Soil Erosion on Toranmal Plateau: An Application of RUSLE

S.M. Bhamare[1,] N.M. Kazi[2] and Vikram Agone[3]

[1]*P.G. & Research Department SSVPS Science College Dhule,*
[2]*P.G. & Research Dept. of Geography SPDM College, Shirpur MS*
[3]*Project Fellow*
E-mail: [2]nmquazi@hotmail.com

Abstract—*The Toranmal plateau soils are severely suffered from soil erosion as well as soil degradation. Therefore it is necessary to estimate the soil erosion and erodibility of the plateau. The soil erodibility is an estimate of the ability of soil to resist erosion based on physical characteristics of the soils like texture, structure, organic and inorganic matter contents and permeability. There are several methods of estimation of soil erosion. In this project revised universal soil loss equation RUSLE is adopted for estimation of soil loss. Apart from this some experimental observations are also made to estimate the soil loss on the plateau. The universal soil equation USLE was introduced by United States Agriculture research service (Wischmeier and Smith, 1962) for assessment of soil loss from small areas like hill slope and small cultivated field .Further it was revised as RUSLE in 1997 (Renard et al., 1997). This revised equation provides more accurate soil loss and applicable for comparatively large areas like river basin small plateau like Toranmal. The most significant finding in this study is that the soil loss is beyond the tolerance limit. The rainfall and surface runoff factor is the most significantly influencing factor of soil loss.*

Keywords*: Soil Erosion, Soil Erodibility, soil Texture, Permeability, RUSLE.*

1. INTRODUCTION

Soil is erosion is the major threat to the sustainability of agriculture in mountain regions of the world (Astha Gulati and Rai S.C.2014). Soil is the superficial layer of the earth surface that forms naturally by weathering and pedogenic processes mixed with mineral matter and organic material. Soil formation is the gradual process. The soil plays a key role in agriculture especially in crop production. One inch of soil layer formation requires thousands of years. However it may wash away within few minutes of high intensity rainfall. The soil is destructed by both natural and anthropogenic forces. The natural soil erosion agents include rainfall, runoff, slope and wind. The anthropogenic activities include intensive agriculture, deforestation, shifting cultivation, infrastructure and urbanization. Soil erosion is defined as the wearing and tearing of topsoil. It involves three distinct actions-detachments, transportation or removal and accumulation of soil particles. The most affected area is the top soil layer. Topsoil layer is most fertile for agriculture crops production, because it contents the most productive ingredients like organic and inorganic nutrient rich materials. In view of the sustainable agriculture this layer must be protected. Though the soil erosion is natural process, it is also caused by anthropogenic activities. Apart from this soil is degraded by the processes like soil compaction, lowering of organic matter, loss of soil structure, salinization, and soil acidity. Combined with these processes soil erosion is called accelerated soil erosion. The global rate of soil erosion acceleration is 10 -40 times. The accelerated soil erosion creates two important problems. One is on-site and another off-site. The decrease in agricultural productivity and disturbance of ecological balance are the on-site impact of accelerated soil erosion. The ultimate end is desertification. The offsite impact includes sedimentation in rivers channels and eutrophication of water bodies.

The Toranmal plateau soils are severely suffered from soil erosion as well as soil degradation. Therefore it is necessary to estimate the soil erosion and erodibility of the plateau. The soil erodibility is an estimate of the ability of soil to resist erosion based on physical characteristics of the soils like texture, structure, organic and inorganic matter contents and permeability. There are several methods of estimation of soil erosion. In this project revised universal soil loss equation RUSLE is adopted for estimation of soil loss. The universal soil equation USLE was introduced by United States Agriculture research service (Wischmeier and Smith, 1962) for assessment of soil loss from small areas like hill slope and small cultivated field .Further it was revised as RUSLE in 1997 (Renard et al., 1997). This revised equation provides more accurate soil loss and applicable for comparatively large areas like river basin small plateau like Toranmal.

