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Erosion and control options in the La Ciénega Microbasin in Malinaltepec, Guerrero, Mexico

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ABSTRACT

Objective: To estimate the water erosion rate in the La Ciénega Microbasin in Malinaltepec, Guerrero, Mexico, and to evaluate control options.

Design/methodology/approach: Potential erosion rate, actual erosion rate, and erosion control were estimated using the Universal Soil Loss Equation (USLE) under three conservation practices: contour plowing, successive land terracing, and live terracing with vetiver grass (*Chrysopogon zizanioides* (L.) Roberty).

Results: High erosion potential is shown by 99.18% of the microbasin surface area. Due to vegetation, only 41% of the surface area demonstrates high or very high actual erosion, 53.6% light, and 4.6% moderate. A living barrier using vetiver is the only conservation practice, of those assessed, that effectively diminished erosion.

Study limitations/implications: The lack of accurate data on rain-induced erosion was a limiting factor in this study.

Findings/conclusions: The La Ciénega Microbasin has a high risk of erosion and current erosion is a problem on agricultural land. The most effective option is living barriers using vetiver.

Keywords: Soil loss, USLE, living barriers, Poaceae.

INTRODUCCIÓN

In the Montaña region in Guerrero, Mexico, agricultural soils are susceptible to water erosion due to mountainous conditions and the frequency of torrential rains. Studies for quantifying erosion in this region are nonexistent, although evidence of its significance can be seen in the high concentration of sediments found in runoffs caused by rain.

To estimate erosion, the Universal Soil Loss Equation (USLE) was used, a model widely tested on a global level for diverse environmental and management conditions (Alewell *et al.*, 2019; Mancino *et al.*, 2016; Lin *et al.*, 2016), with reliable results for Mexico (Prado-Hernández *et al.*, 2017). The Universal Soil Loss Equation is used to estimate soil loss and to support in planning agricultural production (Renard *et al.*, 1997). It estimates average soil loss from erosion per unit of surface and time. It uses physical and management parameters, expressed numerically for a specific site and multiplied to estimate the quantity of soil lost. The equation is expressed as: $A=R K L S C P$ (Devata *et al.*, 2015). A is soil loss ($t ha^{-1}$); R is the erosivity factor (dependent on the rainfall's characteristics); K is the soil's erodability (dependent on the soil's characteristics); $L S$ is the slope length and angle; C is the factor for vegetation cover; and P is the factor for management practices. In recent decades, to estimate parameters for the Universal Soil Loss Equation, Geographic Information Systems are widely used (Flores *et al.*, 2003; Mihaiescu, 2013) through interpolation maps, mainly with the Kriging method, in order to apply the equation in the geographic information system (Tesfaye *et al.*, 2018). This helps improve the planning process for soil conservation practices because they can be previously evaluated considering specific scenarios for plots and basins (Bravo *et al.*, 2009). This study had the objective of estimating the water erosion rate in the La Ciénega Microbasin in Malinaltepec, Guerrero, Mexico, and assessing options for its control.

MATERIALS AND METHODOS

The study was carried out in the La Ciénega Microbasin (Figure 1), in Malinaltepec, Guerrero, Mexico. The microbasin has an extension of $91.75 km^2$ ($17^{\circ} 9' 30''$ and $17^{\circ} 18' 30''$ N, and $98^{\circ} 35' 30''$ and $98^{\circ} 44' W$). Climate varies from temperate [C(w2)(w)] in the northern zone to semi-warm and warm [A(C)w2(w) and Aw2(w)] in the southwestern zone. The existing soils are: eutric regosol, lithosol, dystric cambisol, and haplic phaeozem, with the first two predominating. Vegetation is pine-oak, oak-pine, oak, and mountain mesophyll forests, with induced pasture areas and agricultural plots.

To estimate average annual erosion, the Universal Soil Loss Equation (USLE) was used:

$$A=R K L S C P$$

Where: A =Soil loss ($ton*ha^{-1}*year^{-1}$); R =Rainfall erosivity factor ($MJ mm*ha^{-1}*h^{-1}*year^{-1}$); K =Soil erodability factor ($t*ha^{-1}*h$) ($MJ mm*ha^{-1}$); L =Slope length (dimensionless); S =Slope angle (dimensionless); C =Crop or vegetation cover factor (dimensionless); and P =Management practices (dimensionless).

