

# GIS estimation of annual average soil loss rate from Hangar River watershed using RUSLE

Mahmud Mustefa, Fekadu Fufa and Wakjira Takala

## ABSTRACT

Currently, soil erosion is the major environmental problem in the Blue Nile, Hangar watershed in particular. This study aimed to estimate the spatially distributed mean annual soil erosion and map the most vulnerable areas in Hangar watershed using the revised universal soil loss equation. In this model, rainfall erosivity (R-factor), soil erodibility (K-factor), slope steepness and slope length (LS-factor), vegetative cover (C-factor), and conservation practice (P-factor) were considered as the influencing factors. Maps of these factors were generated and integrated in ArcGIS and then the annual average soil erosion rate was determined. The result of the analysis showed that the amount of soil loss from the study area ranges from 1 to 500  $\text{tha}^{-1} \text{yr}^{-1}$  with an average annual soil loss rate of 32  $\text{tha}^{-1} \text{yr}^{-1}$ . Considering contour ploughing with terracing as a fully developed watershed management, the resulting soil loss rate was reduced from 32 to 19.2  $\text{tha}^{-1} \text{yr}^{-1}$ . Hence, applying contour ploughing with terracing effectively reduces the vulnerability of the watershed by 40%. Based on the spatial vulnerability of the watershed, most critical soil erosion areas were situated in the steepest part of the watershed. The result of the study finding is helpful for stakeholders to take appropriate mitigation measures.

**Key words** | annual soil loss, Hangar watershed, RUSLE, soil erosion

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## INTRODUCTION

Soil erosion is among the biggest global environmental problems, resulting in loss of fertile top soil, minimizing the water holding capacity of the soil, nutrients and minerals being carried off by water silting up dams, disruption of lake ecosystems, contamination of drinking water, and increased downstream flooding (Tamene *et al.* 2006). The economic implication of soil erosion is more serious in developing countries because of the capacity to cope with it, and replacing the lost nutrients is difficult. The condition is worst in countries like Ethiopia, whose economy is extremely dependent on agriculture (Angima *et al.* 2003; Shiferaw 2011). The severity of soil erosion in Ethiopia is mainly due to most of the country being steeply sloped and mountainous, and the existence of higher and frequent rainfall amounts with higher

intensities. Likewise, human activities, rapid population growth, poor cultivation system and poor land use practices, deforestation and overgrazing have made a great contribution to soil degradation in Ethiopia (Hurni 1993; Kebede 2012).

The main river in the study area (Hangar River) is one of the major tributaries of Didesa River, which finally joins the Blue Nile River. However, the larger part of this area is degraded due to deforestation for intensive agricultural activities like farm expansion, extraction of fuel, constructional wood, overgrazing, and for other related purposes which are the consequences of population growth and expansion over the area. As a result, agricultural land in the study area is less productive (Hangie 2010). Farmers use different fertilizers on agricultural land in order to

compensate for some of the loss of nutrients in the soil due to soil erosion, and this is costly.

In order to predict and evaluate soil erosion quantitatively, different prediction models have been efficiently developed and employed by different soil scientists in the last few decades. Of these, the revised universal soil loss equation (RUSLE) with remotely sensed data and Geographic Information System (GIS) software was used in this study. Even though this model was developed after the parameters were tested and validated under the diverse soil, climate, and management conditions of the USA, several efforts have been made to calibrate and validate the use of the RUSLE model for other countries, including Ethiopia. Studies include, for instance, those of [Hurni \(1988\)](#) and [Hellden \(1987\)](#) in Ethiopia, [Angima \*et al.\* \(2003\)](#) in Kenya, and [Prasannakumar \*et al.\* \(2012\)](#) in India. In all these studies, RUSLE was publicized and the model showed satisfactory results. The major software which was used for this analysis is GIS software, which was developed in 1960 in Ottawa, Canada, by the Federal Department of Forestry and Rural Development ([Wikipedia 2017](#)).

