Soil Erosion Calculation using Remote Sensing and GIS in Río Grande de Arecibo Watershed, Puerto Rico

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Abstract

Sediment production estimates from watersheds are very important, because these sediments decrease the lake capacity, to impact the ecosystems in the bays and the water quality. So is necessary locate the areas potentials in the watershed where exist major erosion and to establishment a program to watershed management. Soil erosion assessment is a capital-intensive and time-consuming exercise.

A number of parametric models have been developed to predict soil erosion at drainage basins, yet Universal Soil Loss Equation (USLE) (Wischmeier and Smith, 1978) is most widely used empirical equation for estimating annual soil loss from agricultural basins. While conventional methods yield point-based information, Remote Sensing (RS) technique makes it possible to measure hydrologic parameters on spatial scales while GIS integrates the spatial analytical functionality for spatially distributed data.

This work uses the USLE equation to calculate and evaluate these zones in Puerto Rico, basically in Río Grande de Arecibo basin. Some of the inputs of the model such as cover factor and conservation practice factor can also be successfully derived from remotely sensed data.

The LS factor map was generated from the slope and aspect map derived from the DEM. The K factor map was prepared from the soil map, which was obtained from SURGO data and K factor values from a Soil Survey of United States and Virgin Islands (1998). Maps covering each parameter (R, K, LS, C and P) were integrated to generate a composite map of erosion intensity based on the advanced GIS functionality.

Keywords: Remote sensing, USLE equation, GIS, soil erosion.

Introduction

Problems associated with soil erosion, movement and deposition of sediment in rivers, lakes and estuaries persist through the geologic ages in almost all parts of the earth. But the situation is aggravated in recent times with man's increasing interventions with the environment. At present, the quality of available data is extremely uneven. Land use planning based on unreliable data can lead to costly and gross errors. Soil erosion research is a capital-intensive and time-consuming exercise. Global extrapolation on the basis of few data collected by diverse and non-standardized methods can lead to gross errors and it can also lead to costly mistakes and misjudgments on critical policy issues. In this case study, GIS functionality was extensively utilized in the preparation of erosion map. The Río Grande de Arecibo River discharges to the Dos Bocas Lake and it's one of the most important reaches to water supply to lake. This Basin is influenced by the man development and the soil erosion and sediment transport to the lake decrease your capacity. Scientific management of soil, water and vegetation resources on watershed basis is, very important to arrest erosion.

Remote sensing provides convenient solution for this problem. Further, voluminous data gathered with the help of remote sensing techniques are better handled and utilized with the help of Geographical Information Systems (GIS).

II. Objectives of the Study

- The hypothesis of this work is to predict the soil erosion quantity due to rainfall drops impact in a specific watershed.
- The Universal Soil Loss Equation (RUSLE) from NRCS will be used. Additionally with LandSat 7 ETM+ satellite image and Geographical Information Systems to obtain a spatial distribution of soil erosion.

III. Methods

Soil loss is defined as the amount of soil lost in a specified time period over an area of land which has experienced net soil loss. It is expressed in units of mass per unit area (Ton ha-1 y-1)

This paper uses the USLE (Universal Soil Loss Equation) to predict annual soil loss from agricultural lands. The **USLE** can be expressed as follows:

$$\mathbf{A = R\,K\,L\,S\,C\,P} \qquad \textbf{(1)}$$

Where A is the computed soil loss per unit area, expressed in the units selected for K and the period selected for R.

R is the rainfall and runoff factor.
K is the soil erodibility factor.
L is the slope-length factor.
S is the slope-steepness factor.
C is the cover and management factor.
P is the support practice factor where here was assumed to be one.

Figure 1, shows a schematic about the general methodology used in this work.