The potential erosion was estimated considering only the $R K L S$ parameters of the USLE. To estimate the rainfall's erosivity (R Factor), a regression model was obtained for average annual precipitation (Pm) and altitude (H), with data from 10 weather stations and a Digital Elevation Model with a 15 m resolution. The resulting equation was:

$$Pm=1375.163+0.410H R^2=0.791, p=0.001$$

With the Raster Calculator tool from the ArcMap 10.3 program, rainfall erosivity and average annual precipitation per pixel were estimated using the equation reported by Cortés (1991) for the V zone:

$$R=3.4880P-0.000188P^2$$

(R is the annual EI30, in $MJ mm/ha hr$; P is annual rain, in mm). Erodability (K Factor) was obtained from morphological, physical, and chemical characteristics of the soils in each soil unit (INEGI, 2014), considering the values reported by the FAO (1980). In the vector soil mapping, a field with the K value was added and it was converted to raster format with a 15 m pixel resolution.

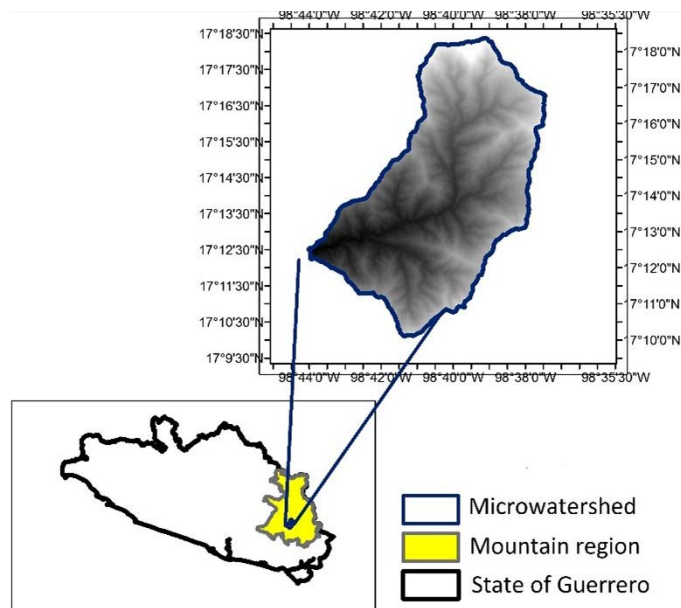


Figure 1. Location of the La Ciénega Microbasin.

The LS factor was estimated based on a digital elevation model with a 15 m resolution. The L factor was calculated using the following formulas, according to Pastrana (2014):

$$L = (l / 22.3)^m; m = F / (1 + F); F = (Senb / 0.0896) / [3(senb)^{0.08} + 0.56]; L_{(i,j)} = \left[\left(A_{(i,j)} + D^2 \right)^{m+1} - A_{(i,j)}^{m+1} \right] / \left[X^m * D^{m+2} * (22.3)^m \right]$$

Where: L is the slope length factor; l is the slope length in meters; m is a parameter for the slope's steepness; $A_{(i,j)}$ [m] is the unit catchment area at a cell's opening; D is the cell or pixel size, in this case with a 15 m resolution; X is the form correction factor.

In ArcGis 10.3, the Raster Calculator tool was used by applying the previous formulas (Pastrana, 2014):

$$F = ((\sin(\text{Slope} * 0.01745) / 0.0896) / (3 * \text{Power}(\sin(\text{Slope} * 0.01745), 0.8) + 0.56))$$

To estimate m , the formula $F/(1+F)$ was used, and the following expression was used for L :

$$\frac{(\text{Power}(\text{Flow}_{acc} + 625), (m + 1)) - \text{Power}(\text{Flow}_{acc}, (m + 1))}{\text{Power}(25, (m + 2) * \text{Power}(22.13, m))}$$

The S factor was estimated considering the following formulas: $S_{(i,j)} = 10.8 \text{ Sen } b_{(i,j)}$ if $b_{(i,j)}$ is less than 0.09; $S_{(i,j)} = 16.8 \text{ Sen } b_{(i,j)}$ if $b_{(i,j)}$ is more than 0.09. The S factor was estimated as:

$$\text{Con}((\tan(\text{Slope} * 0.01745) < 0.09), (10.08 * \sin(\text{Slope} * 0.01745) + 0.03), (16.8 * \sin(\text{Slope} * 0.01745) - 0.5))$$

To estimate the C factor (vegetation cover), six types of soil use were digitalized using Spot 5 images from Google Earth with a spatial pixel resolution of 2.5 m. A C value was assigned for each type of soil (human settlements, pastures, natural forests, landslides, secondary vegetation, and croplands).

