PRINT ISSN 2319-1775 e-ISSN 2320-7876, www.ijfans.org
Volume.11, Issue13, Nov- 2022
Research Paper
UGC CARE Listed (Group -I) Journal

Assessment of Soil Loss based on Stehlik's Method using GIS in Tamastirth Watershed, Dapoli Tahsil, Ratnagiri District, Maharashtra

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Abstract:

Watersheds are natural geohydrologic units that are most appropriate for appraisal of available natural resources and subsequent planning and developmental initiative. In the present research work, an attempt has been made to estimate the soil loss in Tamastirth watershed, with the help of the GIS data integration and analysis. The Tamastirth watershed is located along the western coast of India in Ratnagiri District of Konkan region in Maharashtra. The Tamastirth Watershed is a mini-watershed covering a geographical area of 26.44 sq. km. The Stehlik's method has been used for the estimation of the annual rate of soil loss in the study area. The Tamastirth watershed has been divided into 1116 grid cells of 5 seconds by 5 seconds dimension. The values of the factors used in the Stehlik's soil loss equation have been calculated based on criteria presented in Zachar (1982). The values for each grid cell for each factor have been calculated based on the criteria tables and equations. The mean annual soil loss calculated in millimeters per year (m y^{-1}) has been converted to meters per year. The mean annual soil loss has been converted to kg m^{-2} y^{-1} by multiplying the soil loss 'X' (m y^{-1}) by the bulk density of the soil (kg/m^3). The average annual soil loss in the Tamastirth watershed has been estimated to be 11.27 mm y^{-1} (15.53 kg m^{-2} y^{-1}).

Keywords: *Stehlik's method, soil loss, mini-watershed, GIS.*

Introduction:

A watershed (catchment or river basin) is a topographical area draining into a single water body or course. A watershed starts with small headwater streams in the higher elevations of the drainage basin. Water flows downhill from the drainage divide into larger streams, eventually joining a river. A watershed has homogeneity of geomorphic sculpturing processes. Watersheds are natural geo-hydrologic units that are most appropriate for appraisal of available natural resources and subsequent planning and developmental initiative. Lands can be treated on "ridge to valley" approach. A land lying in a valley cannot be improved if the land at upper reaches is not treated. The treatment of land in a scattered manner will not lead to watershed development.

Study area:

The Ratnagiri district lies between 16^0 30' and 18^0 North latitudes and 73^0 and 74^0 East longitudes on the Konkan strip along the Western Coast of India in Maharashtra. Dapoli Tahsil is situated in the northernmost part of Ratnagiri District. The study area selected for the present work is the watershed of a coastal river flowing through Tamastirth and other nearby villages. It is located along the western coastal stretch of Ratnagiri District in Dapoli Tahsil (Figure 1). The watershed extends from 17^0 40' to 17^0 44' North latitudes and 73^0 7' 30'' to 73^0 12' East longitudes. The total geographical area of the watershed is 26.44 sq. km. The Tamastirth watershed is a mini watershed (area between 10 and 30 sq. km).

