Research article

Evaluation of Soil Erosion Risk from Weathering Effects on K Factor of RUSLE in Cobija, Bolivian Amazonia

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Abstract Soil erosion by water is a serious problem in the Amazonia region of Bolivia. In the area of Cobija, Bolivia, around 8 Mg ha^{-1} of Amazon soil is lost to the nearby watershed annually. The physical weathering of soils under natural conditions is one of the key processes for understanding structural changes in the soil. The soil erodibility (*K*) factor in RUSLE represents the susceptibility of soils to erosion, which can be measured with the standard unit plot experiment or through calculation with particle sizes and organic matter. Soil weathering affects soil particle distribution that is closely related to the *K* factor. Therefore, the purpose of this research is to evaluate and determine the change in the distribution of soil particles as well as the *K* value. The experiment was conducted in a laboratory setting. A total of 120 cans containing 1 g of soil each were used and treated with different periods and volumes of water added to represent weathering. The simulated weather conditions were set in line with conditions observed in Bolivian Amazonia. The pipette method was used to determine the distribution of soil particles. The results indicated slight changes in the distribution of the soil particles, reducing the percentage of fine sand and increasing the silt content, which affected the *K* factor as well as the estimate of soil losses based on RUSLE.

Keywords soil erosion, weathering, RUSLE, soil particle, Amazonia, Bolivia

INTRODUCTION

Weathering soils under natural conditions is a pivotal process to quantify sustainability assessments of forestry and land use, as well as to evaluate the rate of soil losses in the field. Accelerated weathering occurs as a consequence of deforestation and the loss of plant cover, which exposes the soil to the direct impact of temperature and wet-drying processes. The impact of raindrops on the soil causes changes in the percentage distribution of soil particles, ultimately altering the values in the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) and influencing the results of soil loss calculations. For this study, a total of 120 containers filled with the soil from the Bolivian Amazon were subjected to weathering conditions identical to the study area, maintaining the same temperature and applying water for various periods. The objective was to determine if the changes observed in the percentage distribution of soil particles. After a 100-days experimental period, the pipette method was used to assess particle distribution in the soil, followed by the calculation of the *K* factor as well as other factors in the RUSLE. Accordingly, this study aimed to discuss the weathering effects on the *K* factor and the amounts of soil loss.

OBJECTIVE

The objective of this study was to assess soil erosion risk, focusing on the weathering effects on the *K* factor and the amounts of soil loss in Cobija, Bolivian Amazonia, using the Revised Universal Soil Loss Equation (RUSLE).

METHODOLOGY

Site Description

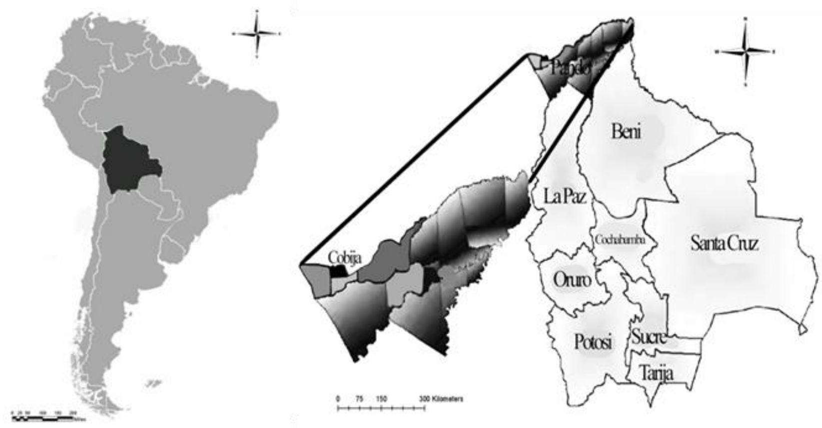

Fig. 1 Location of the soil sample collection in the city of Cobija, Bolivian Amazonia

