Research article

Evaluation of Soil Erosion Risk in the City of Cobija, Bolivian Amazonia Using RUSLE and GIS

JUAN UEGO PEREZ
Graduate School of Agro-Environmental Science, Tokyo University of Agriculture, Japan
E-mail: uego.juan@gmail.com

MACHITO MIHARA*
Faculty of Regional Environment Science, Tokyo University of Agriculture, Japan
E-mail: m-mihara@nodai.ac.jp

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Abstract In recent years, deforestation has increased remarkably in the region of Bolivian Amazonia. So, research interests have been focused on how the deforestation affects the soil erosion risk. Accordingly, this study was conducted in the city of Cobija, Bolivian Amazonia to evaluate the erosion risk employing the Revised Universal Soil Loss Equation (RUSLE). For calculating the rainfall-runoff erosivity factor (R), an emperical model based on measured annual precipitation was applied. To calculate the soil erodibility factor (K), the experimental models based on soil properties (composition of sand–silt–clay percentages, organic matter, structure, and permeability of the soil profile) was employed. Also, to generate the topographic factor (LS), a digital elevation model (DEM) image was applied. In addition, the cover management factor (C) of each land use and the support practice factor (P) for different conservation practices were based on the outcomes from former studies. The results of RUSLE analysis, the annual soil loss per unit area (A) was in the range of of the medium soil loss from 5 < 7 t/ha/year. With accelerating soil erosion, soil organic matters as well as soil aggregate have been lost, and soil loss would be severer gradually. So, effective soil conservation measures should be implemented for minimizing the loss of soil organic matters as well as soil aggregate.

Keywords RUSLE, soil loss, amazonia, erosion

INTRODUCTION

Soil erosion is one of the main global threats to water and food security (Amundson et al., 2015). Soil provisioning, regulatory, and supporting services are essential for sustaining water, food, and energy security nexus (Keesstra et al., 2016). In recent years, Bolivia has been recognized as one of the countries that has the highest rate of deforestation in the world, the city of Cobija is located in the Amazonia, has experienced annually expansion of the city simultaneously with the expansion of the agricultural frontier and generated deforestation in the areas. The adverse influences of widespread soil erosion on soil degradation, agricultural production, water quality, hydrological systems, and environment, have long been recognized as severe problems for human sustainability. However, estimation of soil erosion loss is often difficult due to the complex interplay of many factors, including climate, land cover, soil, topography, and human activities. This paper describes research that seeks to evaluate the erosion risk in the city of Cobija - Pando, Bolivian Amazonia and apply the Revised Universal Soil Loss Equation (RUSLE) for estimate the soil loss.

OBJECTIVE

The objective is to apply the Revised Universal Soil Loss Equation (RUSLE), and geographic information system (GIS) to determine the risk of erosion and the soil loss in the city of Cobija Bolivian Amazonia area. Cobija is a Bolivian City, capital of the Department of Pando and the

Province of Nicolás Suárez. Cobija has experienced high deforestation rates during the past two decades (Bolivian Institute, 2015) following the national strategy of regional initiated by the Bolivia Government in 2015 played a major role in this process. The local farmers transformed the forested landscape slowly into urban city the climate in this study area is classified as equatorial hot and humid with tropical transition. A well-defined dry season lasts from June to August, and the annual average precipitation is 2016 mm (Mayoralty of Cobija, 2020). The surface of the research area is 411 km^2, the annual average temperature is 32˚C - 22˚C, and monthly averages for air moisture range from 80 to 85 percent. The terrain is undulating, ranging from 100 to 120 m above sea-level.

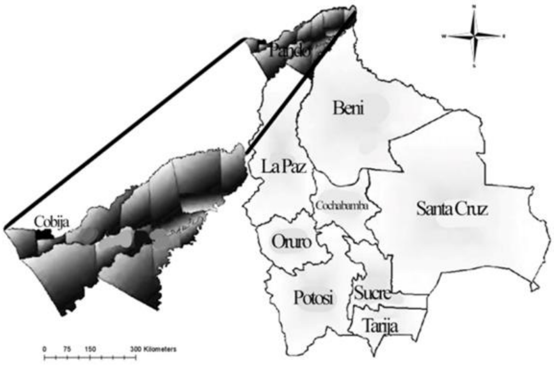

Fig. 1 Location of the study area in the city of Cobija, Bolivian Amazonia

METHODOLOGY

Brief Description of RUSLE

The RUSLE represents how climate, soil, topography, and land use affect rill and interrill soil erosion caused by raindrop impact and surface runoff (Renard et al., 1997). It has been extensively used to estimate soil erosion loss, to assess soil erosion risk, and to guide development and conservation plans in order to control erosion under different land-cover conditions, such as croplands, rangelands, and disturbed forest lands (Millward and Mersey, 1999; Boggs et al., 2001; Mati and Veihe, 2001; Angima et al., 2003). The RUSLE is expressed by Equation 1.

$$A = R \times K \times L \times S \times C \times P \quad \text{Eq. 1}$$

Where A is the average annual soil loss in tons per hectare; R is the rainfall-runoff erosivity factor; K is the soil erodibility factor; L is the slope length factor; S is the slope steepness factor; C is the cover management factor; and P is the support practice factor. Table 1 summarized the calculating methods for estimating each factor.

