

Application of Universal Soil Loss Equation in Estimation of Sediment Yield Using Arc Gis on Ong Catchment, India

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ABSTRACT: Soil erosion is one of the main forms of land degradation. Erosion contributes to loss of agricultural land productivity and ecological and esthetic values of natural environment, and it impairs the production of safe drinking water and hydroenergy production. Thus, assessment of soil erosion and identifying the lands more prone to erosion are vital for erosion management process. Revised Universal Soil Loss Equation (Rusle) model supported by a GIS system was used to assess the spatial variability of erosion occurring at ONG river basin in Odisha. Digital Elevation Model (30x30 m), twenty years' rainfall data measured at 11 rain gauge stations across the basin, land use and soil maps, and published literature were used as inputs to the model. The average annual soil loss in ONG river basin varied from 0 to 134 t ha⁻¹ year⁻¹ and mean annual soil loss was estimated at 0.63 t ha⁻¹ year⁻¹. Based on erosion estimates, the basin landscape was divided into four different erosion severity classes: very low, low, moderate, and high. About 1.68% of the areas (4714 ha) in the river basin were identified with moderate to high erosion severity (>5 t ha⁻¹ year⁻¹) class which urgently need measures to control soil erosion. Lands with moderate to high soil erosion classes were mostly found in Mahanandi and Sonapur divisional secretarial divisions. Use of the erosion severity information coupled with basin wide individual RUSLE parameters can help to design the appropriate land use management practices and improved management based on the observations to minimize soil erosion in the basin.

I. INTRODUCTION

Soil erosion is a natural process of removal of soil material and transportation through the action of erosive agents such as water, wind, gravity, and human disturbance [1], and it has been accelerated by human activities such as intensive agriculture, improper land management, de-

forestation, and cultivation on steep slopes [2]. It is a se- rious and continuous environmental problem when combined with climate-induced high-intensity rainfall [3]. Degradation of agricultural land by soil erosion is a worldwide phenomenon leading to loss of nutrient rich surface soil, increased runoff from more impermeable subsoil, and decreased water availability to plant [4]. Worldwide, the average soil erosion rate in crop lands is about 30 t ha⁻¹ yr⁻¹ ranging from 0.5 to 400 t ha⁻¹ yr⁻¹ [5]. Estimates indicate that about 85% of land attenuation, globally, is due to soil erosion reducing crop productivity by about 17%, affecting the soil fertility initially and in the long term resulting land desertion [6].

Though soil erosion is a naturally occurring process, this has been accelerated by human activities such as in- tensive agriculture, improper land management, de- forestation, and cultivation on steep slopes [2]. Removal of vegetation cover and shaping of surface topography induce or accelerate soil displacement and movement [7]. Serious

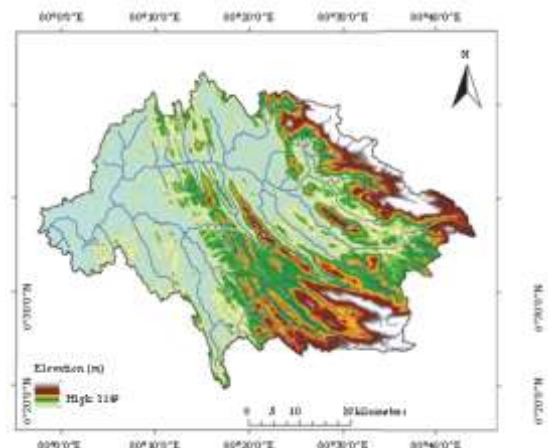


FIGURE 1: Geographical location and DEM of ONG river river basin.

soil erosion is occurring in most of the

world's major agricultural regions [5] due to the expansion of agriculture without adequate soil conservation practices.

Several areas in Odisha are subjected to severe soil erosion [2, 8, 9]. Soil loss in agricultural areas in steep central highlands of Odisha is 10–100 times more compared to natural rates of erosion [8]. Soil erosion in intensively cultivated vegetable and tea lands with poor land management is higher than that in the forested landscapes or in well-managed tea and home gardens in Kurudu Oya sub-catchment in upper Mahaweli area [9].

Moreover, crop residues are removed for fodder, biofuel, and industrial uses leaving the soil surfaces bare from a protective cover enhancing the vulnerability to lands to erosion. The resulting runoff ultimately transports sediments, organic material, nutrients, and pesticide residues off-site impacting both water and soil quality. When lands are left as fallow to recover, the erosion problem is worsened due to minimal vegetative cover [10]. Soil erosion is reported to increase with higher magnitude of rainfall and frequent occurrences of heavy precipitation [11].

