Estimation of the soil loss in micro watersheds using morphometric analysis and GIS techniques

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Abstract: Remote Sensing (RS) and Geographic Information System (GIS) has now become the fastest growing technology which is found to be useful in many aspects. In current scenario, we face many problems in the form of flood in one side due to improper drainage system and on the other side we face water scarcity. There is a great demand for water at present. This is an ironical situation. As per the rainfall analysis, the amount of rainfall remains same during the years and it is not reduced, but the pattern of rainfall varied greatly. These factors lead to the inefficiency of water storage structures. For that, water resource management has become an inevitable study. RS and GIS acts as a tool used to delineate the watershed. Estimation of Morphometric parameters is done using GIS. Morphometric parameters are of three aspects—Linear aspects, Aerial aspects, Relief aspects. On determining the morphometric parameters, the most eroded region in the watershed is found and for that particular region, run-off is calculated using SCS-CN curve number method. The soil loss is estimated using USLE for the watershed. These techniques are used to find soil loss in the highly eroded sub-watershed in the Noyyal basin. This helps us in estimating the severity of soil erosion and thus a suitable soil-conservation method can be implemented in the watershed.

1. INTRODUCTION

Water resource is one of the most abundant in our planet. Rainfall emerges to be the main source for water resources, used for various purposes by the living organisms on Earth. Rainfall flowing through mountains forms rivers, streams joining the sea at the mouth of the river. Rivers are the main source of fresh water which constitutes only 3% of the water resources of the world. In the path of flow of rivers, there are many storage structures constructed for future uses. One such structure or naturally formed structure is said to be the watershed. Watershed in simple words describes us that it collects water from many branches of the river and has a single common drainage outlet. Nowadays the development of science and technology has reached its peak and it has completely changed the climate pattern of the world. Rainfall pattern has also changed whereas the intensity remains the same. The surface run-off keeps increasing day by day and the resources are not used efficiently. Hence, watershed management is important for today’s scenario for an effective and efficient use of water resources[1].

Our Earth has about 70% to 75% of water, but only 3% is of fresh water. In the amount of fresh water present, only 5% of it is readily available for daily usage. India has 1850 km³ volume of water resources which only holds nearly 4% of the world’s water resources. In current scenario, we face many problems in form of floods on one side due to improper drainage system and on the other side we also face water scarcity[2]. Ironically, we have both water scarcity as well as surplus water as run-off. So, to meet out these issues, research on management of water is needed[3]. The base and main livelihood of our country is agriculture. The basic need for agriculture is water and a land with fertile
soil. But the farmers are being denied of these resources due to the improper planning and designing of water structures. Groundwater also plays a vital role in agriculture. Due to the improper management of water resources, surface run-off is occurring in an alarming rate where the run-off meets the oceans/seas as a waste. The run-off meeting the seas as a waste just not only means the surplus surface water, but also it washes out the fertile soil present, which is a major threat for all farmers. The soil loss makes the land infertile which in turn makes it not suitable for agriculture and if the soil loss occurs in larger rate, the water resources management would be difficult.

Tamil Nadu as a whole state constitutes[3] only 2.5% of India’s water resources. Out of these resources, 75% of it is used for agriculture. The state has 17 river basins of which Cauvery river basin is the major one. There are 13 medium and 3 minor river basins. Tamil Nadu has 61 reservoirs and nearly 41,948 tanks. Tamil Nadu merely depends on the South-West (SW) and North-East (NE) monsoon for rainfall. The state gets relatively more rainfall during North-West (NW) monsoon, especially in the coastal regions. Tamil Nadu receives an average rainfall of 930 mm, 47% during NE monsoon and 35% during SW monsoon. The per capita availability of the state is 800 cubic meters. The state has a total surface water potential of 24,864 MCM or 36 km$^3$. Of about 24 lakh hectares are irrigated using the surface run-off potential of the state. The utilisation of surface water for irrigation is about 90% of the total. Of the annual water potential of 46,540 MCM of Tamil Nadu, surface water flow accounts to its half.

