Assessing Soil Erosion Rate in a Catchment Area in Cyprus Using Remote Sensing and GIS

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Abstract. The objective of this work is the development of the overall methodology to estimate the erosion rate in a catchment area in Cyprus with the integrated use of satellite Remote Sensing (RS), Geographical Information Systems (GIS) and precipitation data. Two models were implemented in a water basin in the central part of Cyprus (Yialias River) which is generally prone to erosion processes: the Analytical Hierarchical Process (AHP) and the Revised Universal Soil Loss Equation (RUSLE) model which is considered to be a contemporary approach in soil loss assessment. RUSLE method is based on the estimation of soil loss per unit area and takes into account specific parameters such as precipitation data, topography, soil erodibility, erosivity and runoff. On the other hand, AHP method contributed to the construction of a risk assessment map with the use of almost the same agents with RUSLE methodology. RUSLE and AHP approaches were compared and evaluated for their efficiency. The study indicated that using RS and GIS technologies together with precipitation data resulted to an effective and accurate assessment of soil erosion in considerable short time and low cost for large watersheds.

Keywords. RUSLE, AHP, GIS, remote sensing, Cyprus.

1. Introduction

Soil erosion is considered as a major environmental problem as it seriously threatens natural resources, agriculture and the environment. During the last years, there has been a growing awareness of the importance of problems directly related to erosion in the broader Mediterranean region. The widespread occurrence and importance of accelerated erosion in the Mediterranean region has driven to the development of models at scales ranging from individual farm fields to vast catchment areas and different types of administrative areas [1]. In some parts of the Mediterranean region, erosion has reached a stage of irreversibility while in some places there is no soil left [2]. Although soil erosion is characterised as a natural phenomenon, human activities, such as agriculture, can accelerate it further [3]. The objective of this work is to develop and evaluate two different erosion models. The first is an empirical multi-parametric model which is mainly based in expert's knowledge (Analytical Hierarchical Process - AHP) and the second (Revised Universal Soil Loss Equation RUSLE) is the model which is considered to be a contemporary simple and widely used approach of soil loss assessment.

2. Study area and data

2.1. Study area

Located in the central part of the island of Cyprus, the study area is a watershed with an extent of about 110 km ^{2}. The area under investigation is the Yialias River at Potamia catchment area in the broader region of Nicosia – Cyprus (Figure 1).

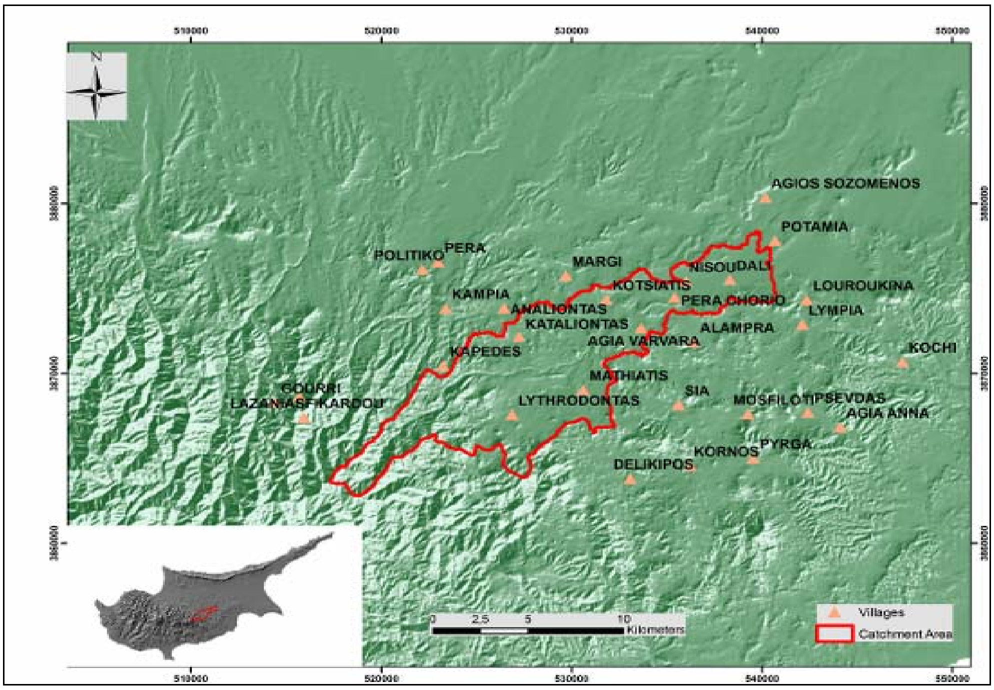

Figure 1: The study area.

2.2. Data

A Digital Elevation Model (DEM) (25m pixel size) was used for the study to generate digital DEM sub-products (slope, aspect and drainage network).