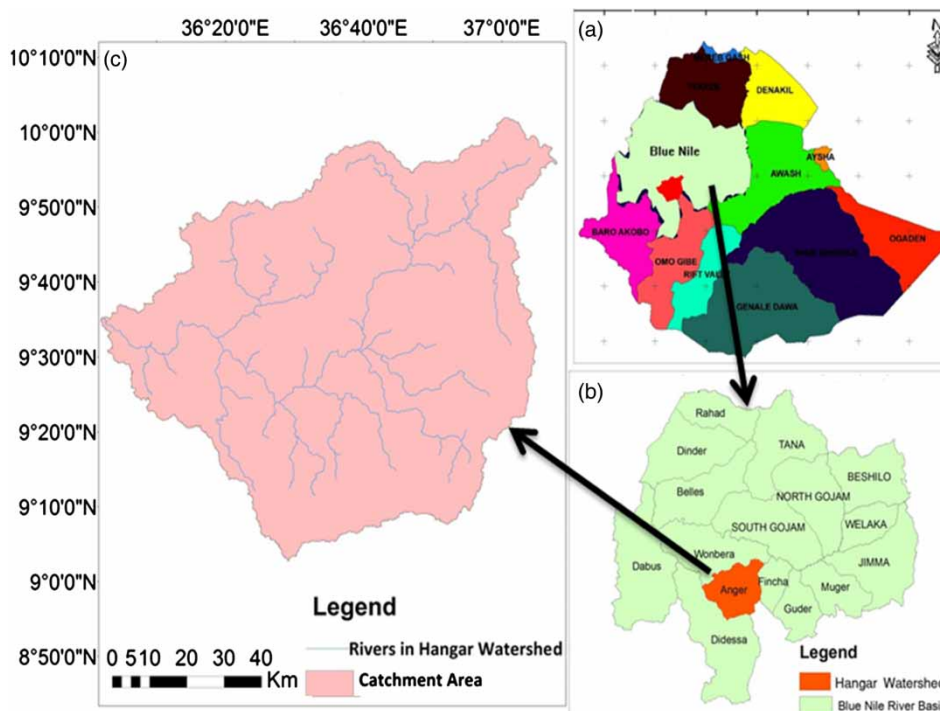
This research contributes to identify the most severe soil erosion areas in the specified catchment. Knowing and

identifying the most prone area is very important in order to take intervention measures in line with the identified vulnerable erosion area. The information gained helps decision-makers by identifying the severely affected area. Therefore, this makes it easy to take immediate action in the identified prone area and to plan an appropriate soil conservation practice (contour ploughing or contour ploughing with terracing) in the whole study area.

## MATERIALS AND METHODOLOGY

### Study area

The study area was the Hangar River watershed ([Figure 1](#)), which is located in the north-west part of Ethiopia. The major part of the catchment is found in East Wollega Zone in the Oromia National Regional state, and with some in Benishangul Gumuz National Regional state. The study area covers a total area of 7,790 km<sup>2</sup>. The geographical location of the study area extends from 36° 02' 21" to 37° 58' 50" E longitude and 9° 01'



**Figure 1** | Location map of the study area: Ethiopian river basins (a), Blue Nile River basin (b), Hangar River watershed (c).

26'' to 9° 59' 50'' N latitude. Hangar River is one of the largest tributaries of Didesa River, which emerges from Horo district and flows in a south-west direction to join with Didesa River.

## Definitions and determination of RUSLE parameters

### Rain fall erosivity (R) factor

R-factor is the quantitative expression of the erosive power of local average annual precipitation and runoff causing soil erosion (Farhan *et al.* 2013) (see Table 1). It is a measure of the erosive force of specific rainfall. The most suitable expression of the erosivity of rainfall is an index based on the kinetic energy of the rain. There are different empirical equations which are used in different countries to calculate the R-factor from the given rainfall; however, for the Ethiopian condition, the R-factor is determined by Equation (1), given by Hurni (1988):

$$R = -0.812 + (0.562 * p) \quad (1)$$

where, p is mean annual precipitation from nearby rain gauge stations (mm).

Interpolation of point data of rainfall was made by GIS 10.3, inverse distance weighted method in order to form a surface of data from the scattered set of point data. From this continuous rainfall data, the R-factor values for each grid cell were calculated in a GIS database raster calculator.

### Soil erodibility (K) factor

K-factor expresses the soil susceptibility to the detachment and transportation of soil particles. It is the ratio of soil

loss from the field's slope length and steepness to that of a standard slope length of 22.1 m and steepness of 9% slope (Morgan 1995). It reflects the combined effect of soil properties, showing the general proneness of a particular soil type to erosion (Tegegne & Biniam 2017). According to Morgan (1995), soils which have different characteristics have different resistance to erosion. Hence, erodibility varies with the physical and bio-chemical properties of soil such as soil texture and structure, aggregate stability, shear strength, infiltration capacity of organic matter, and chemical content. However, soil data in Ethiopia often do not contain detailed information about such soil parameters (Bewket & Teferi 2009). Therefore, the K-factor values for the study area were assigned based on a qualitative index of soil adapted by Hellden (1987) and Hurni *et al.* (2015) based on the color of the soil, which is believed to be a reflection of soil properties. These researchers recommended K-factor values based on easily observable soil color as an indicator for the erodibility of the soil in the highlands of Ethiopia, and they suggested calibration-based values of K-factor based on soil color for Ethiopian soil conditions. Based on the existing soil types in the study area, the respective K-factor values were assigned for each type of soil. Then, the respective K-factor map was generated to consider the effects of soil type on soil erosion as one factor (Table 2).