Tamil Nadu has improper management of water resources and the poor maintenance of water conservation structures. India is a country known for its agriculture. Tamil Nadu is mainly known for cultivation of crops, mainly in the banks of Cauvery River (delta regions). Coimbatore is called the Manchester of South India and Cauvery delta regions are known for its paddy cultivation. Water resources for agriculture in Tamil Nadu are solely dependent on monsoons. As the climate patterns have changed drastically due to the urbanisation of the state, the rainfall period has reduced. Tamil Nadu receives rainfall seasonally only during the second half of the year i.e., the SW monsoon from June to September and the NE monsoon from October to December. But the rainfall intensity remains the same. Hence, large amount of water flows as surface run-off joining the seas as a waste. There are no proper management of the structures to store water for future purposes. Ironically, we face both water scarcity and flood conditions. The purpose of the study is therefore to expand the knowledge on the management of water resources.

2. METHODS

2.1. Study Region
The selected study region is Noyyal river basin. It originates from Vellingiri hills in western part of Tamil Nadu and flows through the districts of Coimbatore, Erode and Tirupur as shown in figure 1. The river basin is 180 km long 25 km wide over an area of 3500 km$^2$. The rivers depend on Northeast and Southwest monsoon seasons for water. The River drains into Cauvery at Noyyal near the village Kodumudi in Erode District[4]. The river basin lies between the latitudes $10^\circ53'1.06''$ to $11^\circ21'57''$ and longitudes $76^\circ37'49''$ to $78^\circ12'55.06''$. It is also said to be a tributary of Cauvery River.
2.2. Morphometric Parameters
Morphometric parameters are the parameters which are used to know about the geographical nature of the watershed. It’s actually the Quantitative analysis of characteristics of a watershed or landform unit [12]. With respect to these parameters it is possible to infer the relief features of watershed. These parameters are broadly classified into Aerial, Linear and Relief aspects [5]. These three aspects can also be called as one dimensional, two dimensional and three dimensional.

Linear aspects: Stream Order, Stream Length, Stream Number, Bifurcation Ratio, Basin Area, Drainage Density, Stream Frequency, Infiltration Number, Basin perimeter [6]
Relief aspects: Basin relief, Relief ratio
Aerial aspects: Elongation Ratio, Circulatory Ratio

2.3. Digital Elevation
The Delineation of the watershed would be found using series of steps.
The first step is the addition of DEM data to the file and then fill option in spatial analyst tool is followed. The DEM data is given as input to the dialogue box. The output is saved as Fill output as shown in figure 2. The second step is the creation of Flow direction file. The Fill output is taken as the input for the flow direction in the spatial analyst tool. The output is saved as Flow Direction output. The next step would be the creation of the Accumulation output. The Flow Direction output is taken as the input to the dialogue box. The output would be saved as accumulation output. The next step is the creation of New basin and the input is taken as the flow direction in the shape file format. The raster data is converted to polygon and the file is saved. A New Basin would be created. Using selector icons, the particular watershed is selected. After selection Geo processing option is done to clip the file. The input is the new basin map and the clip feature option should have the same basin map and output would be saved separately. The new file would be the delineated map of the Noyyal watershed as shown in figure 3.
Figure 2. DEM representation of Noyyal Basin
2.4. Determination of Morphometric parameters
Once the watershed is delineated, some parameters would be calculated already in the previous steps. The basin area, basin perimeter of the sub-watershed would be available in the attribute table of the particular watershed shape file. To find the other parameters, creation of the streamlines are inevitable[7]. To create streamlines, map algebra option in the spatial analyst tool is used. Raster calculations were done and the streamlines were created.
All streamlines of different order should be in same colour. To differentiate the stream orders, symbology option is used. In symbology add all orders of streams are added to the field and it is applied to the entire file. The file should have an attribute table. Export the table to the Excel sheet. Then categorise the streamlines according to the order and then added up the length of streams of same order to get the stream length of particular stream order. Then to get the cumulative length of stream add up all the length of the streams. And then total number of streams in the watershed is calculated by adding all the cumulative number of streams.