Soil erosion and degradation of lands in Odisha are affecting the national food production and sustainability of natural eco systems [2]. Erosion rates are high in highlands as well as in low lands due to land use changes including the removal of vegetative cover and urbanization [7]. Several studies conducted in Odisha to assess soil erosion, based on both numerical modeling and actual quantification, have shown that soil erosion is a severe problem in Odisha [12–15]. Therefore, it is useful to identify the areas more prone to soil erosion, so that farmers and land managers can incorporate appropriate soil conservation measures to minimize extensive soil erosion.

There are several erosion prediction approaches widely used [16] comprised of empirical, conceptual, and physical based models [6, 17]. The Universal Soil Loss Equation (USLE), Modified Universal Soil Loss Equation (MUSLE), and Revised Universal Soil Loss Equation (RUSLE) are the most popular empirical models used globally for erosion prediction and control [14, 18]. RUSLE developed by the U.S. Department of Agriculture is used as a decision support system in soil conservation and land use planning [19]. It uses a set of mathematical equations to describe ecological processes related to conservation practices and erosion in a given landscape [20].

RUSLE is a flexible tool that has been adapted to landscape and watershed scales

combined with Geographic Information Systems (GIS) [21–26] in soil erosion assessments. The study of annual soil loss using GIS-based RUSLE to the Pamba watershed in a mountain landscape demonstrated the applicability of RUSLE in investigating erosion hazard where soil erosion rate is minimum in natural forest areas and maximum in places with human influence [22]. In Odisha, a few studies have been conducted to assess soil erosion using the RUSLE model [14, 15].

ONG river is the 4th longest river (129 km) in Sri Lanka and entirely located in the wet zone of the country [27]. As a result, it accounts for the largest amount of

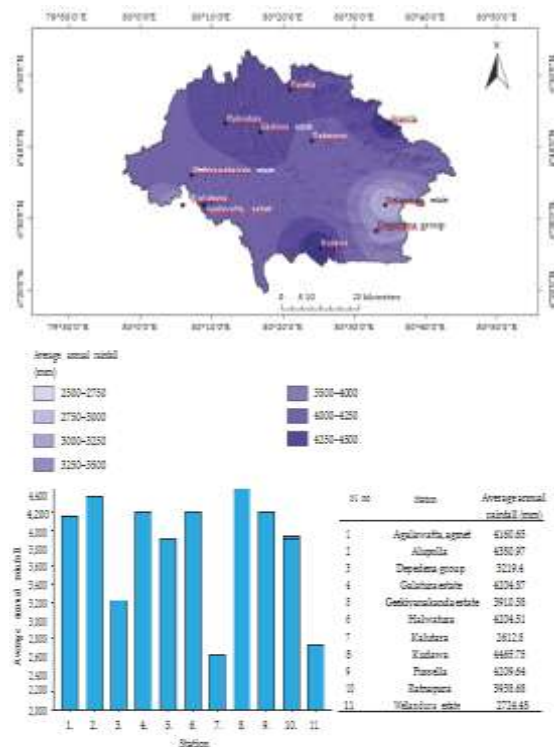


Figure 1. Average annual rainfall variation.

discharge to the sea in the country [28]. There are drinking water scheme and mini and medium scale hydropower generation stations associated with the river [29]. In addition, the main land use of the basin is agriculture. ONG river basin is in the area where the climate-induced rainfall expected to increase with an elevated potential for floods and landslides [30]. Thus, it is worth analyzing the spatial variation of soil loss in the basin so that planner can take precautions to minimize soil erosion. The present study estimates the average annual soil loss in the ONG river river basin using the Revised Universal Soil Loss Equation (RUSLE) in combination with an ArcGIS

in-terface to develop the soil erosion hazard map of the ONG river river basin.

II. MATERIALS AND METHODS

Study Area. The ONG river river basin (2,766 km²) is located in the Southwestern part of Odisha. The river length is about 130 km long and extends from 80.00° to 80.67°E and 6.42° to 6.83°N. The ONG river starts in the central hills of the country at an altitude of 2,250 m and runs into the Indian Ocean near the town Kalutara after travelling through one of the highest rainfall areas of the country. Upstream area of the basin is higher in gradient while downstream area of the basin is more or less flat and elevation varied from 2149 m to 0 m [28] (Figure 1).

