# Adaptation of the Universal Soil Loss Equation to the Tropical Pacific Coastal Region of the Chiapas State, Mexico

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**Abstract**: The Tropical Pacific Coastal Region of the Chiapas State is one of the most affected areas by accelerating water erosion in Mexico. Governmental Institutions like the National Water Commission (CNA) are requiring reliable information on the reasons and principal sources of growing sediment transport downstream to the lower parts of the watersheds. Two erosion studies based on the USLE carried out in1997 led to extremely different results for estimated soil loss amounts at the different parts of the watersheds. A careful analysis and comparison of the basis for C-, K- and R-factor calculation at each study detected the main reasons for the differences. To improve the information of soil erosion related to principal agricultural production systems and provide a better data basis for the application of the USLE at the zone, in 1999 a Soil Erosion Monitoring Project was started.
**Keywords**: USLE, soil erosion monitoring, R-factor, runoff, small agricultural watersheds

## 1 Introduction

The region is characterized by a very high climatic erosive potential with medium precipitations that ranged from 1,400 mm (coastal plain) up to 4,500 mm in the middle and upper parts of the watersheds between 550 to 1,000 masl. In combination with the rugged topography and some highly erodible soils originated from deeply weathered granite, the region is highly susceptible to degradation processes by unfavorable land use changes (Baumann 1999). Ever since prehispanic times this natural region has been recognized as the Soconusco province. In the middle parts of the watersheds the most important coffee plantation zone of Mexico is localized, meanwhile the coastal plain is characterized by intensive tropical cash crop plantations of mango, banana, cultivation of soya beans and along the coastal plain extensive grazing pasture fields. Deforestation, spreading of maiz cultivation and erroneous land management on the steep slopes at the mountain upper parts of the watersheds are considered as the principal reasons for accelerating erosive processes and increasing sediment transport, causing serious problems downstream in the fluvial regimen and drainage systems at the coastal plain, the estuaries, natural lakes systems and affecting the infrastructure of drains and roads as occured during the greatest hydrometeorological storm event ever recorded in this region in September 1998 (Arellano, 1999; JICA, 1999). Governmental Institutions like the National Water Commission are requiring reliable information on the reasons and sources of increasing erosion and sediment transport as a basis for establishing well orientated soil conservation programs and support the political decision process.

## 2 Estimation of soil erosion at watershed-scale by the USLE

The application of the Universal Soil Loss Equation (USLE) developed by Wischmeier and Smith (1979) is often recommended as a valuable tool to estimate water erosion in the concept of *Integrated Watershed Management* and in GIS based studies (Chen 2000, FAO 1997). The soil erosion in Chiapas state was evaluated in a regional study by Arellano (1994) using the USLE with some variations related to rainfall and tropical steep lands conditions at 1:250,000 scale. In 1997 two erosion studies were made for the Tropical Pacific Coastal Region of the Chiapas State, both applying the USLE at watershed scale (CNA, 1997 and Gomez, *et al*., 1997). The estimation of medium soil loss amounts for the zone resulted in extremely different values, ranging from 57 to 300 $t \cdot ha^{-1}$ for the middle and upper parts of the watersheds, and 20 to 859 $t \cdot ha^{-1}$ for the lower parts of the watersheds (Baumann and Gonzalez, 2000). Comparison of the two studies and analysis in which way the USLE was applicated in each study showed partly differences in the cartographic database, but also differences in the way of interpretation and evaluation of the same data sources. The analysis was focused on the three principal USLE factors: C, K and R, expressing the influence of vegetation, soil conditions and rainfall characteristics in the erosion process (Table 1).

**Table 1 C, K and R-factor values used in the CNA (1997) and Gomez, *et al*. (1997) study for calculating soil loss by the USLE on watershed scale at the Pacific Coastal Region of Chiapas**

| Study | C-factor | | K-factor [$ton \cdot ha \cdot hr \cdot MJ^{-1} \cdot mm^{-1} \cdot ha^{-1}$] | | R-factor [$MJ \cdot mm \cdot ha^{-1} \cdot hr^{-1} \cdot year^{-1}$] |
|---|---|---|---|---|---|
| | range | medium | Range | Medium | Huixtla station, 3,370 mm |
| Gomez *et al*. | 0.0005—0.19 | 0.092 | 0.028—0.080 | 0.040 | 77,198 (equation 2) |
| CNA | 0.001—0.25 | 0.011 | 0.013—0.026 | 0.022 | 28,505 (equation 1) |

**C-factor**: The estimation of the expanse and distribution of different vegetation and land use types in the zone is the basis for the calculation of weighted C-factors. Meanwhile the Gomez, *et al*. (1997) study based on thematic vegetation and land use maps (scales 1∶1,000,000 and 1∶250,000), the CNA (1997) study used Landsat- TM and Landsat-MSS satellite pictures. Once the areas of different vegetation types are estimated, the following step is to assign C-values for each type and area. If no direct measured values exist, it is necessary to select C-values from literature. The most common used source are the C-values published in Wischmeier and Smith (1978). Nevertheless the variation for a certain vegetation or crop type can be wide, and the choice which source will be considered can influence significantly in the final result. Table 2 shows the range of C-value variation for different crops (ISSS 1996).