2.5. Determination of the highest eroded sub-watershed
The highest eroded watershed is found using Basin relief, which is one among the morphometric parameter. The higher the basin relief, higher the erosion.
2.6. Run-off and Soil Loss estimation

Run-off is calculated using SCS-CN method and soil loss is estimated using USLE[8]

\[
S = \frac{25400}{CN} - 254
\]

\[
Q = \frac{(P - 0.2S)^2}{(P + 0.8S)}
\]

Soil Loss is estimated using [9]

\[
A = RKLSCP
\]

Where

- A = Average annual soil loss in tonnes/acre
- R = Rainfall erosivity index
- K = Soil erodibility factor
- L, S = Topographic factor L - Length & S - Slope
- C = Cropping factor
- P = Conservation practice factor

3. RESULTS AND DISCUSSIONS

3.1. Morphometric parameters

The results of Morphometric parameters are as follows.

Linear aspects

a) **Stream order:** The river basin has a maximum of 6 orders. There are 2095 streams in first order. This region has much structural disturbance. There are 967 streams of second order. These streams are formed when 2 first order streams meet. There are 594 streams of third order. These are formed when a first order and second order streams meet. There are 251 streams of fourth order. These are formed when any order of stream less than third order and third order stream meet. There are 147 streams of fifth order. These can be formed with any of the fourth order stream. There are 123 streams of sixth order.

b) **Stream Length:** The total length of a stream of same order is called as stream length. The average length of all the streams of same order is called the mean stream length. This is directly proportional to the topography and size of the basin. The total length of 2095 first order river is 2006.46 km. The individual length of order of streams are given in Table 2.

c) **Stream number:** The number of streams of same order is called as stream number. The total number of streams of all order in a river is called stream number. The total number of streams is counted in the GIS platform. From that we could infer that as the stream order increase the stream number decrease. These variations are due to physiographical, geomorphological and geological conditions in the existing basin. The individual stream numbers in watershed are listed in Table 2.

d) **Bifurcation Ratio:** The ratio of number of streams in a given order to the number of streams in the next higher order. This is a dimensionless quantity. With respect to this ratio, the structural property of the basin can be identified. If the bifurcation ratio is low, then the basin is less structurally disturbed and the values are given in Table 2.

e) **Basin Area:** The area of land being cover by the river is called as the basin area. It gives the total surface area, which is further used in various calculations of the Morphometric Parameters. The total basin area of the watershed is 3476.29 km². The individual basin area of 19 watersheds are given in Table 1.

f) **Drainage density:** The ratio of stream length of all order to the total area is called drainage density. The relationship between precipitation and the slope gradient which determines the run-off rate in the basin. The drainage density of the entire basin is 1.13 km/km².

g) **Stream Frequency:** The ratio of stream order of river to the area of basin is called as the stream
frequency. The value depends on the origin and rainfall pattern in the sub-basin. Lower the value then the sub-basin is less structurally disturbed. The stream frequency of the entire watershed is 1.20/km².

h) Infiltration number: The product of stream frequency and drainage density of a basin is called the infiltration number. If the infiltration number is high then the infiltration will be low and run-off would be high. The infiltration number for his watershed is 1.36. The Infiltration number is inversely proportional to the infiltration Capacity.