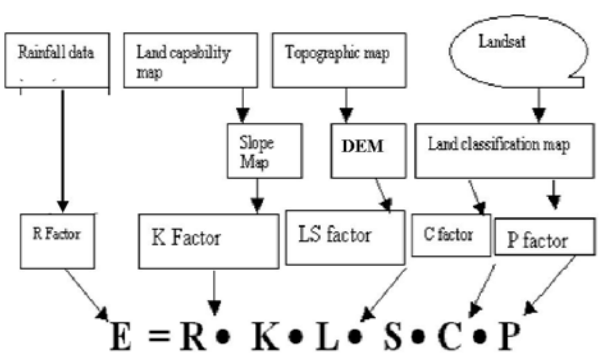


Figure 1. General Methodology

It includes the different components to obtain and calculate for the final computation of the soil erosion in Rio Grande de Arecibo.

IV. Study Area

The study was carried out at the basin of the Rio Grande de Arecibo River (Figure 2) in the north of Puerto Rico. It is located between 300 25' 3.33" N to 300 35' 13.71" N latitude and 770 22' 34.75" E to 770 39' 42.31" E longitude. The total area drained by the river Bata being 268.6769 km2.

The river basin has a sub-continental mountain type of sub-tropical monsoon climate with moderately warm to hot summers, high monsoon rains and a cool to cold winter season.

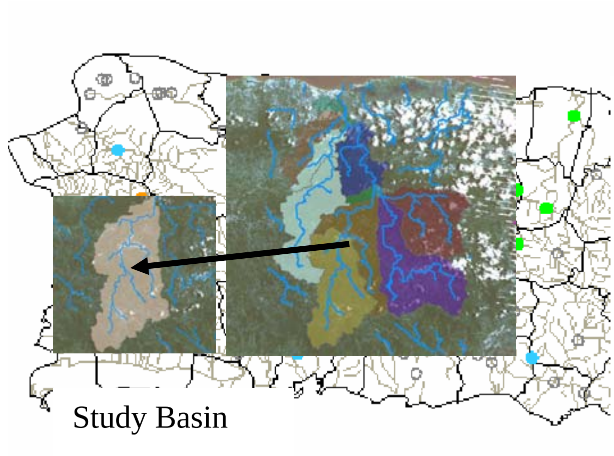


Figure 2.Study Area, Río Grande de Arecibo Basin

V. Calculation of the RUSLE Factors

Modified LS factor

Using the DEM (Digital Elevation Model) with 30 meters of spatial resolution for the study area, the L*S factor was calculated using:

$$LS = \sqrt{L/22(0.065 + 0.045 * S + 0.0065 * S^2} \quad \textbf{(2)}$$

L = Slope length (m) fixed to 30 meters.

S = Slope steepness (radians).

The LS factor map was created from the DEM and calculating a slope grid first to obtaining in each pixel a value of LS. (Figure 3). The terrain elevation are 0 to 1397 m.

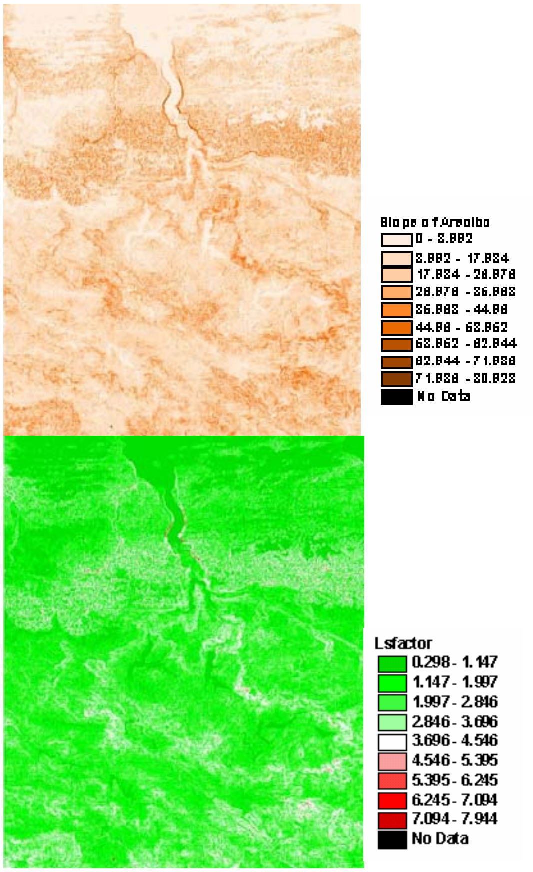


Figure 3. Arecibo Slope Grid and Arecibo LS Factor.