The annual rainfall average is about 4,000 mm and the annual water flow is about 4,000 million m³ [28]. Average

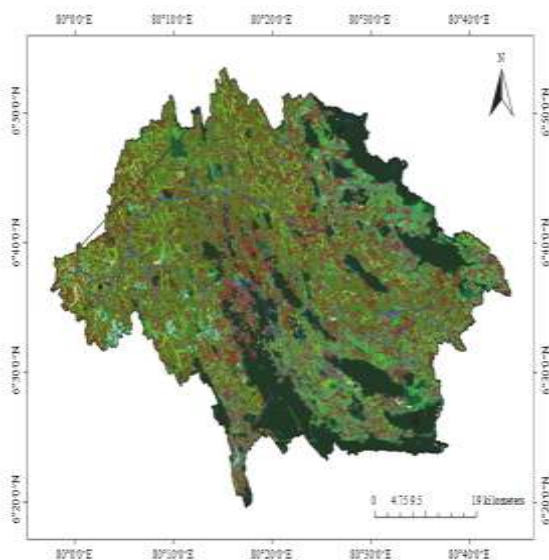


FIGURE 3: Land use and land cover map of ONG river river basin.

FIGURE 3: Land use and land cover map of ONG river river basin

annual rainfall variation of the basin is shown in Figure 2. The maximum rainfall value of 4,466 mm was recorded in Kudawa and the lowest average annual rainfall value of 2,613 mm was recorded in Kaluthara rain gauge station. Compared to average annual rainfall of Odisha, this river basin receives higher rainfall [27].

The year 2019 land use and land cover map of the Survey Department of Odisha (Figure 3) indicates that land uses of the ONG river river basin comprised agricultural lands, bare lands, built up areas, forests, rocky areas, water bodies, and wetlands. Rubber is the main commercial crop grown in the ONG river river basin along with home gardens and

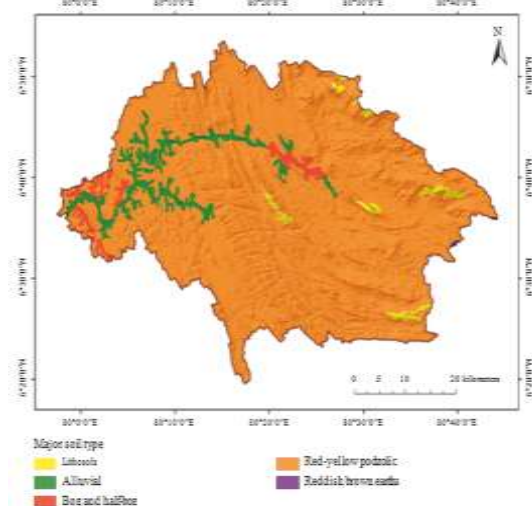


FIGURE 4: Major soil types in ONG river river basin

TABLE 1: Soil erodibility values for soil types in ONG river river basin (source: [12, 14, 15]).

Soil	Erodibility (K)
Red Yellow Podzolic	0.22
Reddish brown earth	0.27
Alluvial	0.31
Lithosols	0.25
Bog and Half Bog/organic soils	0.05

small holder tea. The forest cover of the basin is more than 30% with a 77% canopy cover. The soil map of the basin (Figure 4) indicates that Red Yellow Podzolic is the main soil type found in the basin and Alluvial soil is found in the flood areas of the river (Figure 4). Bog and Half Bog and Lithosols are the other soil types found in the basin but to a lesser extent.

Data Collection. Monthly rainfall data at eleven rain gauging stations within and near the ONG river river basin (Figure 2) were obtained from the Department of Meteorology and the Natural Resource Management center (NRMC), Peradeniya, Odisha. Rainfall data were collected from 1997 to 2017. The soil map of Odisha was obtained from the Natural Resource Management Center (NRMC), Peradeniya, Odisha. Land use maps of the districts (Kaluthara and Rathnapura) located in ONG river river basin were collected from the Survey Department of Odisha. To cover the spatial extent of the

ONG river area, relevant grids of 30 * 30 m resolution Digital Elevation Model (DEM) were downloaded from RUSLE Parameter Estimation. The RUSLE was used as the model and it was interfering with the ArcGIS 10.2.1. RUSLE [19] can be expressed as ASTERwebsite(<https://asterweb.jpl.nasa.gov>) and processed to developed the Digital Elevation Model (DEM) of the basin.