The scenarios considered for conservation and erosion control practices were: 1) Contour plowing, 2) Successive land terracing, and 3) Live terracing with vetiver grass (*Chrysopogon zizanioides*), assigning them P values of 0.8, 0.6, and 0.01, respectively.

RESULTS AND DISCUSSION

Erosion potential of the microbasin

The microbasin's erosion potential is high (Figure 2; Table 1). The majority of the surface area has an erosion potential greater than $299 \text{ t ha}^{-1} \text{ year}^{-1}$, which is characteristic for the vast majority of the national territory (Montes-León et al., 2011), in contrast to countries like Argentina where only 9.1% of its territory presents erosion potential levels greater than $200 \text{ t ha}^{-1} \text{ year}^{-1}$ (Gaitán et al., 2017). This indicates a high risk of erosion in the whole microbasin if the vegetation is removed or if adequate soil conservation practices are not used in agricultural lands.

Actual Erosion

Of the microbasin's surface area, 53% has light erosion (Figure 3; Table 2). This is associated with the presence of forests and other types of vegetation in more than half of the microbasin's area. However, strong erosion is

Table 1. Potential erosion.

Potential erosion ($\text{t ha}^{-1} \text{ yr}^{-1}$)	Level	km^2	hectare	%
0 - 10	Low	0.010575	1.0575	0.01
10 - 50	Moderate	0.039825	3.9825	0.04
50 - 200	High	0.7029	70.29	0.77
> 200	Very high	91.006875	9100.6875	99.18

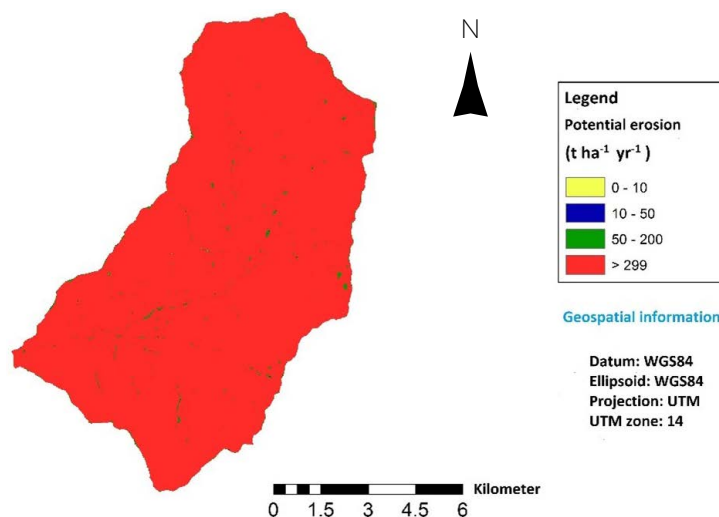


Figure 2. Erosion potential of the La Ciénega Microbasin.

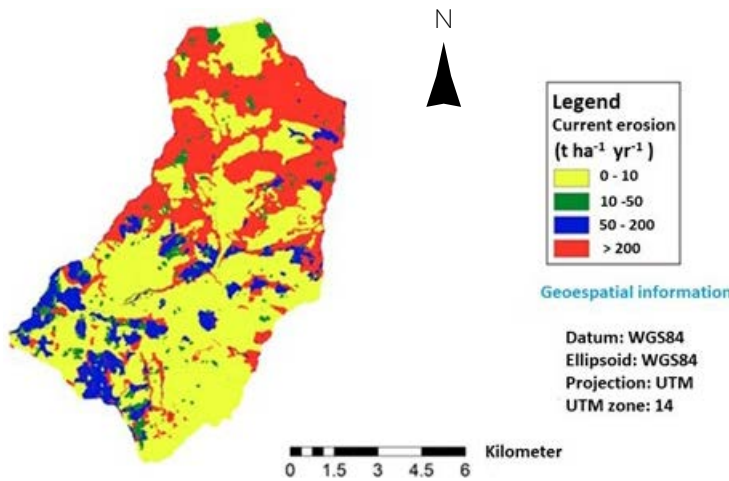


Figure 3. Actual erosion in the microbasin (2020).