The geological formations found in Ratnagiri District include those of the Precambrian Groups (Kaladgi Group), Mesozoic and Tertiary Ages (Deccan Trap) and Quaternary Age (Laterites). Maharashtra state is divided into Konkan coast in its western part, Western Ghats (Sahyadris) and northern Deccan plateau. The Konkan coast is a narrow coastal strip lying to the west of the Sahyadris. Ratnagiri district is a coastal district. The study area falls under low-lying coastal strip. Landforms of fluvio-marine origin are most common along the coast of the study area. The study area falls in the hot tropical climatic region. Ratnagiri experiences a hot climate with very high relative humidity. Heavy rainfall results in highly eroded landscape in the coastal region. The drainage network of the study area is dense and well developed. In Tamastirth watershed, various streams forming a dendritic drainage pattern are present. Drainage pattern is characterized by irregular branching of tributaries in many directions. The 1^{st}, 2^{nd} and 3^{rd} order streams are seasonal in nature and remain dry in non-rainy seasons. The main source of water are numerous springs and a few perennial streams. The main river in the Tamastirth watershed is a 5^{th} order river debouching into the Arabian Sea in the west. Small amount of water is available only in the downstream portion of the main stream. The colour of the soil varies from dark brown to red. The soil is sandy to sandy clay loam in the study area. The soils are mostly sandy in nature. On steep slopes, soils are generally shallow and have coarse texture. Due to steep slopes and heavy rainfall, the soil cover in most parts has been steadily eroded away over the years and is very thin, holding little moisture. The study area comes under the agroecological region of Western Ghats and Coastal Plains Ecoregion, the climate of which is hot and humid and the forest type is tropical moist deciduous forest. The main villages in the watershed are *Burondi, Karajgaon, Nigade, Chikhalgaon, Tamastirth, Kinhal, Olgaon, Teleshwarnagar* and *Devke*. *Burondi* village has the highest population (3817) among these villages according to 2011 Census of India data.

Objectives:

In the present research work, soil loss in Tamastirth Watershed in Dapoli Tahsil of Ratnagiri District has been analyzed using Stehlik's method. The objectives of the present work are:

(i) To estimate the soil loss in the study area.

(ii) To analyze the spatial variations in the soil loss in the study area.

Database:

Data for the present study has been acquired from the following sources:

(1) **Toposheet:** SOI (Survey of India) Topographical Map on 1:50,000 map scale has been used as a base map. The study area is covered in Survey of India Toposheet Number 47G/2 in B1 and C1 quadrants. It has been published in 1954.

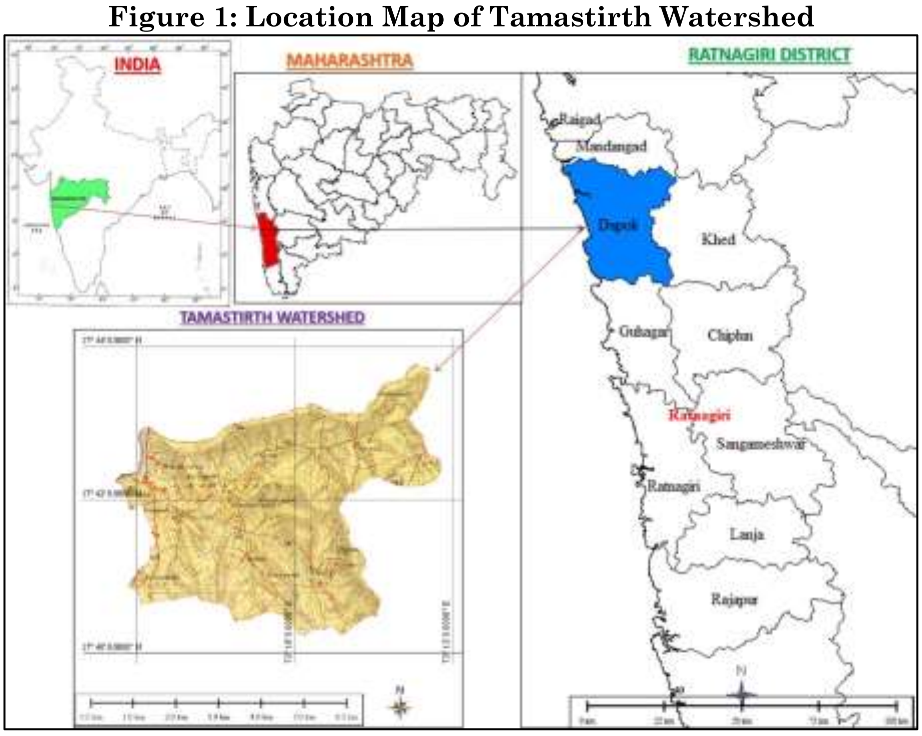
(2) **Google Earth Image:** The Google Earth image has been acquired from Google Earth Programme, 2022.

(3) **Satellite Imagery:** LANDSAT 8 satellite image, 2022 has been used for the preparation of Land Use Land Cover Map.