### Slope length and slope steepness (LS) factor

LS-factor is the ratio of soil loss per unit area from a field slope to that of the standard field slope (22.1 m long and 9% slope) (Wischmeier & Smith 1978). This factor is a combined factor of slope length (L) and slope steepness (S). A

**Table 1** | Rain gauge stations with respective average rainfall and erosivity values

| Station name | Locations |           |              | Average rainfall (mm) | R-factor values (MJ mm ha <sup>-1</sup> .hr <sup>-1</sup> .yr <sup>-1</sup> ) |
|--------------|-----------|-----------|--------------|-----------------------|---|
|              | Lat. (N)  | Long. (E) | Altitude (m) |                       |   |
| Hanger Gute  | 9.5645    | 36.6317   | 1,390        | 1,604                 | 901   |
| Kiremu       | 9.9586    | 36.8605   | 2,144        | 1,892                 | 1,063   |
| Gida Ayana   | 9.8781    | 36.6272   | 2,098        | 1,708                 | 959   |
| Shambu       | 9.5655    | 37.0997   | 2,582        | 1,570                 | 881   |
| Nakamte      | 9.0909    | 36.5454   | 2,133        | 2,130                 | 1,196   |
| Gimbi        | 9.1667    | 35.7833   | 2,031        | 1,675                 | 941   |

**Table 2** | Soil type of the study area with physical colors and corresponding K-factor values

| Soil types        | Soil color     | K-factor (t ha hr ha <sup>-1</sup> MJ <sup>-1</sup> mm <sup>-1</sup> ) |
|-------------------|----------------|--|
| Dystric Leptosols | Gray           | 0.35   |
| Eutric Leptosols  | Gray to yellow | 0.35   |
| Eutric Vertisols  | Black          | 0.15   |
| Haplic Acrisols   | Yellow         | 0.3  |
| Haplic Alisols    | Brown          | 0.2  |
| Haplic Arenosols  | Gray           | 0.35   |
| Haplic Nitisols   | Red            | 0.25   |
| Rhodic Nitisols   | Red            | 0.25   |

slope length is the distance from the point of origin of overland flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel. Slope steepness is the gradient from point of origin of flow to the point where either the slope decreases enough that deposition begins or runoff water enters a well-defined channel (Wischmeier & Smith 1978).

A flow direction and flow accumulation map were processed and generated from digital elevation model data after fill operation in Arc Hydro tools of the GIS extension to use as an input for the calculation of the LS-factor. In order to generate the map of the LS-factor, Equation (2) was used in the raster calculator of the GIS database. The equation was developed by Wischmeier & Smith (1978).

$$LS = Power \left[ (FA) * \frac{Resolution}{22.1} \right], 0.6 \left[ \frac{\sin(slope) * 0.01475}{0.09, 1.3} \right] \quad (2)$$

where, *FA* (flow accumulation) is the raster-based total of the accumulated flow to each cell, and (Resolution) is cell size or length and width of the pixel size.

### Vegetative cover (C) factor

The land use and land cover (LU and LC) factor expresses the effect of land use and land cover on soil erosion rate (Renard et al. 1997) (Table 3). It is the ratio of soil loss from a field with specific vegetation cover to the corresponding soil loss from continuous fallow with the same rainfall (Wischmeier & Smith 1978).

**Table 3** | LU and LC types and corresponding C-factor values (Bewket & Teferi 2009; Gelagay 2016)

| Land use land cover types | Area (km <sup>2</sup> ) | Percent area coverage | C-factor values |
|---------------------------|-------------------------|-----------------------|-----------------|
| Grazing land              | 65                      | 0.83                  | 0.05            |
| Bare soil                 | 2                       | 0.03                  | 0.6             |
| Agricultural lands        | 4,632                   | 59.5                  | 0.15            |
| Dense forest              | 348                     | 4.5                   | 0.01            |
| Grass land                | 928                     | 12.0                  | 0.01            |
| Open forest               | 1,092                   | 14.0                  | 0.05            |
| Shrub land                | 717                     | 9.2                   | 0.014           |
| Water body                | 6                       | 0.08                  | 0               |

As much as is available of current LU and LC data, which show the current condition of the study area, are needed to determine this factor. Therefore, for this study, the land use and land cover classification map of 2013 was used. It shows detailed classification of LU and LC in the specified year for the study area. Using the classified map, the corresponding recommended C-factor values for different LU and LC classes were assigned. These values were collected from previous studies and assigned for corresponding LU and LC types. Finally, the C-factor map was generated by the GIS database.

### Soil and water conservation practice (P) factor

In the RUSLE model, the P-factor is considered as the ratio of soil loss with a specific conservation practice to the corresponding loss with up and down slope cultivation (zero management), which has a value of one (Wischmeier & Smith 1978). Therefore, the effect of this factor depends upon the actual agricultural activities undertaken in the given area. Even though the effectiveness varies for different types of soil conservation practice, it reduces the amount and rate of runoff, increases infiltration and subsequently reduces the amount of erosion. Related to this, different researchers (Adimassu et al. 2014; Saeid et al. 2016; Zhang et al. 2016) have attempted to evaluate the most common physical management practices such as only contouring and contouring with terracing at the same time.