Cobija is a Bolivian city, serving as the capital of the Department of Pando and the Province of Nicolás Suárez. Over the past two decades, Cobija has experienced substantial deforestation rates (Bolivian Institute, 2015). This process was greatly influenced by the regional development strategy initiated by the Bolivian Government in 2015. Local farmers gradually transformed the forested landscape into an urban city. The climate in the study area is classified as equatorial, characterized by hot and humid conditions with a tropical transition. There is a distinct dry season from June to August, and the average annual precipitation is 2016 mm (Mayoralty of Cobija, 2020). The research area spans 14 km^2, with an average annual temperature ranging from 32˚C to 24˚C. The monthly average air moisture ranges from 80 to 85 percent. The terrain is undulating, with elevations ranging from 100 to 120 meters above sea level.

Soil Sample Source and Preparation

Twenty soil samples were collected from an area of 60 ha in the Bolivian Amazonia that was recently deforested. And after mixing to give a homogenous sample the soil was air-dried. A quantity of 5.4 kg of each soil sample was transported from Bolivia to Japan for physical experiments conducted in the Land and water laboratory using engineering equipment at the Tokyo University of Agriculture, Tokyo, Japan.

Weathering Experiment

A weathering experiment was undertaken to replicate the climatic conditions prevalent in the Bolivian Amazon. A total of 120 soil containers were meticulously prepared, with each container containing 1 g of soil. These cans were then subjected to a controlled environment in an incubator, simulating the temperature conditions found in the Bolivian Amazon.

To mimic the effects of rainfall, 0.4 ml of water was carefully added to each soil can at specific intervals of 2, 4, and 12 hrs. This process was repeated 100 times for each treatment, ensuring sufficient replication for reliable analysis and accurate data collection.

Determination of Soil Particle Distribution Experiment using the pipette method

To determine the percentage distribution of particles in the soil samples before and after the treatment, the pipette method was employed for each treatment and repetition. This method allows for the determination of the percentage of coarse sand, fine sand, silt, and clay. The experiment involved using 10 g of dry soil, with the organic matter content initially removed with a previous treatment using H_2O_2. A 20 ml solution of sodium hexametaphosphate at a concentration of 6% was prepared for each analysis. The gravel and sand content were collected by filtering the soil through sieves with a mesh size of 2.0 and 0.2 mm, respectively. The remaining silt and clay contents were placed in 500 ml measuring bottles, and 20 ml of the 6% sodium hexametaphosphate solution was added. Subsequently, 10 ml of the solution was collected at different time intervals based on Stokes' law to determine the content of clay, silt, and fine sand.

Brief Description of the RUSLE

The RUSLE represents how climate, soil, topography, and land use affect rill and inter-rill soil erosion caused by raindrop impact and surface runoff (Renard et al., 1997). It has been extensively used to estimate soil erosion loss, assess soil erosion risk, and 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) The RUSLE is expressed by Eq. (1) as follows.

$$A = R \times K \times LS \times C \times P \tag{1}$$

Table 1 summarizes the terms for estimating the factors using Eq. (1), where A is the average annual soil loss in t/ha; 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 summarizes the methods for estimating these factors.

Table 1 Summary of methods for developing RUSLE used in this research

Term	Methods	References
R	A regression model based on the measurement of annual precipitation uses averages monthly precipitation and average annual precipitation	Renard and Fremund, 1994
K	Experimental models based on soil properties (composition of coarse sand, fine sand, silt, clay, percentages.	El-Swaify and Dangler, 1976
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

Soil Erodibility *K* Factor

Soil Erodibility *K* Factor was calculated using inherent soil properties following the procedure for tropical soils and determined using inherent soil properties, following the El-Swaify and Dangler (1976) procedure for tropical soils, which uses the percent-modified silt (0.002-0.2 mm), percent modified sand (0.1-2.0 mm), base saturation, percent unstable aggregates, and percent very fine sand. The values for the measured soil properties were used to calculate *K* Factor using Eq. (2).

$$K = -0.03970 + 0.00311X_1 + 0.00043X_2 + 0.00185X_3 + 0.00258X_4 - 0.00823X_5 \tag{2}$$

Where X_1 is the percent unstable aggregates < 2.0mm, X_2 is the product of the percent of modified silt (0.002-0.01 mm) by the percent of modified sand (0.1-2.0 mm) present in the sample, X_3 is the percent base saturation of the soil, X_4 is the percent silt present (0.002-0.05 mm), and X_5 is the percent of modified sand in the soil (0.1-2.0 mm). The calculated results of *K* factor were summarized in Table 2.