Table 2. Actual erosion in the La Ciénega Microbasin (2020).

Current erosion (t ha ⁻¹ yr ⁻¹)	Level	km ²	hectare	%
0 - 10	Low	49.15395	4915.4	53.6
10 - 50	Moderate	4.244175	424.4	4.6
50 - 200	High	8.991225	899.1	9.8
>200	Very high	29.29635	2929.6	32.0

present in 32% of the microbasin, in lands of agricultural use and much degraded zones, with erosion rates higher than 200 t ha⁻¹ year⁻¹. This constitutes a significant area where soil conservation practices should be promoted.

Erosion control options

Contour plowing and terracing practices, considered to be mechanical practices, have a very low impact on erosion reduction (Figure 4, Table 3). Incidence on the erosion rate of zones of high and very high actual erosion is low. Living barriers using vetiver will significantly reduce erosion in agricultural lands with high and very high actual erosion (Figure 5). The effectiveness of live vetiver hedges has been documented, reporting reductions of 56.2 to 87.9 % in steep terrain (Donjatee *et al.*, 2010).

Vetiver is currently being tested in the microbasin (Figure 6). The plant can adapt to a diverse range of environmental conditions and because of its growth type, it does not compete with crops and does not become a weed (National Research Council, 1993). Live vetiver hedges accumulate soil and avoid the loss of soil productivity and the decrease of crop yields due to soil erosion (Oshunsanya, 2013). This suggests that it can be accepted by rural producers in the microbasin.

CONCLUSIONS

The erosion potential in the La Ciénega Microbasin is high, with potential erosion rates greater than 299 t ha⁻¹ year⁻¹. Actual erosion in almost half of the microbasin surface area (53.6%) is light, due to the presence of primary forest. Meanwhile, very high erosion (32 % of the microbasin area)