Soil conservation and management practice information practiced in the study area were collected during the time of the site visit. Based on the information gathered at that time, contour ploughing was found to be the common soil and

water conservation measure. Therefore, for this research, the pre-fixed P-factor values suggested by Deore (2005), for different watershed management and corresponding slope, were used (Table 4).

This study aimed to consider two types of watershed management and to compare the results of these conditions. This was done and showed variation of soil loss rate between the current condition of watershed management; that is, considering only contour ploughing as the dominant soil conservation practice, and the suggested watershed management (contour ploughing with terracing). The values of the P-factor for the current condition and for the suggested management condition with the respective classified slope in percent are given in Table 4.

Therefore, to estimate the annual rate of soil erosion, the data layers or maps of R, K, LS, C, and P factors of the RUSLE model, as discussed above, were integrated through the multiplication algorithm within the raster calculator in a GIS database. According to Wischmeier & Smith (1978) and Renard et al. (1997), the empirical equation of the RUSLE model is given by Equation (3):

$$A = R * K * LS * C * P \quad (3)$$

where,  $A$  = computed annual soil loss per unit area in [ $t \text{ ha}^{-1} \text{ yr}^{-1}$ ],  $R$  = rainfall erosivity factor in [ $\text{MJ mm ha}^{-1} \text{ hr}^{-1} \text{ yr}^{-1}$ ],  $K$  = soil erodibility factor in [ $t \text{ ha hr ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ ],  $LS$  = slope length and steepness factor (dimensionless),  $C$  = land use and land cover factor (dimensionless), and  $P$  = support practice (dimensionless).

**Table 4** | P-factor values for commonly practiced soil conservation activities

| Slope in percent | P-factor values     |                               |
|------------------|---------------------|-------------------------------|
|                  | For only contouring | For contouring with terracing |
| <2               | 0.4                 | 0.1                           |
| 2–5              | 0.5                 | 0.11                          |
| 5–8              | 0.55                | 0.11                          |
| 8–12             | 0.6                 | 0.12                          |
| 12–16            | 0.7                 | 0.14                          |
| 16–20            | 0.8                 | 0.16                          |
| >20              | 0.9                 | 0.18                          |

The RUSLE model analysis in the GIS database from the data source to the result is given in Figure 2. It shows the detailed process of the methodology.

## RESULTS AND DISCUSSIONS

### RUSLE model parameters

#### R-factor

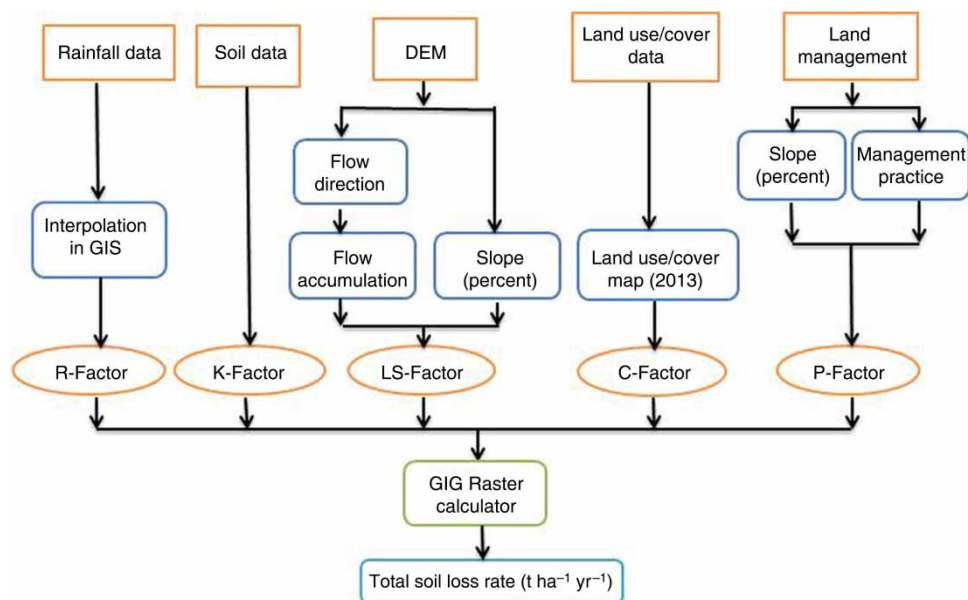
In the study area, the long-term mean annual rainfall amount varied between 1,570 and 2,130 mm. The rainfall erosivity values estimated from mean annual rainfall of the selected rainfall stations varied from 882  $\text{MJ mm ha}^{-1} \text{ hr}^{-1} \text{ yr}^{-1}$  at Shambu to 1,196  $\text{MJ mm ha}^{-1} \text{ hr}^{-1} \text{ yr}^{-1}$  at Nakamte. The calculated values show that, as the mean annual rainfall increases, the rainfall erosivity also increases. Following this, the study area faces highly erosive rainfall in the southern part of the study area around Nakamte and gradually a decrease towards the central and eastern parts of the study area around Hanger Gute and Shambu, respectively.