(4) **Soil Data:** The data has been obtained from the laboratory analysis of soil samples which have been collected during the field work

(5) **GPS Survey:** The entire watershed area has been tracked with the help of handheld Garmin GPS (Global Positioning System) device. The soil sample points have been tracked by using the GPS device.

Figure 1: Location Map of Tamastirth Watershed



Methodology:

(1) Base Map Preparation: This has been done using toposheet no. 47G/2 (1:50,000) covering the study area. The data from topographical map has been processed in Surfer 10 and Global Mapper (version 22) Softwares. Rectification of the base map has been done in Global Mapper Software.

(2) Digitization of Layers: The contours, streams etc. layers have been digitized from the toposheet in Global Mapper Software and these layers have been used for further analysis. DEM (Digital Elevation Model) of the study area (Figure 2) has been prepared using elevation data of digitized contours. Slope map has been prepared using DEM of the study area (Figure 3).

(3) Preparation of Thematic Maps: Various thematic maps have been prepared in Surfer (version 10) Software by the technique of spatial interpolation.

(4) Preparation of LULC (Land Use Land Cover) Map: The LULC map of the study area (Figure 4) has been prepared by using Multi Spec Win 32z software.

Figure 2: DEM (Digital Elevation Model) of Tamastirth Watershed

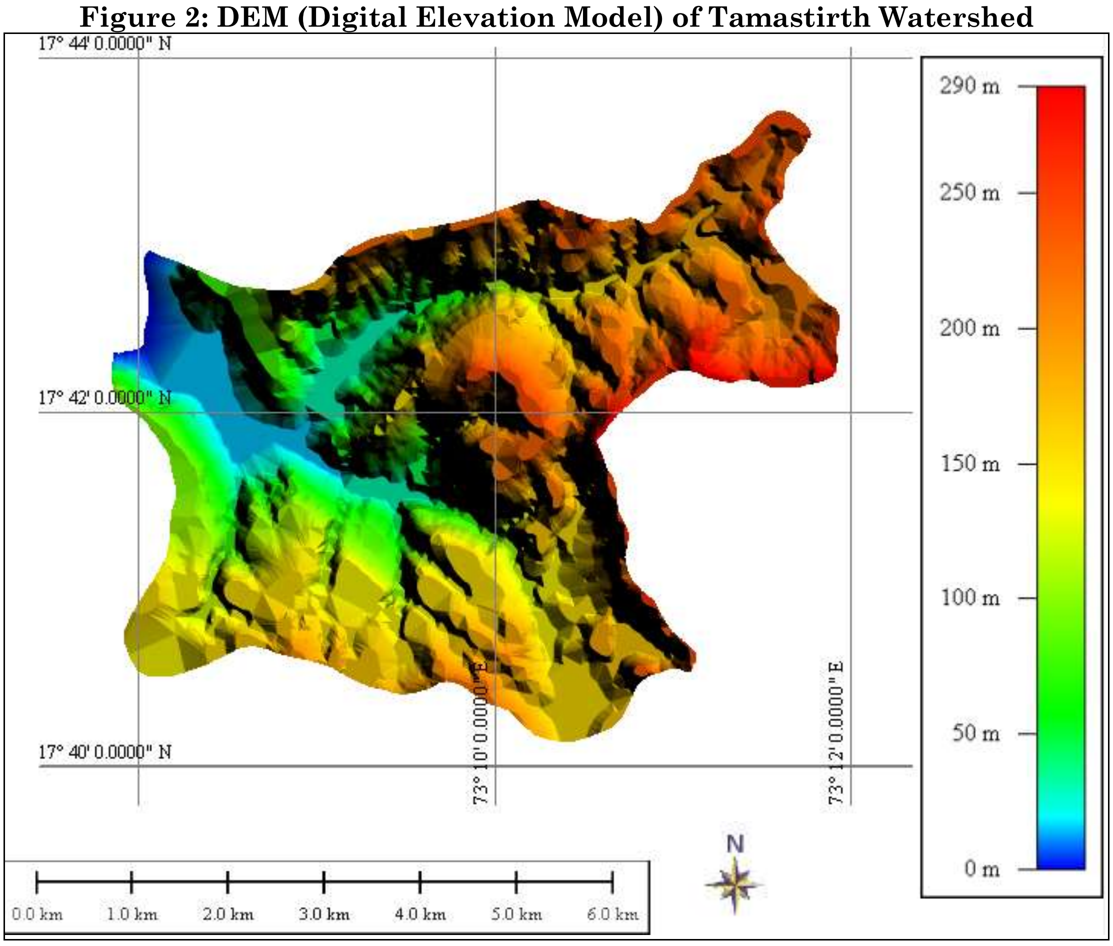
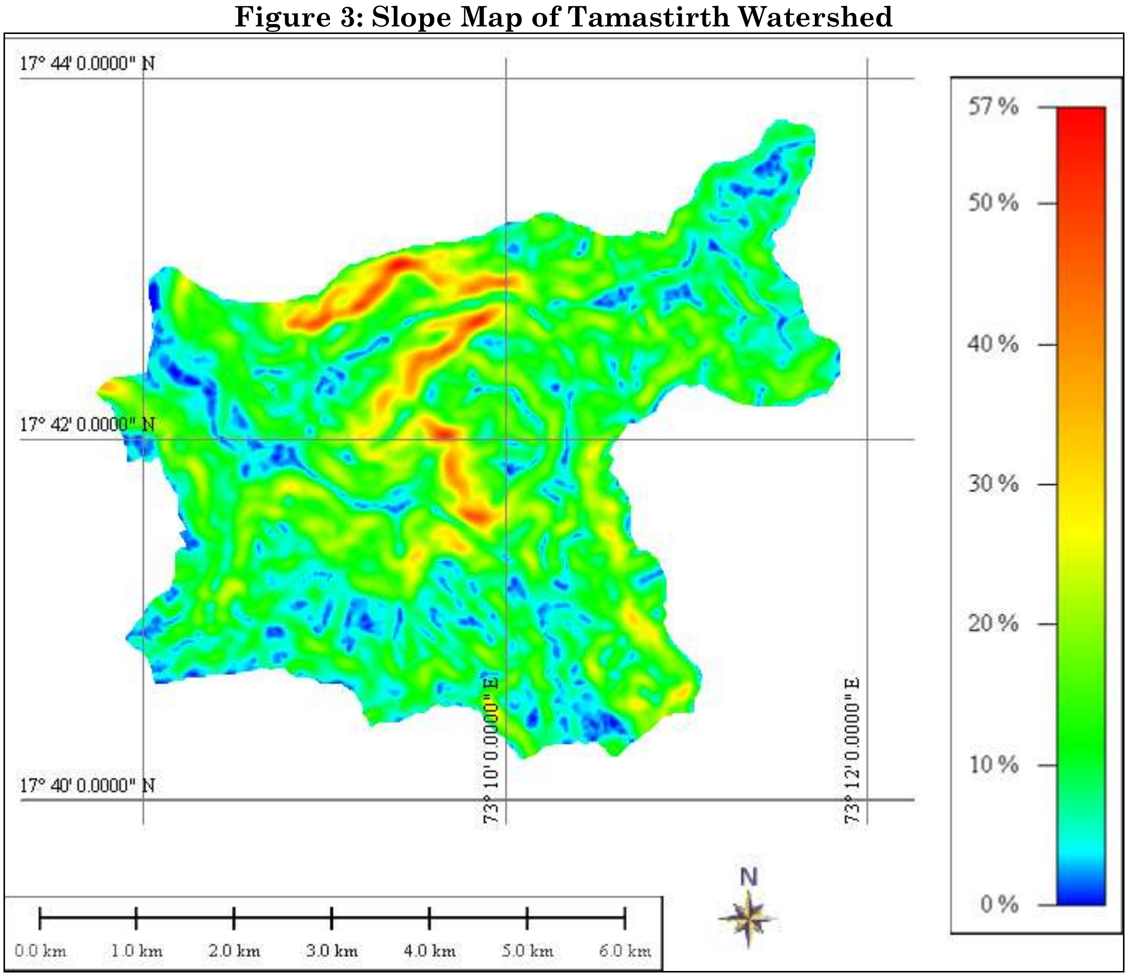