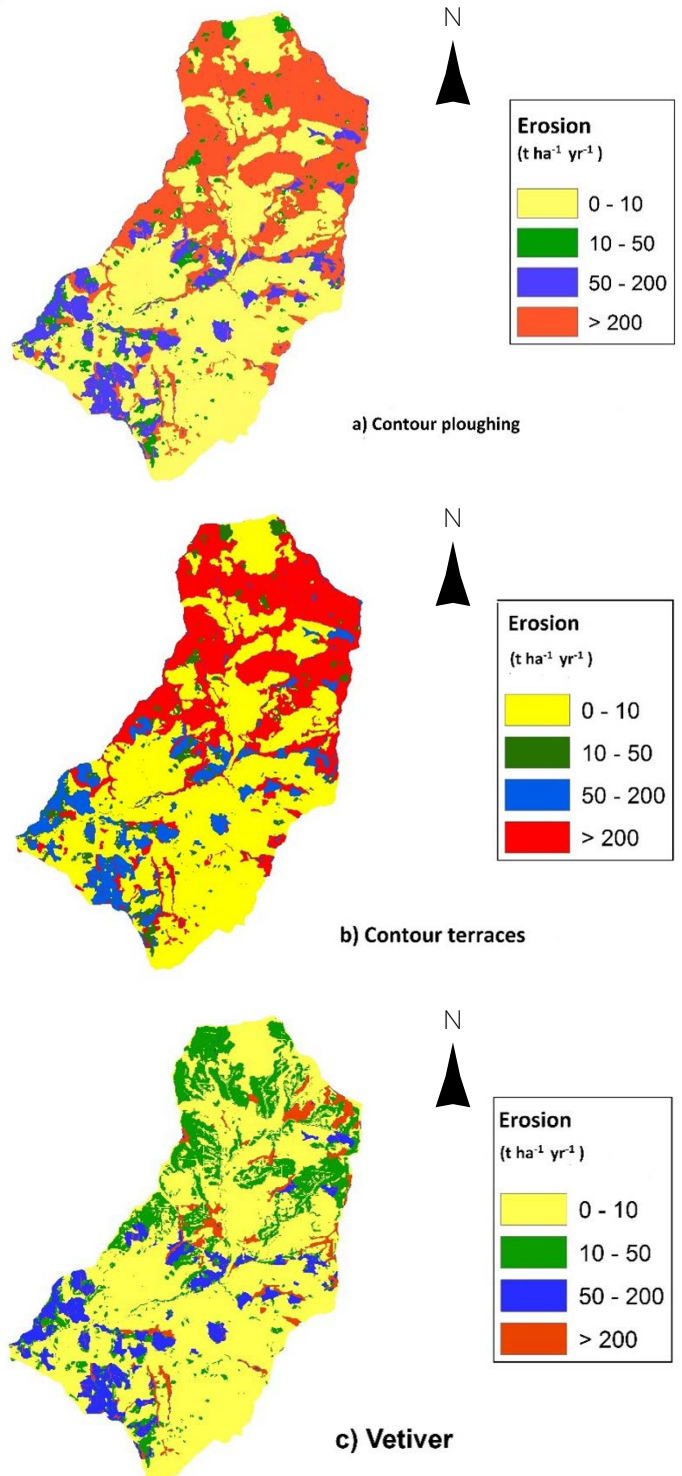
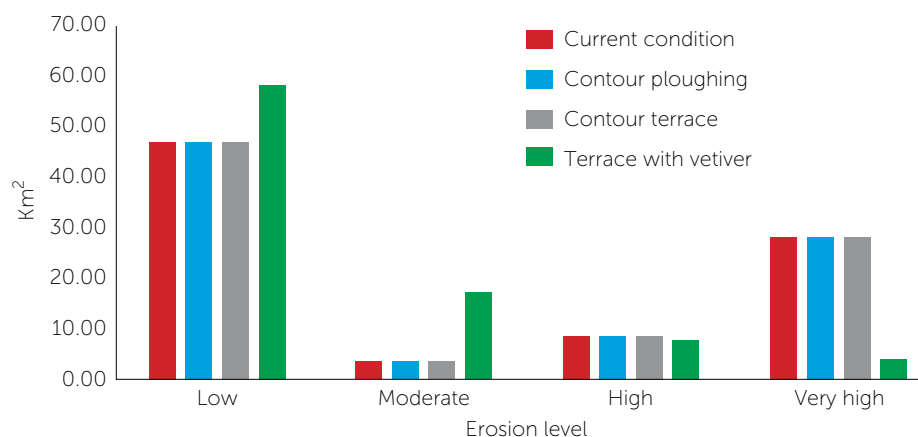


Figure 4. Maps of estimated erosion using contour plowing practices, contour terracing, and live vetiver barriers.

Table 3. Effects of conservation practices on surfaces with erosion levels.

Erosion t ha ⁻¹ yr ⁻¹	Level	Current condition		Contour ploughing		Contour terrace		Terrace with vetiver	
		km ²	%	km ²	%	km ²	%	km ²	%
0 - 10	Low	49.15	53.6	49.15	53.6	49.15	53.6	60.83	66.3
10 - 50	Moderate	4.24	4.6	4.27	4.7	4.31	4.7	17.73	19.3
50 - 200	High	8.99	9.8	9.12	9.9	9.36	10.2	8.67	9.5
>200	very high	29.30	32	29.14	31.8	28.86	31.5	4.46	4.9

**Figure 5.** Microbasin area and degree of erosion for scenarios of conservation practices.**Figure 6.** Vetiver plant (*Chrysopogon zizanioides* (L.) Roberty) in a nursery and in lands in the microbasin.

is associated with agricultural activities and degraded areas. Of the three management scenarios evaluated for water erosion control, both contour ploughing and successive land terracing do not result in reducing soil loss at an acceptable level. On the other hand, the use of live barriers with vetiver hedges (*Chrysopogon zizanioides*) in agricultural lands and degraded zones results in a 27.1% reduction in erosion within the very high to moderate and light categories.

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