#### K-factor

From the digital soil map of the study area, eight different soil types with different characteristics were identified. The erodibility characteristics of the existing soils in the study area varied with the range of K-factor values of 0.15 to 0.35  $t \text{ ha hr ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ . As the K-factor values approach 1, it indicates the soil has higher susceptibility to erosion and as the K-factor values are close to 0, it indicates the soil has good erosion resistance capacity. Hence, Dystric Leptosols, Eutric Leptosols, and Haplic Arenosols which account for about 12.8, 2.3, and 0.004% of the total area, respectively, have the highest K-factor values of 0.35. Eutric Vertisols, which cover a smaller area (about 0.1%) have the lowest K-factor values of 0.15.

Generally, more than 60% of the total area of the catchment was covered with soils that have lower to moderate K-factor values of 0.2 and 0.3  $t \text{ ha hr ha}^{-1} \text{ MJ}^{-1} \text{ mm}^{-1}$ . Such soil types were found mostly in the central and south-western parts of the catchment with some coverage in the northern part as well. Therefore, in terms of soil erodibility condition,





**Figure 2** | Conceptual frameworks to determine soil loss using RUSLE in Arc GIS.

the catchment is characterized as moderately vulnerable to erosion.

### LS-factor

The values of LS-factor in the study area vary between 0 (flatter and lower part) and 61 (steeper and upper part). The higher LS-factor values of 10 to 61 were mostly observed in the mountainous and hilly region of the study area and along the sides (banks) of the rivers. This is because, as the slope gradient increases, the value of the LS-factor also increases. Therefore, in the area where smaller LS-factor values existed, the expected soil erosion due to this factor would be less and in the area where larger LS-factor values existed, the expected soil erosion would be more. Most of the central and south-western parts of the study area show a lower LS-factor value of 0 to 0.05.

### C-factor

Over the study area, dense forest and grassland, which have smaller values of C-factor (0.01), collectively cover an area of only 16.5% and are found around the border of the catchment that has higher altitude. About 59.5% of the study area is agricultural land that is exposed to direct rainfall during the time of crop preparation. Soil erosion from this area

was expected to be high because the soil is exposed to the first rainfall events without any cover. In this area, the larger value of C-factor (0.15) was assigned next to a small area coverage (0.03%) of bare soil in the north-western part, which has a C-factor value of 0.6. Consequently, the contribution of this factor for erosion in the central and south-western part is high and the contribution at the western and highland areas of the watershed is less.

### P-factor

Depending on the current land management practice employed in the study area, the value of P-factor ranges from 0.4 to 0.9. Based on the result, the central part of the study area is characterized by lower P-factor values and the rest of the study area shows higher P-factor values. Because the P-factor values are highly influenced by slope steepness conditions, the upper part of the study area is characterized with higher values of P-factor. Considering the implementation of a fully developed watershed management practice such as contouring with terracing, the P-factor values range from 0.1 to 0.18. In this condition also, the lower values of P-factor were concentrated in the central part of the study area and the higher values of P-factor were for the upper and outer parts of the study area.

### Estimated average annual soil loss for existing condition

The pixel-based modeling results show that the spatial distribution of the annual soil loss rate varied from  $1 \text{ t ha}^{-1} \text{ yr}^{-1}$  in the lowland and flat area to  $500 \text{ t ha}^{-1} \text{ yr}^{-1}$  in the degraded sloped area, with an average annual soil loss rate of  $32 \text{ t ha}^{-1} \text{ yr}^{-1}$  for the entire study area (Figure 3). On an annual basis, the total soil loss of the watershed was found to be 24.93 million tons of sediment from  $7,790 \text{ km}^2$  of land.