**Table 2 Range of C-factor values for different crops and pasture (ISSS 1996)**

| Crop | C-factor values |
|---|---|
| Corn | 0.25—0.90 |
| Coffee | 0.002—0.3 |
| Banana | 0.007—0.04 |
| Pasture | 0.003—0.2 |

Taking into account the possible variation of C-factors, in some cases it may be difficult to select the best value for a certain vegetation type. The medium weighted C-values for the entire zone in the two studies were 0.011 (CNA, 1997) and 0.092 (Gomez *et al*., 1997). The use of different sources may be easily lead to variations in the estimated area of different land use types in the zone.

**K-factor**: In both studies the basis for calculation of K-factors was the INEGI 1∶250,000 soil map. However, the results are showing significant differences in the estimated K-values for the principal soil types and zones of the watersheds. While the K-values for the major soil types in the CNA (1997) study were taken from Figueroa *et al*., (1991), according to the FAO (1980) proposal, the Gomez, *et al*., (1997) study estimated K-values according to superficial soil texture. In the first study estimated K-factors for the principal soil types ranged from 0.039—0.055, while the second study concluded values between 0.013 and 0.026. The variation of the K-factor for a certain soil type can be high, and if no direct measured values are available, the approximation should be best realized by the Wischmeier nomogram. For example, K-values for Oxisols can range from 0.01 to 0.22 (ISSS 1996).

**R-factor**: Most watershed and GIS-studies in tropical zones using the USLE are lacking as database direct measured rain erosivity values. R-factors are indirectly derived by empiric formulas from total monthly and annual rain depth. (Chen, 2000; Dickinson and Collins, 1998). Rainfall erosivity (R factors) were derived from mean annual rainfall amount, using two different polinomial models:

$R = 2.4619P_a + 0.006067P_a^{(2.055-0.000061Pa)}$ (Figueroa *et al*. 1991) (Equation 1)

$R = 2.4619P_a + 0.006067P_a^2$ (Cortés, 1991) (Equation 2)

where:

R = Erosivity Wischmeier factor in MJ • mm • $ha^{-1}$ • $hr^{-1}$ • $year^{-1}$

Pa = Annual rain depth in mm

In view of the high medium rainfall the differences in the R-values calculated by both equations is highly significant. For example, the Huixtla station shows a mean annual precipitation of 3,370 mm (Table 1). Applying the two equations, results show an annual erosivity of R = 28,505 MJ • mm • $ha^{-1}$ • $hr^{-1}$ • $year^{-1}$ for equation 1, and R = 77,198 MJ • mm • $ha^{-1}$ • $hr^{-1}$ • $year^{-1}$ for equation 2.

## 3 The erosion monitoring project

In view of the great divergence of the calculated medium soil loss amounts for the zone, the National Water Commission (CNA) in collaboration with the Center for International Migration and Development (CIM) and the Autonomous University of Chiapas (UNACH), started in 1999 the "Erosion Monitoring and Evaluation of Soil Conservation Practices"- Project in the watershed of the Huehuetán river. One of the main purposes of the project is to determine the influence of principal agricultural production systems such as coffee, maiz and pasture in the erosion process and evaluate the efficiency of different soil conservation measures. Because of that, the project is primarily geared to small agricultural watershed research and much less on plot investigations at micro-scale (Lal, 1990). Relating to the calibration of the USLE to the climatic conditions of the region, special interest is focussed on the determination of real R-factor values for the zone, because the R-factor is considered to be the parameter who mostly restricted the application of the USLE to other regions different to those in the US (Foster *et al.*, 1982). Reliable information on real R-factor-values and rainfall intensities appears very scarce and rarely available for most parts of the world (Dickinson and Collins 1998).

### 3.1 Methods

The investigations are carried out at three different sites along the Huehuetan watershed (Table 3). At each site daily precipitation is registered by a rainfall chart recorder according to Hellmann with an advance of 20 mm*$hour^{-1}$. This provides a good graph resolution for digitizing. The infrastructure for measuring runoff at the micro-catchment scale consisted of H-type-flumes in combination with Stevens water level recorders (Lal, 1990). The equipment for runoff sampling consists of an DH-48 manual advice. Unfortunately the 2000 year data set of sediment concentration values is very scarce and will be included in later publications. At the site 3 UNACH Experimental field five Wischmeier plots were installed to investigate soil erosion and runoff on a Fluvisol under corn and soya beans. Results of plot studies will also be presented later.

