

Drainage density (D_d)

The drainage density, D_d , expresses the closeness of spacing of the channels. It is a measure of the total length of the stream segment of all orders per unit area. It is affected by factors which control the characteristic length of the stream like resistance to weathering, permeability of rock formation, climate, vegetation, etc.

In general, a low value of D_d is observed in regions underlain by highly resistant permeable material with vegetation cover and low relief. High drainage density is observed in regions of weak and impermeable subsurface material, sparse vegetation, and mountainous relief. The Umbaniun micro-watershed has a drainage density of $0.0037 \text{ m}/\text{m}^2$ (Table 3) suggesting that the study area is underlain by impermeable sub-surface material having sparse vegetation and mountainous relief.

Stream frequency/channel frequency (S_f)

Higher values of S_f indicate coarse texture, whereas their

Table 3. Drainage pattern parameters of Umbaniun micro-watershed.

| Drainage pattern parameters | Values |
|---|--------|
| Bifurcation ratio (R_b) | 3.898 |
| Drainage density, D_d (m/m ²) | 0.0037 |
| Stream frequency, S_f (per Sq.m) | 6.13 |

Table 4. Total Run-off, Q of Umbaniun Micro-watershed.

| Total run-off, Q | Values |
|------------------------------------|--------|
| Rotundity factor (R_t) | 3.04 |
| Circulatory ratio (R_c) | 0.46 |
| Compactness co-efficient (C_c) | 1.48 |
| Total run-off, Q | 77.63 |

Table 5. Sediment production rate, SPR of Umbaniun micro-watershed.

| Sediment production rate, SPR | Values |
|------------------------------------|---------|
| Rotundity factor (R_t) | 3.04 |
| Circulatory ratio (R_c) | 0.46 |
| Compactness co-efficient (C_c) | 1.48 |
| SPR | 0.16218 |

low values indicate fine texture. This is because impermeable rocks allow more run-off and permit the development of a dense network of streams. Contrary to this, permeable rocks have high infiltration capacity and do not permit the development of dense network of streams. Table 3 shows that the Umbaniun micro-watershed has a stream frequency of 6.13 per square metre which can result in more run-off and peak flow.

Run-off and sediment production rate of the micro-watershed

In the Umbaniun micro-watershed both run-off rate, Q (77.63 Sqkm-cm/Sqkm) and sedimentation production rate, SPR (0.16218 ha-m/100sqkm/year) are found to be low as shown in Table 4 and Table 5, respectively. This again suggests the basin is elongated.

Conclusion

The Umbaniun micro-watershed is an elongated basin with low run-off and sediment production rate. Analysis of drainage pattern parameters has shown that the basin has a low permeability land surface which can bring about about high run-off and peak flow. The result of the study

shows that both shape and drainage pattern analyses are important in watershed management. Thus, the findings of this pilot research are important from land use planning and conservation point of view.

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