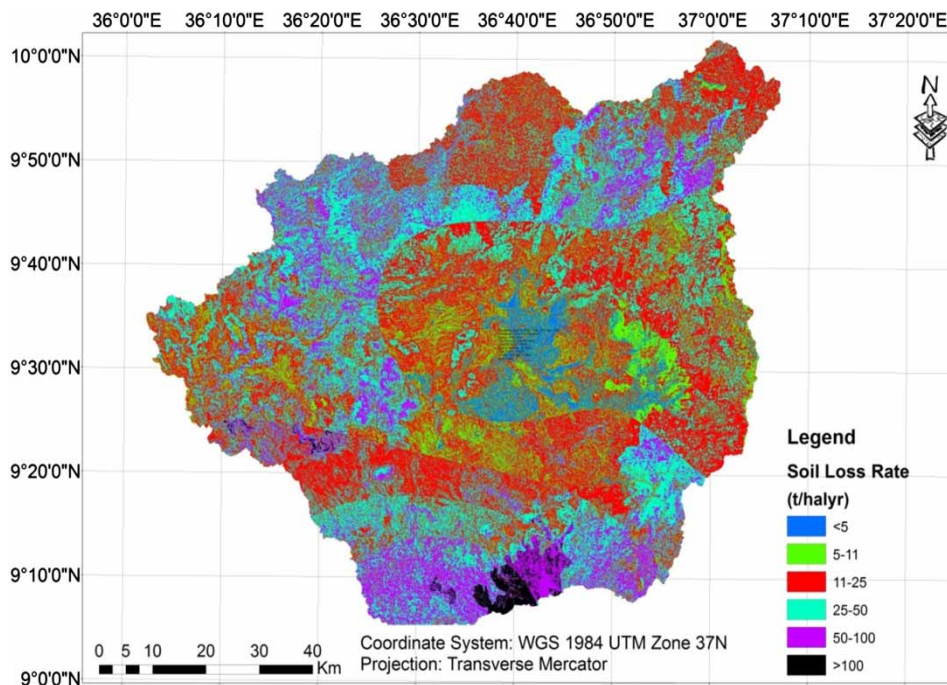
The results showed that the catchment is experiencing quite large spatial variations of soil loss due to the significant differences in topographical condition, land use land cover variation, and higher rainfall variation. Accordingly, the watershed was classified into six severity classes to identify the area most prone to erosion, moderately affected area, and list affected areas and other respective trends of erosion conditions. In terms of exposure to the risk of erosion, about 15.8% of the watershed was characterized by low to moderate soil erosion problems, which ranged from 1 to  $11 \text{ t ha}^{-1} \text{ yr}^{-1}$ , and such areas can be considered as having a tolerable soil erosion risk. The remaining percentage was categorized as high, very high, severe, and very severe soil

erosion risk areas of 39.3, 31.8, 12.1, and 1% of the study area, respectively.

According to the FAO (1985) and Renard *et al.* (1997), soil loss tolerance refers to the maximum soil loss that can occur from a given land without leading to degradation of the soil, and this is estimated to be  $5\text{--}11 \text{ t ha}^{-1} \text{ yr}^{-1}$ . In line with this, the central parts of the study area, which covered about 15.8% of the total area, could be considered as low soil erosion risk areas.

Based on the results found, about 84.2% ( $>4,480 \text{ km}^2$ ) of the study area was identified to be greatly suffering soil erosion. The severity of erosion ranges from high ( $12\text{--}25 \text{ t ha}^{-1} \text{ yr}^{-1}$ ), very high ( $25\text{--}50 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) to severe soil erosion class ( $50\text{--}100 \text{ t ha}^{-1} \text{ yr}^{-1}$ ) (Table 5). About 1% of the total area ( $77.9 \text{ ha}$ ) was exposed to very severe soil erosion risk ( $>100 \text{ t ha}^{-1} \text{ yr}^{-1}$ ). This part of the area is found mostly at the south corner of the catchment and some parts in the western part as well as the eastern part of the catchment.

The estimated soil loss rate and the spatial patterns are generally realistic, compared to previous studies on some Ethiopian basins. For instance, the soil loss rate estimated



**Figure 3** | Map of total soil loss rate for current condition.

**Table 5** | Soil erosion severity class and corresponding percent coverage area

| Soil loss rate (t ha <sup>-1</sup> yr <sup>-1</sup> ) | Current soil erosion status of the study area |                   | Severity class |
|---|---|-------------------|----------------|
|   | Area (km <sup>2</sup> )                       | Area coverage (%) |                |
| <5  | 315   | 4.0               | Low            |
| 5–11  | 915   | 11.8              | Moderate       |
| 11–25   | 3,063   | 39.3              | High           |
| 25–50   | 2,475   | 31.8              | Very high      |
| 50–100  | 941   | 12.1              | Severe         |
| >100  | 80  | 1.0               | Very severe    |
| Total   | 7,790   | 100               |                |

by Hurni (1988) for Ethiopian highlands ranges from 0.0 to 300 t ha<sup>-1</sup> yr<sup>-1</sup>. Temesgen *et al.* (2017) revealed that the soil loss rate ranges from 0 to 237 t ha<sup>-1</sup> yr<sup>-1</sup> in Geleda watershed in the Blue Nile River basin. Another related study, conducted by Adugna & Cerda (2015), showed soil loss variations ranging from 4.5 t ha<sup>-1</sup> yr<sup>-1</sup> for forest to 65.9 t ha<sup>-1</sup> yr<sup>-1</sup> for cropland in a neighboring catchment of the study area, using the same model.