Table 1 Summary of calculating methods for applying RUSLE in this study

	Methods	References
R	Using average monthly precipitation and average annual precipitation Using a regression model based on measured annual precipitation	Renard and Fremund, 1994
K	Using the experimental models based on soil properties (composition of sand–silt–clay percentages, organic matter, structure, and permeability of the soil profile)	Wischmeier and Smith, 1978
LS	Estimated from actual field measurements of length and steepness Calculated from DEM data with various approaches	Hickey, 2000; Van Remortel et al., 2001
C	Land use comparison table	Silva et al., 2007
P	Table of P values for different conservation practices	Bertoni and Lombardi Neto, 1985

RESULTS AND DISCUSSION

Rainfall and Runoff Erosivity R Factor

The rainfall runoff erosivity was calculated from Equation 2 as shown below.

$$EI_{mont\ hly} = 89.823\left(\frac{Pm^2}{Pa}\right)^{0.759} \qquad \text{Eq. 2}$$

Where EI is the monthly mean of the erosion index for the month considering (mm/ha), Pm is the average precipitation of the month considering (mm), Pa is the average annual precipitation (mm) at the Pelvimetric Station located in Cobija. Based on monthly results, the rainfall runoff erosivity was calculated annually. Using the equation, the annual average of rainfall runoff erosivity was determined with the data of the last 5 years as shown in Table 2, the average R factor determined was 8929.2 MJ mm/h ha per year and it was considered the EI value was in the highest class describing the potential of intense erosion.

Table 2 Annual rainfall and rainfall runoff erosivity

Year	Annual Rainfall Pa (mm)	Annual EI (Mj.mm/h ha)
2017	1903.1	9054.6
2018	1687.5	7955.3
2019	2002.2	9628.6
2020	1385.6	7867.2
2021	1950.3	10140.3
Average	1785.7	8929.2

Soil Erodibility K Factor

Soil erodibility K factor was calculated using inherent soil properties following the procedure for tropical soils (El-Swaify and Dangler, 1976), which uses the percent-modified silt (0.002 - 0.1 mm), percent modified sand (0.1 - 2 mm), base saturation, percent unstable aggregates, and percent very fine sand. The calculation for measuring soil erodibility were indicated in Equation 3.

$$K = -0.03970 + 0.00311X_1 + 0.00043X_2 + 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \qquad \text{Eq. 3}$$

Where X_1 is the percent unstable aggregates <0.250 mm, X_2 is the product of the percent of silt (0.002-0.01 mm) and sand (0.1-2 mm) present in the sample, X_3 is the percent base saturation of the soil, X_4 is the percent silt present (0.002-0.050 mm), and X_5 is the percent sand in the soil (0.1-2 mm).

As shown in Table 3, soil erodibility K factor for the soil was calculated as 0.0150Mg h MJ^{-1} mm^{-1} (0.1139 t acre h [hundreds of acre ft-tonf in.] $^{-1}$).

Table 3 Soil properties for use in calculating the RUSLE k – Factor for the Cobija soil

Fraction	Percentage
Clay (<0.002 mm)	53
Silt (0.002–0.05 mm)	34
Sand (0.05–2 mm)	2
Sand (0.1–2 mm)	8
Base saturation	55
Unstable aggregates	3
Permeability class	2

Slope Length and Steepness LS Factor

The length and steepness LS factor represents the loss of soil per unit area on any slope, corresponding to a unit plot with 22 m long and 9% slope as shown in Equation 4.

$$LS = \left(\frac{L}{22.1}\right)^{m} (0.065 + 0.0454.S + 0.0065S^{2}) \qquad \text{Eq. 4}$$

Where m=0.2 for S<1%; m=0.3 for 1%≤S≤3%; m=0.4 for 3%<S<5and m=0.5 for S ≥5%; S average slope of the land (%), and L is the slope length (m).