RUSLE Parameter Estimation. The RUSLE was used as the model and it was interfering with the ArcGIS 10.2.1. RUSLE [19] can be expressed as

$$A = R \times K \times L \times S \times C \times P, (1)$$

where A average annual soil loss per unit area ($t\ ha^{-1}\ yr^{-1}$), R rainfall-runoff erosivity factor ($MJ\ mm\ ha^{-1}\ h^{-1}\ yr^{-1}$), K soil erodibility factor ($t\ ha\ h\ MJ^{-1}\ mm^{-1}$), L slope length factor, S slope steepness factor, C cover and management factor, and P support and conservation practices factor.

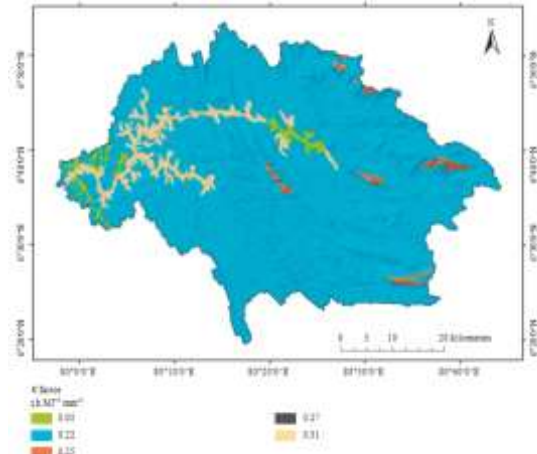


FIGURE 7: K factor map of ONG river river basin

TABLE 2: Area coverage by different soil types.

Soil type	Distribution area (%)
Alluvial	4.76
Bog and Half Bog	1.69
Lithosols	1.09
Red Yellow Podzolic	92.41
Reddish Brown earth	0.04

Rainfall-Runoff Erosivity Factor (R). The erosive power of rainfall can be estimated by calculating the erosivity factor for a particular location [31]. It depends on the amount and the intensity of rainfall [2]. The original equation proposed by Wischmeier and Smith [32] and Renard et al. [33] was not used due to nonavailability of rainfall intensities. As a substitute, regression equations are developed for different regions to calculate the R values. We used the rainfall-erosivity relationship developed by Premalal [34] as in equation (2). The same equation has been used in Kirindi Oya [14], in Kelani river basins [15], and for mapping soil erosion hazard in Odisha [2]. In our study, rainfall-runoff erosivity factor was determined from the average annual rainfall from 1996 to 2019 along with the rainfall erosivity factor equation developed for Odisha conditions by [34] (equation (2)). Thus, this study concerns

the average soil erosion assessment for the period from 1996 to 2019.

$$R = \frac{(972.75 + 9.95 \times F)}{100}, (2)$$

where R rainfall-runoff erosivity factor ($\text{MJ mm ha}^{-1} \text{h}^{-1} \text{yr}^{-1}$) and F average annual rainfall (mm).

The rain gauge stations shape file was created by using latitude and longitude values with ArcGIS 10.2.1.

Among the available interpolation techniques, two types of interpolation techniques were used to select the suitable technique to create rainfall and R factor maps. One method was simple Kriging in geostatistical wizard with spherical semivariogram model. The other one was IDW method, with power 2. According to the cross validation results, IDW provides the least error (RMSE 163.39) for mapping rainfall data over Kriging method (RMSE 190.25). Therefore, both annual rainfall variability map and rainfall erosivity factor map for ONG river river basin were generated using IDW interpolation.

Soil Erodibility Factor (K). Soil erodibility factor (K) is one of the main factors governing soil erosion. It expresses

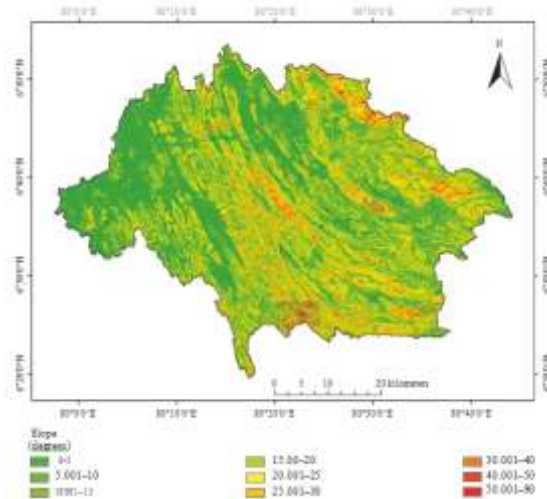


FIGURE 8: Slope map of ONG river river basin.

the susceptibility of soil towards erosion and measures the contribution of soil types [24]. K factor raster map was generated from vector soil map with 30 m resolution using the Feature to Raster tool in ArcGIS (Table 1).