In line with this, the annual average soil loss rate of the study watershed (32 t ha<sup>-1</sup> yr<sup>-1</sup>) is comparable with similar findings reported in Tegegne & Biniam (2017), which was done for Koga watershed with an average soil loss of 42 t ha<sup>-1</sup> yr<sup>-1</sup>, and Haregeweyn *et al.* (2017) for the whole Upper Blue Nile basin, who reported an average of 27.5 t ha<sup>-1</sup> yr<sup>-1</sup> with the same prediction model. The variation in the results of this study with that from the whole Blue Nile River basin is due to specific data usage for this catchment and consideration of the current LU and LC condition.

The scope of this study was the estimation of existing annual average soil loss rate at the watershed level, identification of the most vulnerable region in the watershed, and evaluation of the effects of fully developed terracing with contour ploughing on soil erosion rate. This allows the decision-maker to decide which type of management practice should be applied based on the simplicity of application of the management practice and its implementation cost.

What makes this work different from the previous studies is that the rainfall data used were taken from more than five stations in/near the watershed, allowing the results to be nearly accurate. The study also considered the most

recent land use and land cover map as an input that shows the current condition of the soil erosion problem.

## Impacts of proposed intervention measures

In this study, two cases of P-factor values were tested to check the effects of watershed management on soil erosion rate: the first case, when P-factor values were taken for the existing condition of the study area, and the second case, if there was an implementation of effective terracing with contour ploughing of farm lands in the study area. In this case, the result shows that the annual average soil loss rate was reduced from 32 to 19.2 t ha<sup>-1</sup> yr<sup>-1</sup>, which means it reduced the annual soil loss rate by 40%. This was checked by taking the recommended values of P-factor for both contour ploughing with terracing and considering only contour ploughing separately, and comparing the result of the two conditions. Due to implementation of these physical interventions of soil conservation measures like contour ploughing with terracing, the area, with a soil erosion rate in the range of the maximum limit of soil loss tolerance of 11 t ha<sup>-1</sup> yr<sup>-1</sup>, increases from 15.80 to 41.81% of the total area. On the other hand, the severely affected area, which shows a soil loss rate of >50 t ha<sup>-1</sup> yr<sup>-1</sup> would be reduced from 13.1 to 5.61% of the total area, which indicates a reduction of the severely affected area and an increment in the least affected area by soil erosion.

**Table 6** | Comparisons of soil loss for current management and imagined management practice

| Soil loss rate (t ha <sup>-1</sup> yr <sup>-1</sup> ) | Current soil erosion status of the study area |                   | Soil erosion status considering contour ploughing and terracing |                   | Severity class |
|---|---|-------------------|---|-------------------|----------------|
|   | Area (km <sup>2</sup> )                       | Area coverage (%) | Area (km <sup>2</sup> )   | Area coverage (%) |                |
| <5  | 315   | 4.0               | 948   | 12.17             | Low            |
| 5–11  | 915   | 11.8              | 2,309   | 29.64             | Moderate       |
| 11–25   | 3,063   | 39.3              | 2,949   | 37.86             | High           |
| 25–50   | 2,475   | 31.8              | 1,133   | 14.62             | Very high      |
| 50–100  | 941   | 12.1              | 398   | 5.11              | Severe         |
| >100  | 80  | 1.0               | 47  | 0.59              | Very severe    |
| Total   | 7,790   | 100%              | 7,790   | 100%              |                |



**Table 7** | Vulnerability of soil erosion at district level

| Districts      | Soil loss rate ( $t\ ha^{-1}\ yr^{-1}$ ) |         |                |
|----------------|--|---------|----------------|
|                | Minimum                                  | Maximum | Annual average |
| Limu           | 4  | 320     | 39.2           |
| Belew Jiganfoy | 4  | 160     | 31.5           |
| Sasiga         | 2  | 320     | 36.4           |
| Wayu           | 2  | 500     | 47.2           |
| Sire           | 2  | 250     | 27.7           |
| Seyo           | 2  | 100     | 23.8           |
| Horo           | 1  | 100     | 21.2           |
| Dengoro        | 2  | 160     | 24.3           |
| Jarte          | 2  | 300     | 30.3           |
| Yaso           | 6  | 200     | 27.7           |
| Gida Ayana     | 2  | 100     | 29.5           |

Generally, the results of this section show that the implementation of integrated watershed managements, specifically, terracing with contour ploughing, significantly reduces the vulnerability of soil erosion in the study area. The comparison of these two conditions (current existing condition and imagined contour ploughing and terracing) is presented below (Table 6).