2. METHODOLOGY AND DATA SOURCE

The methodology adopted in this paper is based on field data, R.S. and GIS data. The estimation of soil loss is based on RUSLE (Revised Universal Soil Loss Equation) suggested by

U S Soil Conservation Department. Potential soil loss in natural unit area like plateau or river basin depends on the surface configuration, soil characteristics, local climatic conditions and management practices implemented in that area. According to Renard et.el (1997) soil loss can be estimated with RUSLE on the basis of climate, soil topography and land use. These factors influence on generation of streams, rills and gullies which are formed by direct rainfall and surface runoff. The revised universal soil loss equation can be expressed as:

RUSLE

$$A = R \cdot K \cdot LS \cdot C \cdot P \text{-----------} \quad \text{-------------} \ (1)$$

Where,

A= The computed spatio-temporal soil loss per unit area (tons /ha/year)

R= Rainfall erodivity factor (MJ mm/ha/hr/year) MJ means Mega Joule

K= Soil erodibility factor. (Tones/ha)

LS= Slope length and steepness factor.

C = cover management factor and

P = the conservation practice factor

3. OBJECTIVE

To estimate soil loss on Toranmal Plateau with help of RUSLE Model

4. ANALYSIS

In GIS environment, five types of analyses can be used to estimate potential soil loss (A) with help of the RUSLE parameters. Rainfall factor is derived from geo-statistical method such as Kriging estimators (Goovaerts, 1999). Soil erodibility factor is deduced from experimental models based on soil properties (Wischmeier and Smith, 1978), Topography factor is estimated from actual field measurements of length and steepness of slope.(Wischmeier and Smith, 1978) It is calculated from DEM data with various approaches (Hickey, 2000; Van Remortel et al., 2001),Land use is derived from a combination of individual C factors from empirical models and remote sensing classification images (Millward and Mersey, 1999) while land cover factors are obtained from experimental data (Renard et al., 1997).

4.1 The rainfall and surface runoff factor (R)

Daily rainfall data for 33 years (1980-2013) is obtained from the Indian Meteorological Department. Annual rainfall data is generated from composition of daily rainfall data of surrounding station. Spatial annual rainfall data is derived from each station using Simple Kriging estimator technique with Spherical Semivariogram Model. The erosivity factor (R) is calculated by using the equation from Bol (1978). The formula is expressed as follows:

$$R = \frac{2.5P^2}{100(0.073P + 0.73)}$$

Where,

R = Rainfall erosivity factor (MJ mm/ha/hr/year)

P = The mean annual precipitation in mm.

4.2 The soil erodibility factor (K)

Erodibility means the soil resistance to both detachment and removal of soil particles. The resistance of soil depends on topography, steepness of slope, anthropogenic activity and the soil properties. Soil property is the most determinant. Therefore the soil eodibility factor (K) includes the effect of soil properties such as soil texture, aggregate stability, shear strength, infiltration capacity, and organic content and chemical composition on soil loss. The formula for soil erodibility is expressed as follows:

$$K = \frac{2.1 \times 10^{-4}(12 - OM\,\%)(N1 \times N2)^{1.14} + 3.25(S - 2) + 2.5(P - 3)}{100} \quad \text{(ii)}$$

Where,

OM = Organic Matter (%),

N1 = Clay + Very fine sand (0.002–0.125 mm),

N2 = Clay + Very fine sand + Sand (0.125–2 mm),

S = Soil structure, and

P = Hydraulic conductivity (cm h^{-1}).

Soil erodibility factor (K) is determined by using a combination of actual field sample measurements and secondary data. The individual attribute table of soil series in the digitized soil map is converted to K value. This soil series data is classified into 3 different soil series in the study area.

Table 1: K-Factor

No	Textural Class	K Factor (tones/hectare)
1	Fine sand	0.18
2	Sandy loam	0.29
3	Loamy sand	0.09

4.3 The land cover and cover management factor (C)

The land cover map was derived from Land sat 8 data using supervised classification in ERDAS RS Software. Driver Land use raster value reclassify to C factor value using Arc GIS 10.1.The Cover Management represents the ratio of soil loss under a given crop cover to that of bare soil (Morgan, 2005). It has a close linkage to land use types.