Slope Length and Steepness Factor (LS). Slope length and steepness has the greatest influence on soil loss and describes the effect of topography on soil erosion.

S factor measures the effect of slope steepness and was calculated by equations (3) and (4) using raster calculator based on the relationship given by [33]

$$S = 10.8 \sin \theta + 0.03 \text{ for slope percent } < 9\% \quad (3)$$

$$S = 16.8 \sin \theta - 0.50 \text{ for slope percent } \geq 9\% \quad (4)$$

where S = slope steepness factor and θ slope angle in degree.

L factor was calculated by equation (5) using raster calculator based on equation given by [32]

$$L = \left\{ \frac{\lambda}{22.1} \right\}^m \quad (5)$$

where L slope length factor, λ horizontal projected slope length (m) (λ flow accumulation * cell size), and m slope length exponent.

In this equation, “m” is the slope length exponent that varies based on slope steepness. Slope length exponent equals 0.5 if the slope is 4.5% or more, 0.4 on slopes between 3% and 4.5%, 0.3 on slopes between 1% and 3%, and 0.2 for flatter terrains with gradient less than 1% [25]. L and S factors were calculated by using flow accumulation and slope in degree as inputs and finally LS factor map was generated by the multiplication of both L and S factors in raster calculator in ArcGIS.

Cover and Management Factor (C). The land use and land cover map of the basin was extracted from the land use map produced by the survey department in 2019, and this study assumed that the land use and land cover was not changed significantly during the past 20 years. C factor values (Figure 5) for different land uses were obtained from available literature [14, 15, 35, 36] and matched with the land use map. Based on these C factor values, C factor raster

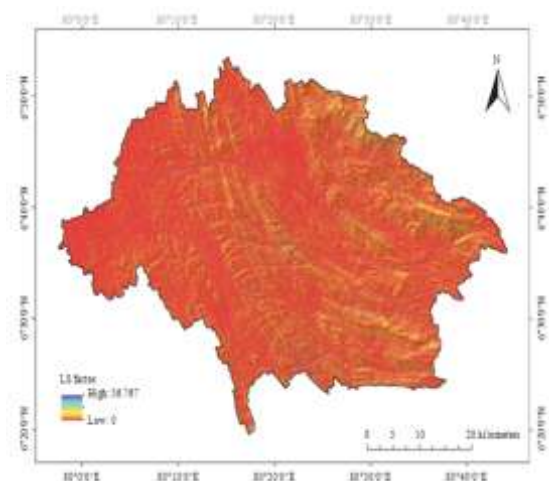


FIGURE 9: LS factor map of ONG river river basin.

map with 30 m resolution was generated for the ONG river river basin.

Support and Conservation Practices Factor (P). P value varies from 0 for good conservation practices to 1 for poor conservation practices. The P factor map was created based on the land use map of the ONG river river basin. P values (Figure 5) were added to the attribute table of land use map and P factor raster map was created with the conversion tool in ArcGIS 10.2.1.

Creation of Soil Erosion Severity Map. Soil erosion severity map was created using a raster overlay analysis with rainfall-runoff erosivity factor, soil erodibility factor, slope length and steepness factor, cover and management factor, and support and conservation practices factor.

Sediment Delivery Ratio (SDR) and Sediment Yield (SY) of the Main Stream. Sedimentary Delivery Ratio (SDR) is a fraction of gross erosion that is transported from a given area at a given time interval. It indicates the capability of a catchment for storing and transporting the eroded soil [37]. According to [38], the average slope of the stream channel is more significant than other parameters in estimating sediment delivery ratio, and it is a function of slope of main stream channel (equation (6)). The papers [39, 40] also used this equation to estimate the sediment delivery ratios in different river basins.

$$SDR = 0.627 \times (SCS)^{0.403}, \quad (6)$$

where SCS is main stream channel slope measured in percent unit.

After determining the flow direction, flow accumulation, and stream network using DEM, main stream channel slope was computed using ArcGIS HEC-GeoHMS extension. Then using those SCS values, SDR for the main river of the ONG river river basin was calculated in raster calculator. Finally, sediment yield was calculated by overlaying the mean annual soil loss raster layer and sediment delivery ratio of the main stream using raster calculator.