Table 2 Changes in soil properties for calculating the RUSLE *K*-factor with weathering

Fraction	Control T0 (0 h)	Treatment T1 (2 h)	Treatment T2 (4 h)	Treatment T3 (12 h)
Silt (0.002-0.05 mm)	29.05%	30.85%	31.88%	33.48%
Modified silt (0.002-0.01 mm)	29.60%	31.50%	32.50%	33.60%
Fine sand (0.02-0.2 mm)	28.68%	27.89%	26.84%	24.70%
Modified sand (0.1-2.0 mm)	7.24%	5.89%	5.78%	5.56%
Aggregates (< 2.0 mm)	0.78%	0.52%	0.29%	0.25%
Base saturation (%)	25.56%	25.56%	25.56%	25.56%

As shown in Table 2, the results were used to calculate the K factor and also indicated a rise in the percentage of soil clay and silt particles following the treatment. These notable increases served as an indication that the soil was exposed under the harsh climatic conditions prevalent in the Bolivian Amazon region, where has a discernible impact on the changes in soil particle distribution. The climate in the study area plays a pivotal role in enhancing the weathering effects, leading to changes in the soil composition and structure. The heightened exposure to the Amazonian climate accelerates the breakdown of soil particles, making them more vulnerable to weathering processes. Thus, the relationship between climate and the weathering effect is crucial in understanding the alterations in soil particle distribution and their implications for soil erosion.

Table 3 Changes in particle size-dependent variations in RUSLE *K*-factor with weathering

Value	Control T0	Treatment T1	Treatment T2	Treatment T3
X_1	0.78	0.52	0.29	0.25
X_2	214.30	185.53	187.85	186.82
X_3	25.56	25.56	25.56	25.56
X_4	29.05	30.85	31.88	33.48
X_5	7.24	5.86	5.78	5.56
K values (hundreds of acre ft ton in.)	0.1175	0.1203	0.1239	0.1293
K values (Mg h $MJ^{-1}mm^{-1}$)	0.0154	0.0158	0.0163	0.0170

In Table 3, the impact of varying K values in the Revised Universal Soil Loss Equation (RUSLE) is elucidated concerning alterations in particle size distribution. These modifications are intricately linked to shifts in the soil particle distribution following the weathering experimental treatment. The data presented therein offers a comprehensive insight into the progressive changes in K values, thereby providing valuable information about the soil erosion susceptibility resulting from shifts in particle size distribution due to the experimental weathering treatment.