Figure 3: Slope Map of Tamastirth Watershed



PRINT ISSN 2319-1775 e-ISSN 2320-7876, www.ijfans.org
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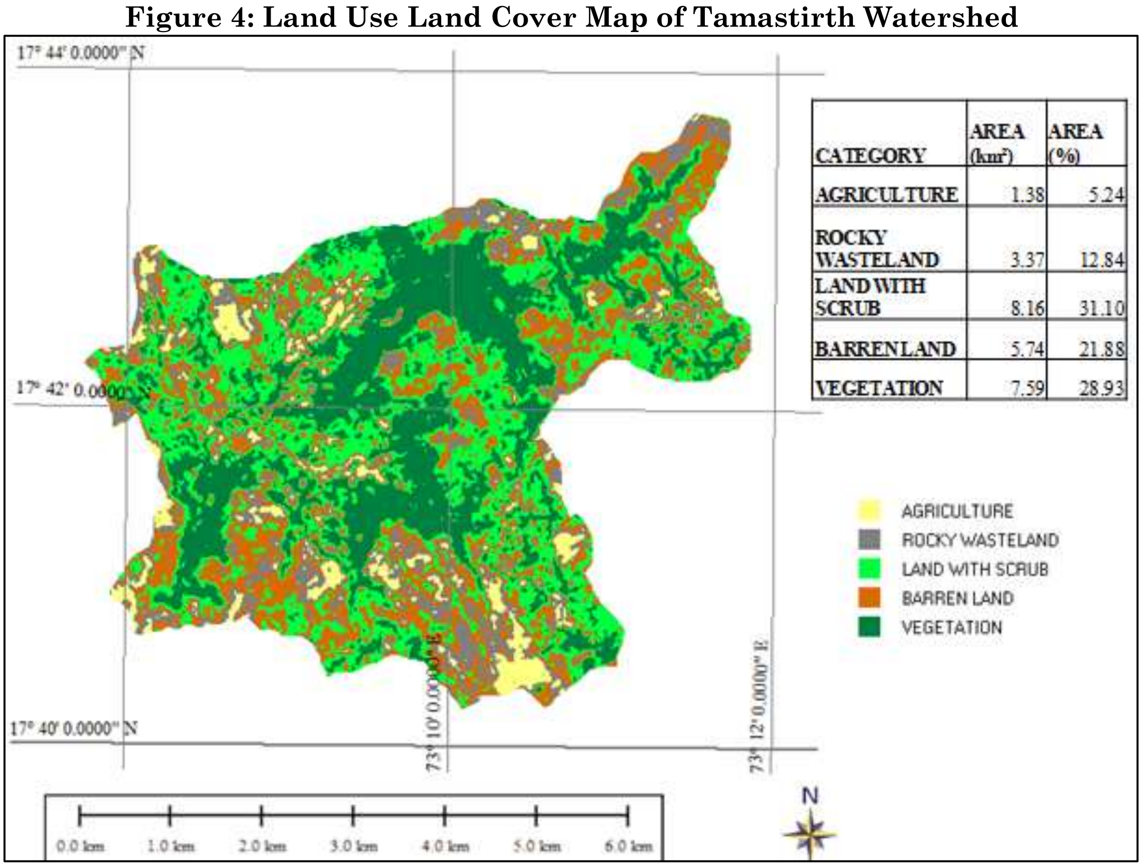
Figure 4: Land Use Land Cover Map of Tamastirth Watershed



Soil Loss Estimation using Stehlik's Equation:

The analysis of soil properties viz. physical and chemical properties is very significant in geomorphological studies. The physical properties especially soil texture, bulk density, etc. and chemical properties such as soil organic matter are very important in obtaining various input parameters in soil loss estimation models. In the context of the present study, in order to determine various input parameters of soil loss estimation by Stehlik's Equation, in depth study of parameters of soil environment has proved to be very important and indispensable. The input parameters have been obtained from the laboratory analysis of the collected soil samples. It is difficult task to monitor the soil loss in the field directly due to lack of appropriate techniques. In order to understand the soil loss due to erosion, there is no substitute for empirical equations. There are many methods which have been used to compute the soil loss viz. USLE (Universal Soil Loss Equation), RUSLE (Revised Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), Stehlik's Soil Loss Equation, MMF (Morgan, Morgan and Finney Model), etc. The USLE predicts the long-term average annual rate of soil erosion. The Stehlik's method and MMF model have been widely used for predicting the annual rate of soil loss.

Stehlik Method for Soil Loss Estimation:

The annual rate of soil erosion has been calculated by using the Stehlik's equation:

$$\mathbf{X} = \mathbf{D} \times \mathbf{G} \times \mathbf{P} \times \mathbf{S} \times \mathbf{L} \times \mathbf{O}$$

Where,
'X' = the mean annual soil loss
'D' = the climatic factor expressed in terms of precipitation
'G' = the petrological factor
'P' = the erodibility of the soil
'S' = the slope steepness
'L' = the slope length factor
'O' = the vegetation factor

(1) **'D' factor:** This is the climatic factor expressed in terms of precipitation falling at intensities (mm min^{-1}) equal to or greater than $\sqrt{5t}$ where 't' is the duration of the rainfall (minutes). The value of D factor is estimated from mean annual precipitation (R) by using the equation: $\mathbf{D = 0.001\ 4\ R - 0.38}$

'G' factor: This is the petrological factor and assesses the rock type according to the permeability of its weathered debris. The values of G for each grid cell are computed based on following criteria table:

Table 1: 'G' Factor Criteria:

Permeability of rock	Granulation of weathered debris	G
Low	Fine	1.5-1.3
Slight	Sandy loam	1.3-1.1
Moderate	Loamy sand	1.1-0.9
High	Coarse sand to stony	0.9-0.7

(2) **'P' factor:** This expresses the erodibility of the soil based on the percentage of particles smaller than 0.1 mm in size and the organic matter content. The values of P factor are decided by using the following table:

Table 2: 'P' Factor Criteria:

Type of Soil	Clay content (<0.01 mm) in %	Content of humus		
		<2%	**2-3%**	**>3%**
Sandy	<10	1.4	1.1	1
Loamy sand to sandy loam	10-30	1.5	1.25	1.75
Loamy	30-45	1.25	1	0.8
Clay/ loam	45-60	1.4	1.15	0.9
Clay	>60	1.5	1.25	1

(3) **'S' factor:** This expresses the slope steepness according to the relationship:

$$S = 0.24 + 0.106\ s + 0.0028\ s^2$$ where, s is the slope in per cent.

Table 3: 'S' Factor Criteria:

Slope Gradient (%)	5	7	9	12	15	20	30	40	50
Slope Factor (S)	0.35	0.65	1	1.45	2	3	5.35	8.61	12.02

(4) **'L' factor:** The slope length factor is calculated by using the following criteria table:

Table 4: 'L' Factor Criteria:

Slope Length (m)	20	50	100	150	200	250	>300
Slope length Factor (L)	1	1.6	2.5	3.2	3.8	4.3	5