III. RESULTS AND DISCUSSION

The soil erosion hazard map was created by using all the five RUSLE layers, rainfall-runoff erosivity factor, soil erodibility factor, slope length and steepness factor, cover and management factor, and support and conservation practices factor. These factors were estimated on a 30 30 m grid.

Rainfall-Runoff Erosivity Factor Map (R). Management practices to reduce the impact of rainfall and sediment control measures can be adopted based on the R values. Estimated R factor ranged from 269.70 to 454.07 MJ mm ha⁻¹ h⁻¹ yr⁻¹ and

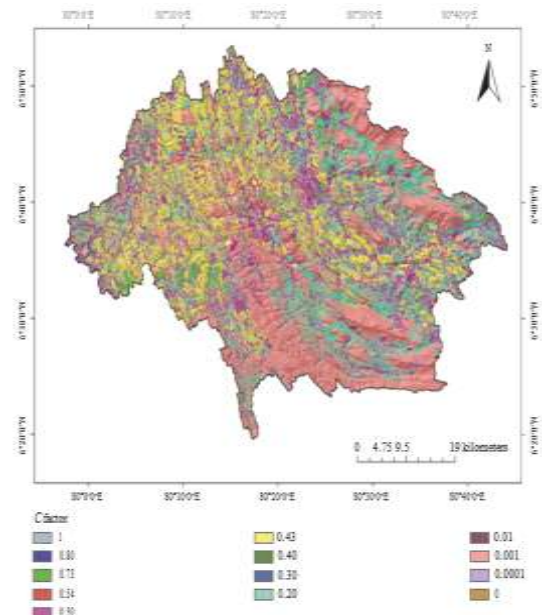


FIGURE 10: C factor map of ONG river river basin

the mean R factor recorded is 387.39 MJ mm ha⁻¹ h⁻¹ yr⁻¹. R factor map developed using Inverse Distance Interpolation (IDW) with a power of 2 is shown in Figure 6.

Soil Erodibility Factor Map (K). K factor (Figure 7) was evaluated based on different soil types (Figure 4) and their properties found in the ONG river river basin. The results showed that more than 92% of ONG river river basin is covered by Red Yellow Podzolic (RYP). Alluvial soil covered more than 4% of ONG river river basin. K factor of the basin varied from 0.05 to 0.31 t h MJ⁻¹ mm⁻¹ (Table 2) with a mean of 0.21 t h MJ⁻¹ mm⁻¹. Alluvial soil has the highest K value and Bog and Half Bog soil has the lowest K value in the basin (Figure 7). K value of RYP (0.22) is less susceptible to soil erosion than Reddish Brown Earth (RBE) (0.27) which is the main type of soil in dry zone, Odisha.

Slope Length and Steepness Factor Map (LS). The average slope of the ONG river river basin was 12.06° and it ranged from 0 to 90° (Figure 8). LS factor was calculated by using flow accumulation and slope in degree as inputs. LS factor value ranged from 0 to 56.77 (Figure 9) and the mean LS factor value was 0.05. When slope and flow accumulation increase, LS factor increases. Higher LS factor was observed in the Northeastern upstream area of the basin.

Cover and Management Factor (C) and Support and Conservation Practices Factor (P). Based on the different land use classes

(Figure 3), the C factor map (Figure 10) was generated. The mean C factor value was 0.28 for the ONG river river basin. C factor for well-protected land is 0 and for bare land it is 1 [4]. Summarized major land use type of the basin is shown in Table 3. High vegetative cover characterizes the low soil erosion potentials because of its ability to resist high-intensity rains expected as a result of climate change [41].

P factor value indicates the extent of erosion control practices in the ONG river river basin. Spatial distribution of P factor is shown in Figure 11 and mean P factor value for ONG river river basin is 0.28 (Figure 11).

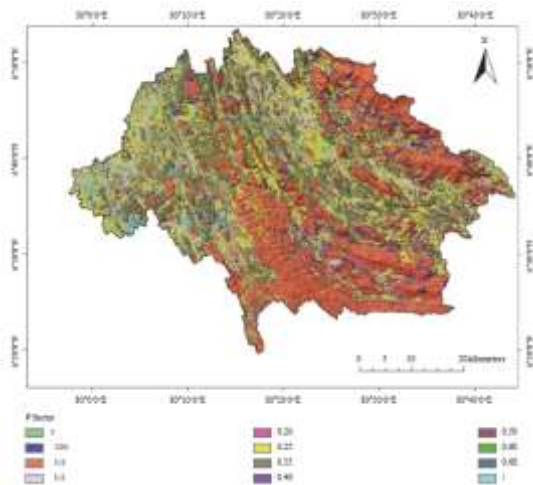


FIGURE 11: P factor map of ONG river river basin.