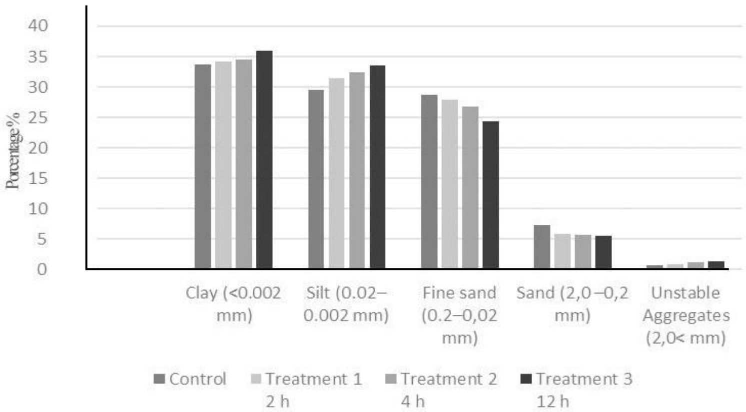

Fig. 2 Changes in soil particle distribution with weathering

As shown in Fig. 2, the changes in the percentage distribution of soil particles in the soil revealed an interesting trend; there is a tendency for the proportion of fine sand to decrease while the silt content experiences a slight increase. This suggests that the weathering processes and exposure to the climatic conditions in the study area contribute to the transformation of soil particle composition. Specifically, the finer sand particles exhibit a decreasing presence, potentially due to their susceptibility to weathering and erosion. On the other hand, the slight increase in silt content could be attributed to the redistribution of soil particles caused by weathering processes. Overall, these observations highlight the intricate relationship between weathering, soil particle distribution, and the impact of climatic conditions in shaping the composition of soil samples.

Table 4 Annual soil losses in the city of Cobija

Year	A0 (t/ha year)	A1 (t/ha year)	A2 (t/ha year)	A3 (t/ha year)
2017	9.36	9.81	10.03	10.15
2018	8.41	8.82	9.02	9.12
2019	10.36	10.86	11.10	11.23
2020	8.48	8.89	9.09	9.20
2021	11.11	11.65	11.91	12.05
Average	9.54	10.01	10.23	10.35

Average Annual Soil Loss in the City of Cobija

The results applied all the factors of the RUSLE on the different treatments to obtain the annual soil loss per unit area are summarized in Table 4. The average annual soil losses were in the range of 10 < t/ha/year before the effects of weathering, but the values were beyond 10 < t/ha/year after affecting weathering. Also, there was a tendency that the values of Treatment 3 affected higher weathering were higher than those of other treatments affected lower weathering. Figure 3 showed the increasing trends in the average annual soil losses, *A* value, in the City of Cobija, based on the changes in soil particle distribution due to weathering processes.

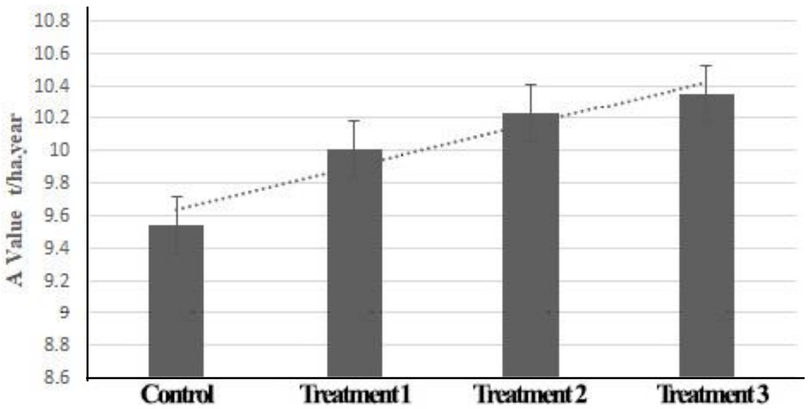

Fig. 3 Increase in *A* values (annual soil loss) with weathering

CONCLUSION

Soil erosion by water remains a big concern in the Amazonia region. This study aimed to assess the weathering effects on the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) in Cobija, Bolivian Amazonia. The experiments utilized Bolivian Amazon soil were conducted to replicate the meteorological conditions prevalent in the study area. The pipette method was employed to measure the distribution of soil particles in a sample. The experimental results indicated remarkable changes in soil particle distribution with weathering, and the changes affected *K* value as well. This trend influences the final results of RUSLE, the average annual soil losses, A value.

In conclusion, this study highlights the significant impact of weathering on the *K* factor of the Revised Universal Soil Loss Equation (RUSLE) in the Cobija region of Bolivian Amazonia. The experimental investigation involving Bolivian Amazon soil, conducted to mimic the local meteorological conditions, revealed alterations in soil particle distribution due to weathering. While the specific changes in K values were not presented in this manuscript, the observed trend of weathering-induced shifts in soil particle distribution undoubtedly plays a crucial role in influencing the accuracy of the RUSLE model's predictions, particularly in terms of average annual soil losses.