### Table 1. Relief aspect of Noyyal.

| Watershed no | Area (in km²) | Perimeter (in km) | Maximum Elevation (in km) | Minimum Elevation (in km) | Basin Relief (in km) | Relief Ratio |
|--------------|--------------|------------------|---------------------------|---------------------------|----------------------|-------------|
| 1            | 106.16       | 53.44            | 385                       | 267                       | 118                  | 0.84        |
| 2            | 144.70       | 51.83            | 370                       | 268                       | 102                  | 0.73        |
| 3            | 344.16       | 95.09            | 409                       | 265                       | 144                  | 1.02        |
| 4            | 152.43       | 53.26            | 507                       | 229                       | 278                  | 1.99        |
| 5            | 381.79       | 100.95           | 1449                      | 306                       | 1143                 | 8.16        |
| 6            | 17.25        | 19.03            | 288                       | 228                       | 60                   | 0.42        |
| 7            | 171.05       | 56.81            | 394                       | 236                       | 158                  | 1.13        |
| 8            | 71.13        | 43.80            | 390                       | 265                       | 125                  | 0.89        |
| 9            | 45.37        | 30.70            | 379                       | 291                       | 88                   | 0.63        |
| 10           | 92.63        | 43.78            | 410                       | 237                       | 173                  | 1.24        |
| 11           | 140.91       | 51.71            | 437                       | 294                       | 143                  | 1.02        |
| 12           | 296.01       | 73.87            | 512                       | 176                       | 336                  | 2.33        |
| 13           | 114.02       | 46.90            | 317                       | 175                       | 142                  | 1.01        |
| 14           | 93.15        | 40.61            | 240                       | 142                       | 98                   | 0.7         |
| 15           | 69.14        | 36.48            | 237                       | 125                       | 112                  | 0.8         |
| 16           | 128.24       | 47.72            | 255                       | 143                       | 112                  | 0.8         |
| 17           | 155.36       | 64.52            | 1579                      | 385                       | 1194                 | 8.53        |
| 18           | 494.60       | 96.11            | 453                       | 306                       | 147                  | 1.05        |
| 19           | 458.19       | 103.43           | 1866                      | 385                       | 1481                 | 10.6        |

### Table 2. Linear aspects of Noyyal

| ID | Stream Order | Stream Number | Stream Length (In km) | Bifurcation Ratio |
|----|--------------|---------------|-----------------------|-------------------|
| 0  | 1            | 2095          | 2006.461              | 2.17              |
| 1  | 2            | 967           | 1024.151              | 1.63              |
| 2  | 3            | 594           | 500.266               | 2.37              |
| 3  | 4            | 251           | 200.268               | 1.71              |
| 4  | 5            | 147           | 102.207               | 1.20              |
| 5  | 6            | 123           | 83.115                | -                 |
| Total= | 4177            |               | Mean Bifurcation Ratio=1.82 |

3.2. Relief aspects

a) Basin Relief: The difference of elevation between the highest and lowest point in a basin is called basin relief. It actually gives the highest and lowest elevation point in the entire basin. This shows the various slope changes in the basin. The basin relief values of 19 watersheds are listed in Table 1.

b) Relief Ratio: The ratio of basin relief to the longest length of the basin which is parallel to the principal drainage line. The relief ratio and the drainage area are inversely proportional to each
other. If the values of relief ratio are low then there will be rise in the drainage area. Refer table 1 for the individual values of 19 sub-watersheds.

3.3. Aerial aspects

a) Elongation Ratio: The ratio of diameter of the circle same as that of basin to the maximum basin length. The elongation ratio helps us to understand the shape of the basin. The value determines the infiltration capacity in the direction of stream flow and also about the relief, sloping conditions in the basin area. The elongation ratio for this basin ranges between 0.21 and 0.27. From this it is inferred that the sub-basins are more elongated if the value is less than 0.5. Refer table 3 for the individual values of 19 watersheds.

b) Circulatory Ratio: The ratio of area of watershed to the circle area having same perimeter of the particular watershed. This factor represents the shape characteristics of a basin area. If the value is less than 1 then it is said that the basin is influenced by the slope, relief, drainage pattern an even by the length and frequency of the stream. The circulatory ratio for this basin are specified in Table 3, it ranges between 0.45 and 0.75.