TABLE 3: Area percentage of major land use types.

Main land use types	Area (%)
Agricultural lands	46.62
Bare lands	0.28
Built up lands	20.49
Forest lands	30.72
Rocky areas	0.72
Water bodies	0.98
Wetlands	0.19

Soil Erosion Estimation. The soil erosion severity map (Figure 12) was generated by overlaying all the parameter layers of RUSLE. Results indicated that ONG river river basin has a mean average annual soil loss of about 0.63 t ha⁻¹ yr⁻¹

A large portion of ONG river river basin is classified as very low erosion and it is more than 93% of the total area of the basin. Low to very low erosion were prominent in ONG river river basin compared to Kelani Ganga river [15] and Kiridi Oya river basins in Odisha [14]. Comparatively

recorded lower erosion rates may be due to the higher % of forest lands in ONG river (31%) river basin compared to Kelani (10%) and Kirindi Oya (27%) river basins. In addition, Red Yellow Podzolic soils are the main soil type in the ONG river river basin with a lower K value with a lower contribution to soil erosion. High erosion areas in Kirindi Oya river basin were occupied by home gardens and scrub lands [14] while high eroded areas in Kelani river basin were bare lands and lands under coconut with relatively high P factor and C factor values [15].

Moreover, the mean R factor recorded (387.39 MJ with a range of 0 to 134 t ha yr⁻¹). Based on soil erosion

mmha⁻¹h⁻¹yr⁻¹) is lower than the R factor estimated for

classification used by [42], the estimated soil erosion was classified into three classes, namely, low (<5 t ha⁻¹), moderate (5–12 t ha⁻¹), and high (>12 t ha⁻¹) per annum. Due to the dominance of low erosion areas, the severity map was further classified into two subclasses as very low (<2 t ha⁻¹) and low areas (2–5t ha⁻¹), respectively (Table 4).

high rainfall areas elsewhere in the world [43]. It is also observed that R values used in other studies that used the same regression equation are also low [14, 15]. This equation which was used in [34] has been developed for the entire country, where 1/3 of the country is in the dry zone. However, ONG river river basin is located in wet

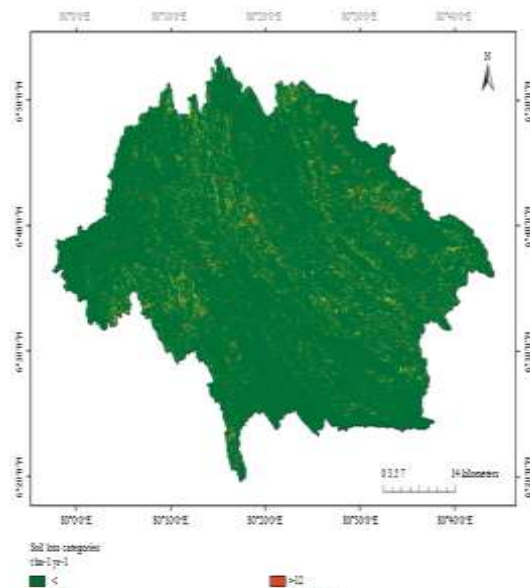


FIGURE 12: Soil erosion severity map of ONG river river basin.

TABLE 4: Estimated soil loss rate and area distribution.

Value (t ha ⁻¹ yr ⁻¹)	Soil erosion class	Area (km ²)	Area (%)
<1	Very low	2631.0	93.5
1-5	Low	129.0	4.6
5-12	Moderate	4.2	1.5
>12	High	11.0	0.4

zone. Therefore, there may be underestimation of the rainfall erosivity factor. Therefore, we suggest to improve the regression equation for the different climatic zone of the country using new rainfall data and validate the proposed equations with the field observations.

The ONG river basin is characterized as having a potential low susceptibility to soil erosion due to the good cover, lower K values of the existing soils, etc. Based on the RUSLE model estimates, about 1.9% of the area in the basin could be categorized into moderate to high soil erosion hazard class. Lands located in Kuruwita, Bulathsinghala, and some parts of Rathnapura divisional secretarial divisions fall into these moderate to high erosion category. To control the soil erosion, it is suggested to use agronomic soil conservation measures especially to crop lands. However, steep slope areas may need comparatively low-cost mechanical

structures such as stone terraces, lock and spill drains, and drop structures to minimize the erosion.