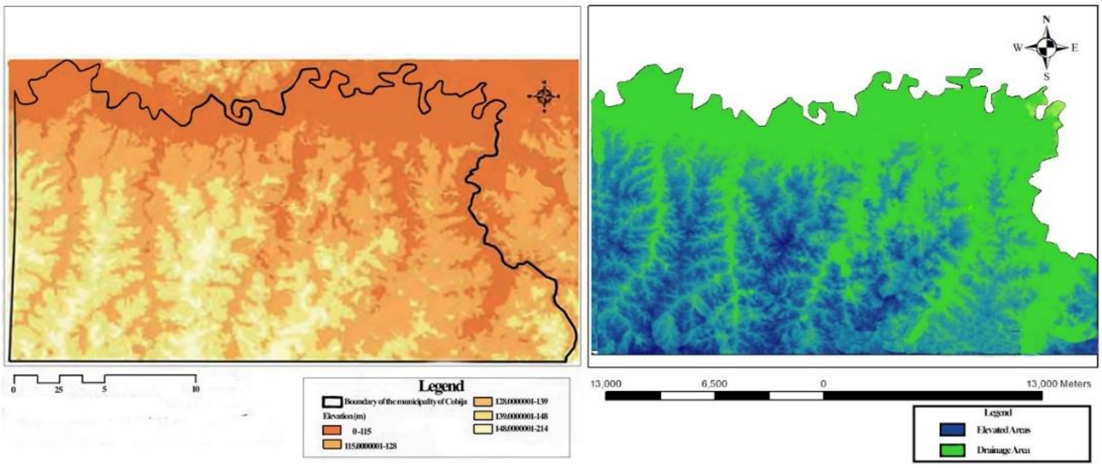

Fig. 2 Digital elevation map (DEM) in Cobija area

For determinate the slope and steepness LS factor, the average slope in the drainage basin area and the average length of the slope are necessary. The result obtained for the slope and steepness LS factor was 0.5987 (Fig. 2).

Cover Management C Factor

The cover management C factor was determined from analyzed land use in the city of Cobija. The main outcomes from the observation of land use changes and the cover management C factor indicated that 66.9% deforested for timber resources, with land use change such as 20.7% for pastures to raise cattle and 12.4% for agriculture as shown in Fig. 3.

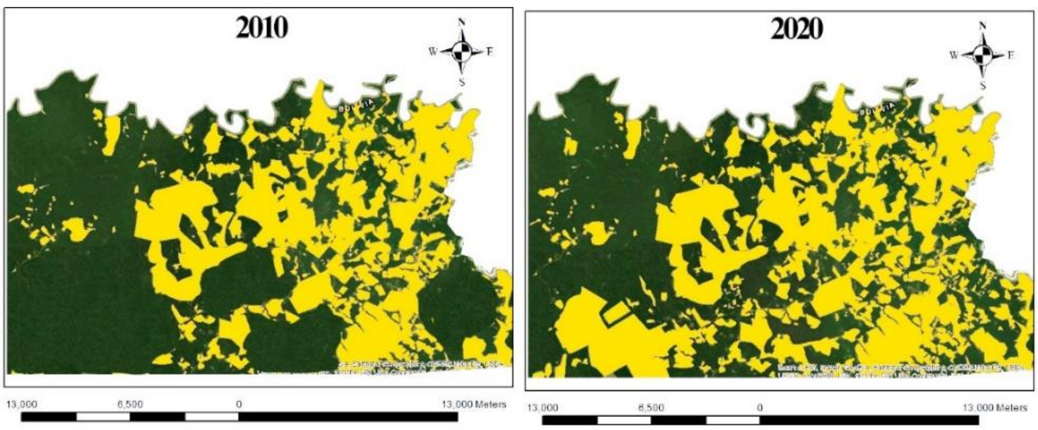

Fig. 3 Land use changes from 2010 to 2020 in the city of Cobija

Although the vegetal cover acts as a shield against the impact of the raindrop on the soil surface, this cover was lost and left the soil exposed to the impact of the raindrop. These trends increased the risk of erosion due to advancing deforestation. The observed result of the cover management C factor in the city of Cobija was 0.368.

Support Practice P Factor

For choosing the support practice P factor of conservation in the city of Cobija, the observations of satellite images and site investigation were conducted. As the results of these observations, the support practice P factor of conservation at 0.2 was decided averagely, as the soil surface was covered with permanent vegetation (Bertoni and Lombardi, 1985).

Average Annual Soil Loss in the City of Cobija

These factors were integrated into RUSLE model (Eq. 1) for obtaining the annual soil loss per unit area (A). The changes in annual soil loss in the city of Cobija from 2017 to 2021 were summarized in Table 4. The annual average was 5.902 t/ha year that was in the range of the medium soil loss from 5 < 7 t/ha/year according to Silva (2008).

As the soil surface was covered with permanent vegetation after the deforestation, the annual soil loss per unit area (A) was in the range of the medium soil loss from 5 < 7 t/ha/year. However, with accelerating soil erosion, soil organic matters as well as soil aggregate would be lost, and soil loss would be severer gradually. So, effective soil conservation measures should be implemented for minimizing the loss of soil organic matters as well as soil aggregate.

Table 4 Changes in annual soil loss in the city of Cobija from 2017 to 2021

Year	A (t/ha year)
2017	5.984
2018	5.258
2019	6.364
2020	5.200
2021	6.702
Total	5.902

CONCLUSION

Soil erosion by water is a serious global problem, especially in Amazonia. This study was conducted to evaluate soil losses by precipitation and runoff in the city of Cobija, Bolivian Amazonia with the RUSLE model. Although the topography showed relatively flat relief, the soil type has medium erodibility and the support practice of conservation was maintaining strands of permanent vegetation. So, the annual soil loss per unit area (A) was in the range of the medium soil loss from 5 < 7 t/ha/year.

In the city of Cobija, Bolivian Amazonia, intense deforestation has been advanced. With accelerating soil erosion, soil organic matters as well as soil aggregate have been lost, and soil loss would be severer gradually. So, effective soil conservation measures should be implemented for minimizing the loss of soil organic matters as well as soil aggregate.

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