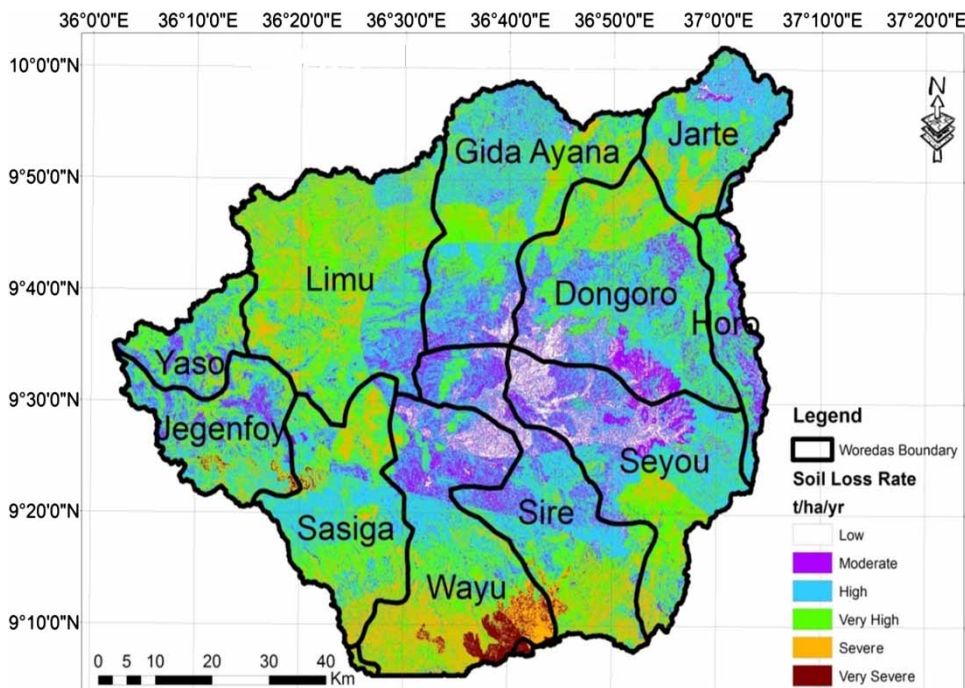
### Prioritization of vulnerable soil erosion area

The minimum, maximum, and average annual soil loss rate for each of the districts in the study area were analyzed and presented in Table 7. Figure 4 shows the boundary of the districts and the color coding severity class of soil erosion for each district in the Hangar River watershed.

Based on the result of the district level annual soil loss rate, Wayu district was identified to be a severe soil erosion-prone area. In this district, the rate of erosion was found to be a minimum of 2 and maximum of  $500\ t\ ha^{-1}\ yr^{-1}$  with an annual average of  $47.2\ t\ ha^{-1}\ yr^{-1}$ , which is the maximum rate of the entire study area. Seyo and Horo districts show relatively a lesser vulnerability with an annual average soil loss of 23.8 and  $21.2\ t\ ha^{-1}\ yr^{-1}$ , respectively. One of the major reasons for the variation in the severity of the soil erosion rates was the variation in the existing physical condition of the areas.

### CONCLUSIONS

This study attempted to present a comprehensive overview of the status of erosion in the study area and its distribution

**Figure 4** | Boundaries of districts in the study area and severity class map.

in the watershed under present watershed conditions and with proposed watershed management practices. The finding of this study reveals that the study area is currently experiencing severe soil erosion by water. Implementing conservation practices such as contour ploughing with terracing could effectively reduce the annual average soil loss from 32 to 19.8 t ha<sup>-1</sup> yr<sup>-1</sup>. Due to the imagined intervention measure of soil erosion, the area that was in the range of maximum soil loss tolerance could be improved from 15.8 to 41.81% of the total area. In the steep slope areas of the watershed, especially in Wayu district, the rate of soil erosion extends up to 500 t ha<sup>-1</sup> yr<sup>-1</sup> with the annual average soil loss of 47.2 t ha<sup>-1</sup> yr<sup>-1</sup>. Central and eastern parts of the study area, including Horo and Seyo districts, have a lesser rate of erosion of 21.2 and 23.8 t ha<sup>-1</sup> yr<sup>-1</sup>, respectively, which demonstrates a lesser vulnerability to erosion.

Based on the findings of this study, the following points are advanced as recommendations:

- Intensive sustainable soil and water conservation practices should be carried out by taking each stream order and agricultural field as a management unit, especially in the upper part where most critical sediment source areas are situated.
- Areas characterized by high to very severe soil loss should be given special attention before irreversible land degradation occurs.
- Watershed management for moderate soil erosion areas should also be provided in order to protect them from further degradation and erosion.
- Local communities should adopt immediate soil conservation measures for their cultivated lands by applying terracing with contour ploughing, and contour ploughing during crop preparation as a soil conservation measure.
- Local stakeholders and decision-makers should implement both long- and short-term timely updated natural resource management systems.

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