C Factor

The vegetation cover has a big impact in the erosion. The land cover intercepts the rainfall, increase the infiltration and reduce the rainfall energy.

The land cover is the parameter more influenced by the hand man and your impact increase the erosion. The C factor depends of the land cover and a LandSat ETM, August 2004 with resolution 30 m was used in C factor calculation.

The image was processed with a no supervised classification to prepare the land use/ cover map of the study area. In this study, best results were obtained from K means classifier with 5 iterations. Using this classifier, the river basin was classified into eight land use/ cover classes namely Dense Forest, Moderate Forest, Grass Land, Soil without vegetation, cities and Clouds, because the LandSat 7 ETM+ had some clouds in study area. To validation the classification a NDVI was generated for the study area.

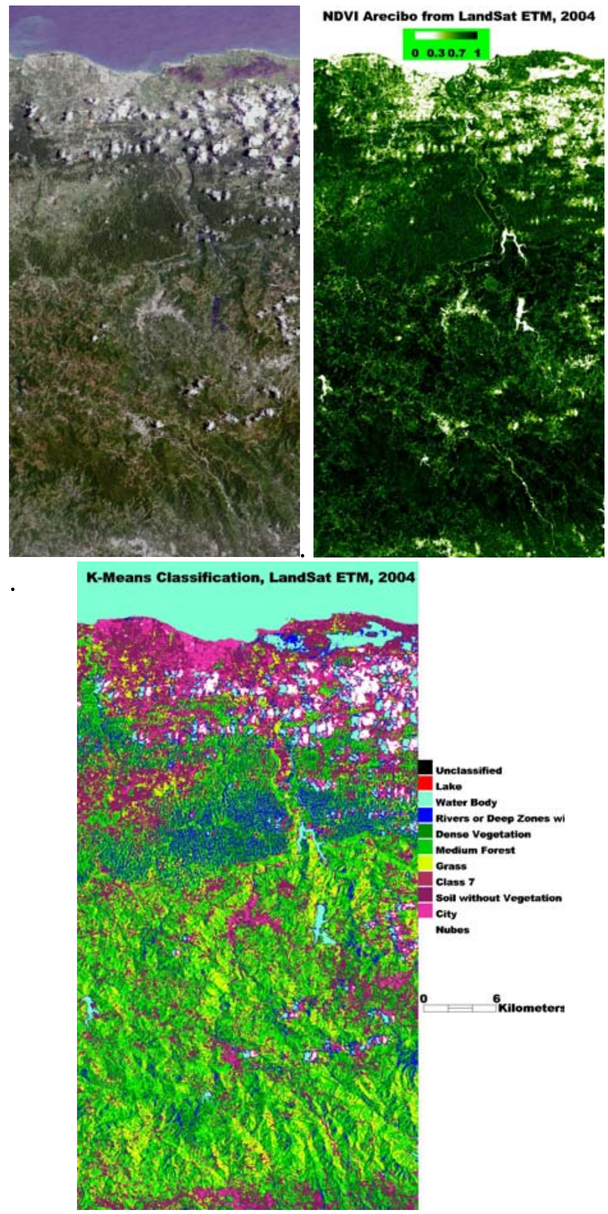


Figure 4. LandSat 7 ETM+ (left), NDVI (right) and K Means Classification images from Arecibo, Puerto Rico.

The values assigned to each classification were obtained from Essa, 1997 and Ogawa, 1997. In the Table 1 the percent of area from the classification and the C factors.