**Table 3 Investigation sites and experimental design within the CNA Erosion Monitoring Project**

| Site | Crop | Scale | Parameters |
|---|---|---|---|
| 1. Argovia farm | Coffee plantation | Small agricultural watershed | Precipitation, runoff |
| 1. Argovia farm | Coffee plant. with terraces | Small agricultural watershed | Precipitation, runoff |
| 2. Santa Cecilia farm | Corn with tropical fruit trees | small agricultural watershed | Precipitation, runoff |
| 3. UNACH Exp. Field | Pasture | Small agricultural watershed | Precipitation, runoff |
| 3. UNACH Exp. field | Corn, soya beans | Wischmeier plots (5) | Precip, runoff, soil los |

### 3.2 Results

**Rainfall characteristics**: In 2000 year a total of 351 rainfall events were registered. For each event the following parameters were calculated with the ERODAT-Program (University of Basel, Institute for Geography): Rainfall amount, Intensities ($I_{max}$, $I_5$, $I_{10}$, $I_{15}$, $I_{30}$), rainfall energy and R-factor ($EI_{30}$) values. The following table present the measured R-factor values at each site compared with the values obtaining by the application of equations 1 and 2:

**Table 4 Measured R-factor values in 2000 year in comparison with estimated values calculated by equations 1 and 2 in the study area**

| Parameter | Argovia farm | | Santa Cecilia farm | | UNACH Experimental field | |
|---|---|---|---|---|---|---|
| | value | % | Value | % | Value | % |
| Rainfall (mm) | 3385 | - | 2325 | - | 1345 | - |
| R measured | 39530 | 100 | 21190 | 100 | 10930 | 100 |
| R calculated by Equation 1 | 28628 | -27.6 | 22459 | + 6.0 | 12346 | + 12.9 |
| R calculated by Equation 2 | 77851 | + 96.9 | 38520 | + 81.8 | 14286 | + 30.7 |

Notes: R in MJ • mm • $ha^{-1}$ • $hr^{-1}$ • $year^{-1}$

It is shown that equation 1 is giving a good approximation of the real measured R-factor-value in the range of 2,000 to 2,500 mm rainfall, meanwhile the deviation grows with increasing rainfall amount. Application of equation 2 is not reasonable because of the great differences up to 97 % at the high rainfall zones. The investigations are providing a data base that will make possible a more confidential use of the USLE in the tropical region of the Chiapas Pacific Coast.

**Runoff**: In the four small agricultural watersheds a total of 182 runoff events were registered in 2000 year. Table 5 shows a classification according to the range of the peak flows. It emphasizes that runoff and peak flow under maiz and pasture is higher than under coffee plantation.

**Table 5 Classification of runoff events according to peak flow from four small agricultural watersheds**

| Range of peak Flow in lt • $sec^{-1}$ | UNACH Pasture | Santa Cecilia Corn/Fruit trees | Argovia Coffee plantation | Argovia Coffee terraces |
|---|---|---|---|---|
| 0.1—49.9 | 10 | 22 | 62 | 49 |
| 50—99.9 | 2 | 4 | - | 6 |
| 100—199 | 1 | 5 | - | 5 |
| 200—500 | 6 | 7 | - | - |
| > 500 | - | 1 | - | - |
| Total events | 19 | 39 | 62 | 62 |

**Table 6 Correlation coefficients r (Pearson) for the relation between rainfall parameters and peak flow in study small agricultural watersheds**

| Parameter | UNACH field experimental n = 19 | Santa Cecilia farm n = 34 | Argovia farm coffee plantation N = 62 | Argovia farm coffee terraces n = 62 |
|---|---|---|---|---|
| Rainfall amount (mm) | 0,757 | 0,551 | 0,861 | 0,798 |
| $I_{max}$ (mm/h) | 0,660 | 0,296 | 0,523 | 0,504 |
| $I_{15}$ (mm/h) | 0,681 | 0,514 | 0,713 | 0,672 |
| $I_{30}$ (mm/h) | 0,700 | 0,598 | 0,811 | 0,767 |
| R-factor [$EI_{30}$] | 0,783 | 0,649 | 0,926 | 0,873 |

The statistical analysis and the calculation of the Pearson correlation coefficient r for the relation rainfall characteristics - peak flow showed, that peak flow was best correlated with the R-factor (Table 6). These are very promising preliminary results, because it seems that the R-factor can be used to develop runoff models for small agricultural watersheds in the zone.

## 4 Conclusions

It seems that the USLE is no appropriate tool to estimate soil loss at watershed-scale in tropical areas. Similar observations are reported by Agus *et al.,* (1988) for Indonesia. There are different possible sources of errors that can strongly influence the result. The correct estimation of different vegetation type distribution in the area is basicly important and depends on the availability of reliable actual cartographic and foto material. The assignment of C- and K-factor values to previous determined vegetation and soil type areas is mostly subjective, and the range of possible values for an specific vegetation or land use type reported in literature is wide.

Nevertheless from possible deviations of the real situation, the CNA (1997) study seems to reflect the situation of soil erosion in the different parts of the watersheds more realistic than the Gomez, *et al*. (1997) study. The medium calculated soil loss amount for the plain zone by the UAM-study of about 859 ton/ha is strongly overestimated.

Real measured R-factor values will provide in the future a more reliable use of the USLE at field scale. Furthermore the Erosion Monitoring Project is providing valuable information on the behavior of runoff on small agricultural watersheds scale for the most important agricultural systems in the zone, which will support the development of runoff-models. According to the first preliminary results a special focus will be given on pastures at the lower slopes in the transition zone and corn cultivation on steep slopes and his influence on sediment transport and offsite effects.

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