Sediment Yield of the Basin Estimated over the Main Stream. Sediment yield (Figure 13) of the basin was determined by sediment delivery ratio (Figure 14) of the main stream. The sediment delivery ratio results ranged from 0 to 0.16 for the main stream of ONG river river. The mean sediment yield for the main stream of the ONG river river basin was 0.29 t ha⁻¹ yr⁻¹ and sediment yield ranged from 0 to 4.66 t ha⁻¹ yr⁻¹. A similar study is reported in central highland of Blue Nile basin, Ethiopia [40]. According to their analysis, sediment delivery ratio of the central highland of Blue Nile basin watershed ranges between 0 and 0.26.

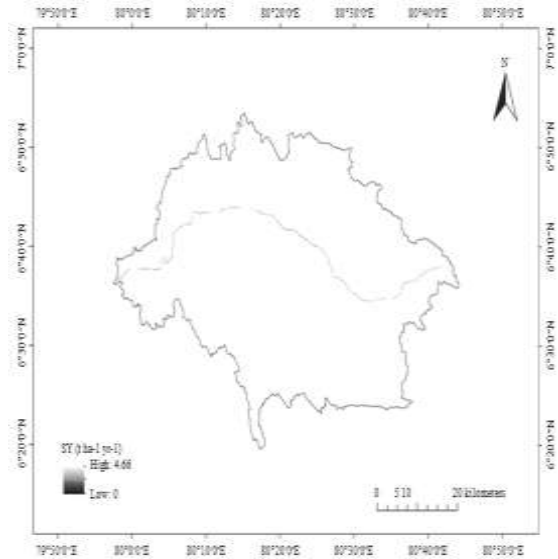


FIGURE 13: Sediment yield over the main stream of ONG river.

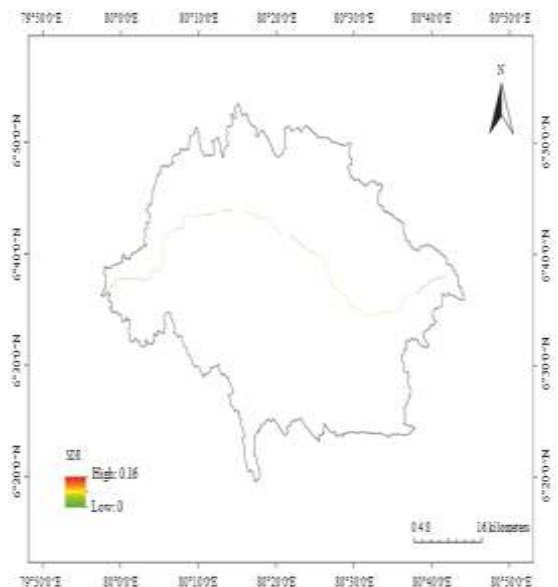


FIGURE 14: Sediment delivery ratio over the main stream of ONG river.

IV. CONCLUSION

The soil erosion severity map at 30 30 m resolution for ONG river river basin based on the RUSLE model integrated with a GIS provided the spatial variation of soil erosion in the ONG river river basin. The entire basin has a low soil erosion severity and the mean annual soil erosion rate of the basin is low which is 0.63 t ha⁻¹ yr⁻¹. Area under moderate to high risk with 5 to over 12 t ha⁻¹ yr⁻¹ erosion severity is about 1.89% of the entire basin. This area is located in Mahanandi

and Sonapurad- ministrative divisions. The mean sediment yield value for the ONG river main stream was 0.29 t ha⁻¹ per annum.

The study highlighted a potential underestimation of the R factor and recommended revisiting the regression equations used to compute rainfall erosivity, presently, generalized to the country, based on a climate zone approach, and also considering the climate predictions for rainfall under different scenarios.

Steep topographic features, poor vegetation cover and poor land management practices, and high rainfall rate may contribute to the high erosion and sediment delivery in the areas where there is high rate of erosion (1.89% of the basin). This identification of the geographic areas critical for effective watershed management helps to target resources to conserve the soil quality and fertility and to meet the increasing erosion potential due to increasing rainfall intensity due to climate change. The best land management practices contributed to the less erosion potential such as enhanced canopy cover observed can be upscaled to other erosive areas of the country after conducting similar erosion analysis using RUSLE.

Data Availability

Rainfall data used are available on the Department of Meteorology, Colombo, and Natural Resources Management Center, Peradeniya, data portals.

Conflicts of Interest

There are no conflicts of interest among authors

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