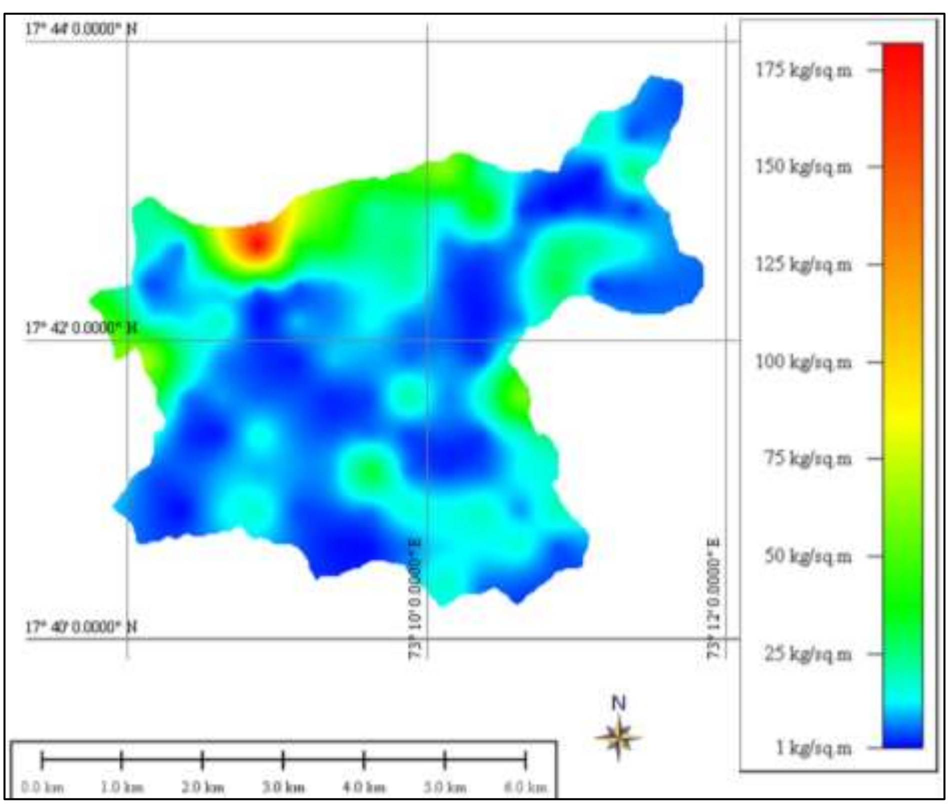
(5) **'O' factor:** This is the vegetation factor and is dependent upon the percentage cover of the vegetation. The following table gives the values of O:

Table 5: 'O' Factor Criteria:

Vegetation Cover (%)	100	95	90	80	70	60	50	40	20	0
Vegetation factor (O)	0.2	0.25	0.3	0.4	1	1.22	2	2.5	3.2	4

The Tamastirth watershed has been divided into 1116 grid cells of the dimension 15″ * 15″. The values of the above factors are calculated based on criteria presented in Zachar (1982). The values for each grid cell for each factor have been calculated based on the above criteria tables and equations.

Figure 5: Estimated Soil Loss (by Stehlik's Method) in Tamastirth Watershed



Results and Findings:

The mean annual soil loss which is calculated in millimeters per year (mm y^{-1}) has been converted to meters per year (m y^{-1}). The mean annual soil loss has been converted to kg m^{-2} y^{-1} by multiplying the soil loss 'X' (m y^{-1}) by the bulk density of the soil (kg/m^3). The average annual soil loss in the Tamastirth watershed has been estimated to be 11.27 mm y^{-1} (15.53 kg m^{-2} y^{-1}). Soil loss is maximum in the northwestern part of the watershed due to occurrence of steep slopes in this region.

Conclusion:

The average annual soil loss in the Tamastirth watershed has been estimated to be 11.27 mm y^{-1} (15.53 kg m^{-2} y^{-1}) which is significantly high. The results of this calculation are highly sensitive to changes in the slope steepness. In absolute terms, however, changes in slope steepness and slope length affect the predictions of the equation about equally. At lower level of sensitivity, the Stehlik's equation gives more importance to changes in the rainfall factor and less importance to changes in soil erodibility. The Land Use Land Cover map reveals that a significant part of the study area is covered by wastelands. The present study has demonstrated the usefulness of GIS for soil loss estimation and analysis. The importance of GIS has been amply demonstrated in the approach and findings of the present research work.

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