On the basis of this research outcomes, it is suggested that the soils should not be exposed for long period after deforestation. Soils should be covered by some sheets or residues as mulching for decrease weathering effects on soil structure.

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REFERENCES

Bertoni, J. and Lombardi, N.F. 1985. Conservação do solo. Piracicaba-SP, 392, Retrieved from https://www.passeidireto.com/arquivo/21438632/conservacao-de-solo/12

Boggs, G., Devonport, C., Evans, K., and Puig, P. 2001. GIS-based rapid assessment of erosion risk in a small catchment in the wet/dry tropics of Australia. Land Degradation and Development, 12 (5), 417-434, Retrieved from DOI https://doi.org/10.1002/ldr.457

Bolivia National Statistical Institute. 2015. Annual report, Retrieved from URL https://www.ine.gob.bo/

El-Swaify and Dangler, E.W., S.A. 1976. Erosion of selected Hawaii soils by simulated rainfall. Soil Science Society of America Journal, 40, 769-773, Retrieved from DOI https://doi.org/10.2136/sssaj1976.0361599 5004000050040x

Hickey, R. 2000. Slope angle and slope length solutions for GIS. Cartography, 29 (1), 1-8, Retrieved from DOI https://doi.org/10.1080/00690805.2000.9714334

Keesstra, S.D., Bouma, J., Wallinga, J., Tittonell, P., Smith, P., Cerdà, A., Montanarella, L., Quinton, J.N., Pachepsky, Y., van der Putten, W.H., Bardgett, R.D., Moolenaar, S., Mol, G., Jansen, B. and Fresco, L.O. 2016. The significance of soils and soil science towards the realization of the United Nations' sustainable development goals. Soil, 2 (2), 111-128, Retrieved from DOI https://doi.org/10.5194/soil-2-111-2016

Millward, A.A. and Mersey, J.E. 1999. Adapting the RUSLE to model soil erosion potential in a mountainous tropical watershed. Catena, 38 (2), 109-129, Retrieved from DOI https://doi.org/10.1016 /S0341-8162(99)00067-3

Mortatti, J. and Probst, J.L. 2002. Silicate rock weathering and atmospheric/soil CO_2 uptake in the Amazon basin estimated from river water geochemistry, Seasonal and spatial variations. Chemical Geology, 197 (1-4), 177-196, Retrieved from https://doi.org/10.1016/S0009-2541(02)00349-2

Renard, K.G., Foster, G.R., Weesies, G.A. and Porter, J.P. 1991. RUSLE, Revised universal soil equation. Journal of Soil and Water Conservation, 46 (1), 30-33, Retrieved from URL https://www.jswconline.org/content/46/1/30

Renard, K.G. and Fremund, J.R. 1994. Using monthly precipitation data to estimate the R-factor in the revised USLE. Journal of Hydrology, 157 (1-4), 287-306, Retrieved from DOI http://dx.doi.org/10.1016/ 0022-1694(94)90110-4

Ryzak M., Bieganowski A., 2011. Methodological aspects of determining soil particle-size distribution using the laser diffraction method. Journal of Plant Nutrition and Soil Science, 174 (4), 624-633, Retrieved from DOI https://doi.org/10.1002/jpln.201000255

Silva, A.M., Schulz, H.E. and De Camargo, P.B. 2007. Erosão e hidrossedimentologia em bacias hidrográficas, Segunda edição. Revista e ampliada. RiMa, ISBN 978-85-7656099-9, Brasil.

Soil Survey Staff. 1999. Soil taxonomy. A Basic System of Soil Classification for Making and Interpreting Soil Surveys, USDA, 869. USA.

Wischmeier, W.H. and Smith, D.D. 1978. Predicting rainfall erosion losses, A guide to conservation planning. U.S. Department of Agriculture, Washington, USA.