Table 2: C-Factor

No	Land use	C factor value
1	Agriculture	0.09
2	Forest	0.004
3	Open Water	0.0
4	Bare land	0.24

4.5 Support practice factor or Conservation Practice Factor. (P)

Conservation practice factor (P) in the RUSLE model expresses the effect of conservation practices that reduce the amount and rate of water runoff, which reduce erosion. It is the ratio of soil loss with a specific support practice on croplands to the corresponding loss with slope-parallel tillage. No any conservation practices in the study area are available therefore it is assigned 1 as default value for support practice factor (P).

4.6 Length and slope factor (LS)

Length and slope factor (LS) is calculated through a series of equations. The equations can be used in single index, which expresses the ratio of soil loss as defined by Bizuwerk et al. (2008). The Digital Elevation Model (DEM) with a resolution of 30 m is used to calculate L and S parameters. The following equation was adopted to compute the LS factor,

LS = (0.065 + 0.045S + 0.0065S2)* (L/22.1)0.5

or

$$LS = \frac{X}{22.1}\, m\,(0.065 + 0.045S + 0.0065S^2) \qquad \text{(iii)}$$

Where:,

X = slope length (m),

S = slope gradient (%), and

m = Value from reference table.

Table 3: Slope factor

m value	Slope %
0.50	> 5
0.40	3–5
0.30	1–3
0.20	< 1

The values of X and S are derived from the Digital Elevation Model (DEM). The value of X is obtained by multiplying the flow accumulation with cell value. Flow Accumulation is derived from the DEM after conducting the Fill and Flow Direction value. The value of X is calculated from the following Equation.

$$X = (\text{Flow accumulation} \times \text{cell value}) \quad \text{---} \qquad \text{(iv)}$$

By substituting the X value, LS equation can be written as:

$$LS = \frac{(\text{Flow accumulation} \times \text{cell value})}{22.1}\, m\,(0.065 + 0.045S + 0.0065S^2) \qquad \text{(v)}$$

The slope (%) is also derived directly from the DEM. The value of m varied from 0.2 to 0.5 depending on the slope (Table).

4.7 Sediment Yield (SY)

Sediment Yield (SY) is calculated from the Sediment Delivery Ratio (SDR). The formula used for the study area is adopted from the USDA SCS as shown below:

$$SDR = 0.51A^{-0.11} \text{ ------------------------------------- ----} \quad (2)$$

Where,

A is the area in km^2

Using the SDR value SY values can be calculated with the formula suggested by Wischmeier and Smith (1978):

$$SY = SDR \times SE\text{--------------------------- -----------} \quad (3)$$

Where,

SY = sediment yield (ton/ ha /yr),

SDR = sediment delivery ratio, and

SE = (RUSLE) annual potential soil loss (A) (ton /ha /yr).

5. RESULTS AND DISCUSSION:

5.1 Estimation of soil loss:

All the computed parameters of the RUSLE are used for estimation of potential soil loss from various places of Toranmal Plateau. Thus spatial potential soil loss, sediment yield and total sediment yield of the Toranmal plateau are estimated and tabulated in the following tables and maps are prepared as follow:

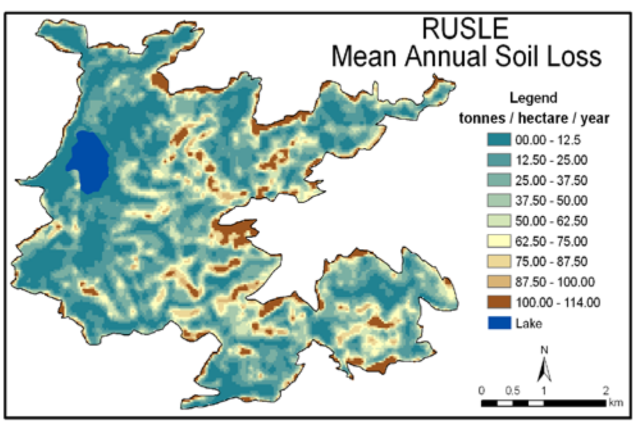
Table 4: Soil Loss on Toranmal Plateau

Soil Loss tones / hectare / year	Area sq km	Area hectare	Area %
0 - 12.5	5.44	544	26.0
12.5 - 25	5.43	543	25.9
25 - 37.5	3.16	316	15.1
37.5 - 50	2.03	203	9.7
50 - 62.5	1.53	153	7.3
62.5 - 75	1.05	105	5.0
75 - 87.5	0.74	74	3.5
87.5 - 100	0.48	48	2.3
100 - 114	1.10	110	5.2
	20.95	2095	100.0