| Watershed | No. of Streams | Elongation Ratio | Circulatory Ratio |
|-----------|----------------|------------------|-------------------|
| 1         | 128            | 0.22             | 0.47              |
| 2         | 174            | 0.26             | 0.68              |
| 3         | 414            | 0.22             | 0.48              |
| 4         | 183            | 0.26             | 0.68              |
| 5         | 459            | 0.21             | 0.47              |
| 6         | 21             | 0.25             | 0.60              |
| 7         | 205            | 0.26             | 0.67              |
| 8         | 85             | 0.22             | 0.47              |
| 9         | 55             | 0.25             | 0.60              |
| 10        | 111            | 0.24             | 0.61              |
| 11        | 169            | 0.26             | 0.66              |
| 12        | 356            | 0.26             | 0.68              |
| 13        | 137            | 0.25             | 0.65              |
| 14        | 112            | 0.27             | 0.71              |
| 15        | 83             | 0.26             | 0.65              |
| 16        | 154            | 0.27             | 0.71              |
| 17        | 187            | 0.22             | 0.47              |
| 18        | 593            | 0.26             | 0.67              |
| 19        | 551            | 0.23             | 0.54              |

Stream frequency = 1.20

3.4. Rainfall analysis

The rainfall pattern is obtained by consolidating the 20 years rainfall data (1997-2017) of Coimbatore block. The rainfall pattern is shown in figure 4.
Figure 4. Annual rainfall in mm from 1997 to 2017

The highest rainfall was recorded in 2011. The lowest rainfall was recorded in 2013. The rainfall has a great impact on the livelihood of a place. The soil erosion parameter varies with the amount of precipitation in the area[10]. The maximum rainfall recorded was 1082.1 mm during 2011 and minimum rainfall of 372.7 mm occurred during 2013.

3.5. Highly eroded watershed
On analysing the basin relief of the watershed, the higher the basin relief, the higher would be the soil erosion[11]. Hence, in Noyyal basin, the 19th watershed was found to be the most soil eroded watershed. 19th watershed comes under the Thondamuthur block in Coimbatore District.

3.6. Run-Off estimation
Curve number was estimated using the USDA values. Curve number was found out for Thondamuthur region. Curve Number for the region was found to be 82. Total Area of Thondamuthur region used for the estimation of CN = 392.20 km². Hydrological Soil Group used for the estimation of Curve Number were groups A, C and D. Run-off of Thondamuthur region was calculated using SCS-CN method. The run-off was calculated on an average for the past 20 years since 1997. The average annual rainfall of the region was found out to be 741.37 mm

Average annual precipititation = 741.37 mm
   S value = 55.76
   Run – off of the given region = 678.414mm
   Run – off volume (cubic meters) = 310.84 x 10⁶ m³
   Run – off volume in TMC = 10.972

The average annual run-off of Thondamuthur region for the past 20 years was found out to be 10.972 TMC.

3.7. Soil Loss Estimation
For the estimation of soil loss, USLE equation was used where

   A = R.K.L.S.C.P
   R = 248.184
   K = 0.3
   LS = 0.5
   C = 0.0328
P = 0.75

The soil loss for Thondamuthur watershed was found.
Soil loss amount = 0.915 tonne / acre / year
Thondamuthur region was found as the most soil eroded region using the analysis of morphometric analysis. The soil loss amount for this region was determined as 0.915 tonne / acre / year.

4. CONCLUSION

Water is an inevitable resource for mankind. But the availability of water is diminishing day-by-day due to human activities and natural calamities. The shortage of water mainly happens due to improper management of water storage structures. It’s an assumption that water scarcity is because of the reduced rainfall over years. But the rainfall amount remains the same till now but the distribution of rainfall varies greatly. The water structures have to be remodelled for the complete utilization of the rainfall. It’s also necessary that the run-off has to be reduced. The soil erosion should be minimized to retain the rainwater. The study was taken up in the Noyyal watershed which covers the districts of Erode, Coimbatore, Tirupur. The amount of soil loss was found to be 0.915 Ton/acre/year. The soil loss has great impact in the development of a watershed. Once soil starts to erode the soil will become less fertile. Cultivation becomes a problem in the infertile soil. As soil loss increase fertility of the area would reduce greatly. So to have a control over the soil loss, certain conservation practices has to be followed. They are Contour cultivation, Strip cropping, Cropping pattern, Broad base terrace, Contour stone wall, Bench terracing.

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