Table 1. Classification Area Percent and C Factors

Class Name	Area Percent	C Factor
Water Body	12.292%	0
Rivers or Deep Zones	6.486%	0.027
Dense Vegetation	20.362%	0.002
Medium Forest	21.304%	0.006
Grass	13.017%	0.12
Soil without Vegetation	19.405%	0.44
City	5.159%	0.85
Clouds	1.974%	0

With the values above can be generated the grid with the C Factor for Arecibo showed in the Figure 5.

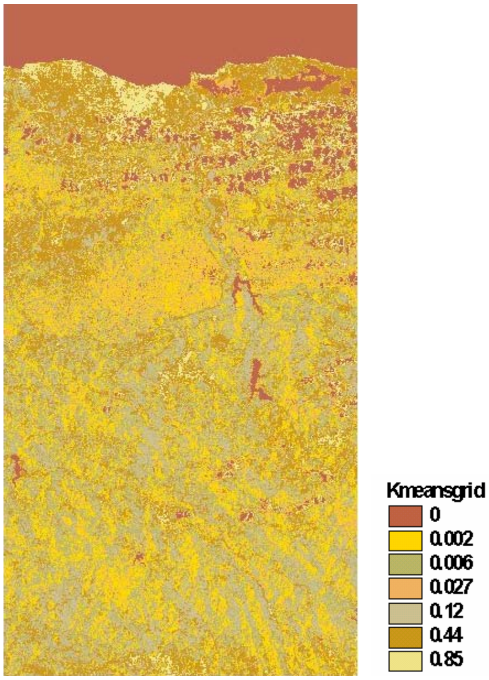


Figure 5. C Factor Grid for Arecibo.

K Factor

The K factor represents the soil susceptibility to the erosion, the sediment transportability and the runoff quantity and rate.

The K factor map was prepared from the soil map, which is obtained from SURGO digital data base. And the soils were classified using previous studies done at Geo-Science Division, IIRS, Dehradun, using the values given in Tables 2. Was assumed 2% organic matter for the soils. The Figure 6 shows the grid for the K Factor.

Table 2. K values for different soil textures

Textural class	Organic matter content (%)		
	0.5	2.0	4.0
Fine sand	0.16	0.14	0.10
Very fine sand	0.42	0.36	0.28
Loamy sand	0.12	0.10	0.08
Loamy Very fine sand	0.44	0.38	0.30
Sandy loam	0.27	0.24	0.19
Very fine sandy loam	0.47	0.41	0.33
Silt loam	0.48	0.42	0.33
Clay loam	0.28	0.25	0.21
Silty clay loam	0.37	0.32	0.26
Clay	0.25	0.23	0.19