(Self-generated table)

The potential soil loss on Toranmal Plateau varies greatly and ranges between 0 and 114 tones/hectare/year. The average rate is 33.62 tons per hectare per year. In the spatial context the soil loss on the plateau can be classified in nine categories at an interval of 12.5, in order to understand the spatial severity. Soil erosion rates are highest in Asia, Africa and South America, with an average rate of 30–40 tones ha–1annually. The potential soil loss of Toranmal plateau is very high. The permissible limit of soil erosion lies between 2.5 tones/hectare/year and 12.5 tones/hectare/year. The maximum tolerance limit of soil loss for mountainous region is 25 tones/h/y. (Hudson 1981). The permissible limit of soil loss is found over 544 hectares of land (26 %) of the Toranmal plateau. The maximum permissible limit of soil los is found on 543 hectares of land (52.9%). The remaining nearly 50 % area of the plateau has potential soil loss beyond the maximum permissible limit. Soil erosion is the very serious problem on Toranmal plateau. Therefore soil erosion is prime problem in agriculture on the Toranmal Plateau. The erosion is the main constraint behind the low productivity and sustainable agriculture in this area. The most significant findings of this study are that soil loss in the area is well beyond the tolerance limit and that is the matter of concern. This is the agriculture area on which tribal survives. If the soil erosion is continued at this rate this may remained unproductive and divested tribal life. There is an immense need of soil conservation practices to protect soil and its productivity in this area. The spatial distribution of Potential soil loss on the plateau is represented by following spatial distribution map. The central part of the plateau shows potential soil loss within permissible limit. The central undulating hilly area reveals the potential soil loss within maximum permissible limit. The soil erosion is very severe on peripheral zone of the plateau. The soil erosion problem is most serious eastern and northern margin of the Toranmal Plateau. The immediate need is soil conservation.

Potential Soil Loss of Toranmal Plateau:



5.2 Sediment Yield of Toranmal Plateau:

With the help of RUSLE the sediment yields per hectare and per year has been estimated as shown in the following table The spatial distribution map also has been prepared for Toranmal plateau . The total sediment yield of the plateau is 27884.5 tons per hectare per years. The spatial distribution of sediment yield ranges between 0 and 41.0 tons per hectare per year. The mean sediment yield rate of the plateau is 13.31 tons per hectare per year. It is well above the permissible limit of sediment yields rate.

5.3 Spatial Distribution of Sediment Yield on Toranmal Plateau:

The Western part of the Plateau has sediment yields well within the permissible loss of soil erosion. The average rate of sediment yield is 3.5 tons per hectare per year. This area covers 786 hectares of land and accounts 37.5 % of Total area of the plateau. The peripheral part of the plateau has higher sediment yields which are beyond the permissible limit. The problem of soil erosion is most serious on eastern and northern margins of the plateau.

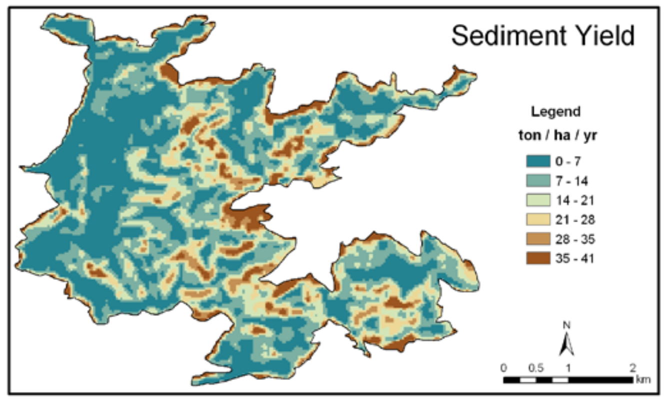


Table 5: Sediment Yield:

Sediment Yield tones / hectare / year	Area sq km	Area hectare	Area %
0 - 7	7.86	786	37.5
7 - 14	5.34	534	25.5
14 - 21	3.25	325	15.5
21 - 28	1.78	178	8.5
28 - 35	1.32	132	6.3
35 - 41	1.40	140	6.7
	20.95	2095	100.0

(Self-generated table)

Table 6: Total sediment Yield

Mean Sediment Yield tones / hectare / year (MEY)	Area sq km	Area hectare	Area %	Total Sediment Yield (tones / year) MEY x Area(ha)
3.5	7.86	786	37.5	2751
10.5	5.34	534	25.5	5607
17.5	3.25	325	15.5	5687.5
24.5	1.78	178	8.5	4361
31.5	1.32	132	6.3	4158
38	1.40	140	6.7	5320
	20.95	2095	100.0	27884.5

(Self-generated table)

5.4. Correlation between RUSLE Parameters and Average Potential Soil Loss

Individual parameters of RUSLE have been correlated with average potential soil loss of the Toranmal Plateau. The linear regression equation developed between them and significant levels estimated as shown in following table

Table 7: Correlation between RUSLE Parameters and Average Potential Soil Loss:

Parameters	R	R2	R. Coef By	R. Coef Bx	Regression Equ. A=a+bx	T	Sign level
R	0.5393	0.290844	0.0893	6.03551	A=0.08937028R-44.535	**1.71518253**	**>0.1**
K	0.8815	0.777042	171.3044	0.005146	A-2.100504+171.304405x	**2.59616445**	**0.05-0.02**
LS	0.7478	0.559205	11.7157	0.06831	A=11.891512+11.71577x	**2.17683831**	**0.1-0.05**
C	0.589	0.346921	296.5497	0.001986	A=9.8738644+296.549795x	**2.0614719**	**0.1-0.05**
P	0.7513	0.564452	56.3333	0.013338	A=56.33333x	**3.24559958**	**0.02-0.01**

From the above table it is evident that significantly very high correlation exists between average potential soil loss and rainfall erosivity factor. The rainfall and surface runoff are dominant factors of oil erosion on the Toranmal plateau. The greater the intensity and duration of rainfall, higher will be the potential soil loss. The surface runoff is more effective when the excess water available on slope. There are very less chances for infiltration on such slope. The maximum rainfall is available for the runoff generation. The surface runoff implies the soil erosion. The slope-length factor (LS) and land cover-land management factors(C) are equally important in soil erosion. The slope length increases the accumulation water. When sufficient depth of water attains, erosion starts. Further erosion is accelerated with increase in depth due to accumulation of water. The velocity is directly proportional to the depth of water. The higher the velocity higher will be its shearing stress, and carrying capacity of sediments. Thus greater will be the soil erosion. The steeper and longer the slope length, the higher will be the potential soil loss. The effectiveness of vegetative cover either of crops or plants is also significant in soil erosion. The crops that provides full protection during the crop season reduces soil erosion. This protective cover loss during non-crop season and allows erosion. But the crop management reduces the erosion. The significant level of soil erodibility (K) is considerable. The soil erodibility is an estimate of soil ability to resist erosion based on physical characteristics of soil. The texture is principal characteristics of soil affecting erodibility. The sand, sandy loam and loam textured tends to be less erodible than clayey soils. Soils with coarse texture soils allows faster infiltrations, higher level of organic matter and improved soil structure have greater resistance to erosion .However conservative factor(P) in the study area is comparatively less significant. Since, there are no conservative practices observed on Toranmal Plateau.

6. CONCLUSION

The most significant finding in this study is that the soil loss is beyond the tolerance limit. The rainfall and surface runoff factor is the most significantly influencing factor of soil loss. The agriculture is the only source of this area on which tribal population survives. If the soil erosion continues at this rate, very soon land will be remained unproductive. The results of the study clearly indicate that soil erosion in this area should be the cause for concern. It becomes necessary to adopt soil conservation measures so as to maintain fertility of soil and preserve the land from degradation. It is also to say that the RUSLE is the most useful tool for predicting soil loss under Indian environmental circumstances.

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