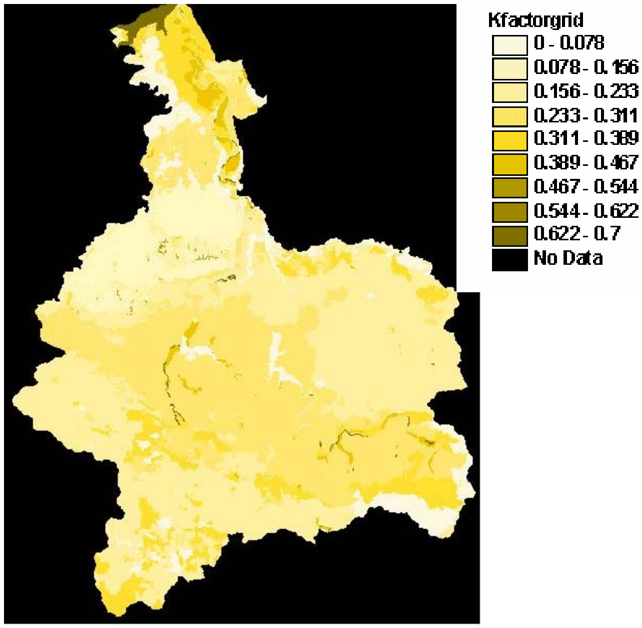


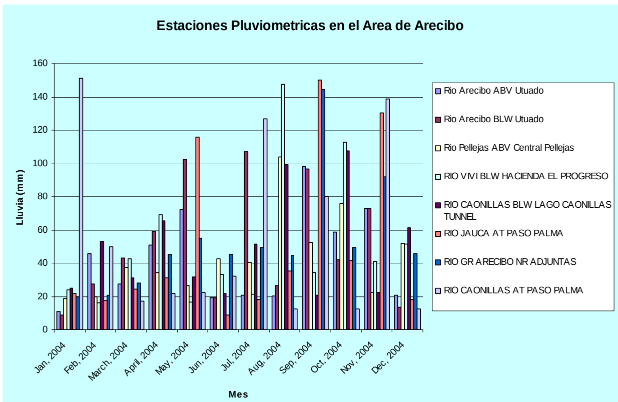
Figure 6. Arecibo Basin Grid for K Factor.

Modified R Factor

The modified R Factor depend of the rainfall quantity and a formula developed by Arnoldus 1997, which uses only average monthly (p) and the annual precipitation (P), was used instead. The relationship (in metric units) was:

$$R = 1.735 * 10\left(\log \sum p^2 / P - 0.8188 \right) \quad (3)$$

The annual and monthly precipitation was recovery from 8 stations in the study area for the year 2004 and R Factor was calculated for each one. Then with these values was generated R factor Grid map. The Figure 7 show the monthly precipitation in the year 2004 for the 8 stations and the mean annual precipitation and the R Factor calculated.



Mean	R Factor
43.14	35.30
51.58	36.95
43.88	34.98
50.78	37.61
49.25	36.08
51.16	39.20
53.23	36.89
56.52	39.45

Figure 7. Precipitation Data and R Factor.

Preparation of Erosion Map

All the factor maps of R, K, LS and C were integrated to generate a composite map of erosion intensity. The Figure 8 shows the final product for Río Grande de Arecibo Basin to Dos Bocas Lake. This result was validated with the Average Annual Soil Erosion by Water on Cultivated Cropland as a portion of the tolerable rate, 1997. This study shows one value of soil erosion average for Puerto Rico, this value around between 2 to 4 ton/hec/year.

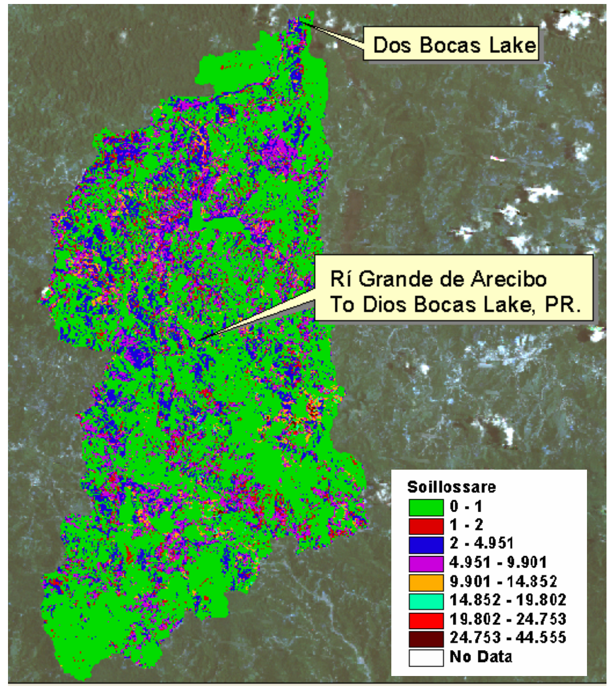


Figure 8. Final Product with the erosion in the basin in Ton/year.

Conclusions

The statistics of the soil loss map have a mean of 1.903 ton/year and a standard deviation of 3.249 ton/year.
The values obtained are annual average, so it's important calculate a map the soil erosion with the maximum precipitation, because in the 2004 year found a precipitation 3 times biggest than the mean annual precipitation. So the soil erosion could be increase considerably.
This methodology can be applied to the island and small basins.
The application of Remote Sensing Images is useful to approximate the land cover of a basin.

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