Two GeoEye-1 images were used for the monitoring of the upstream and downstream of the basin acquired at 12/03/2011 and 11/12/2011 respectively (Figure 2). GeoEye-1 is a multispectral sensor with four spectral bands. Its spectral range is: 450-510 nm (blue), 510-580 nm (green), 655-690 nm (red) and 780-920 nm (near infrared) while its spatial resolution is approximately of 1.65 m.

Concerning meteorological data, these were provided from the Meteorological Service of Cyprus. Specifically a time-series rainfall dataset of 6 rain gauge stations for a period of 20 years (1990 -2010) was provided.

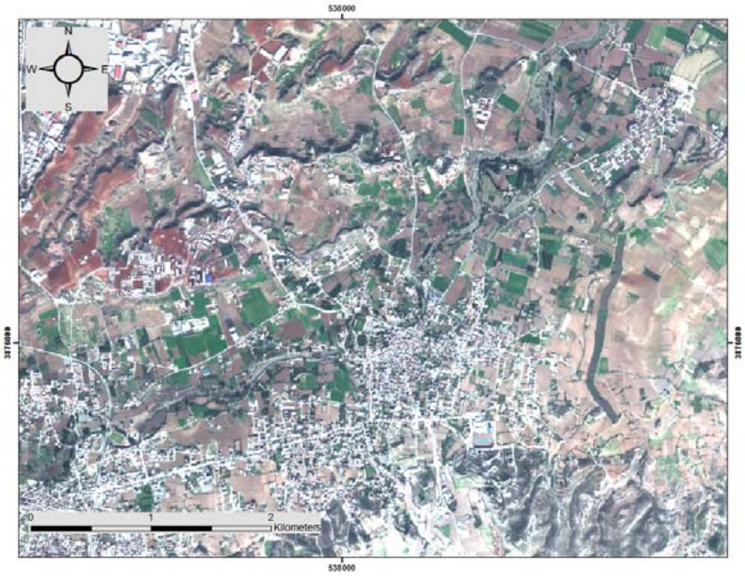

Figure 2: RGB – 321 of GeoEye-1 satellite imagery covering the study area.

3. Methodology

3.1. RUSLE methodology

The RUSLE equation incorporates five different factors concerning rainfall (*R*), soil erodibility (*K*), slope length and steepness (*LS*), cover management (*C*) and support practice (*P*) (Equation 1).

$$A = R*K*L*S*C*P \qquad (1)$$

Concerning the AHP, the final weight of significance for each factor can be defined using the eigen-vectors of a square reciprocal matrix of pairwise comparisons between the different factors. Moreover, a certain grade is assigned to all the different pairs from 1/9 when the factor is "not important at all" to 9 where the factor is "extremely important".

3.1.1. Rainfall (R) factor

The rainfall *R* factor is a measure of the erosive force of a specific rainfall. For the calculation of the *R* factor with the use of the Modified Fournier Index (MFI), two different approaches suggested by [4], [5] for the areas of Sicilly and Morocco were respectively used (Equation 2, 3):

$$R_1 = 0.6120\ MFI^{1.56} \qquad (2)$$
$$R_2 = 0.264\ MFI^{1.50} \qquad (3)$$

The MFI according to [2] is well correlated with the rainfall erosivity. The specific index is considered as an effective estimator of *R* factor because it takes into account the rainfall seasonal distribution. Therefore, the MFI was applied to take into account the monthly rainfall distribution during each year for a period of 20 years (Equation 4).

$$F_f = \sum_{j=1}^{N} \frac{F_{a,j}}{N} = \frac{1}{N} \sum_{j=1}^{N} \sum_{i=1}^{12} \frac{p_{i,j}^2}{P_j} \qquad (4)$$

Where F_f is the MFI index, p_{ij} is the rainfall depth in month / (mm) of the year *j* and *P* is the rainfall total for the same year. After the calculation of the *R*¸ a continue surface was produced by the use of ordinary Kriging method based on Gaussian function was proved to be the most effective one for the production of the final iso-erosivity map. The mean values of R factor range from 267 MJ mm / ha year^{-1} in the most flat areas in Yialias watershed to 694 MJ mm / ha year^{-1} to the mountainous and generally steep areas.

3.1.2. Soil erodibility (K)

The soil erodibility factor (*K*) refers to the average long-term soil and soil profile response to the erosive power associated with rainfall and runoff. It is also considered to represent the rate of soil loss per unit of rainfall erosion index for a specific soil.

A digital soil map of the study area was used and the main soil formations were categorized to 3 different major classes: coarse sandy loam, sandy loam and silty clay. According to [6] the estimated *K* values for the textural groups vary from 0.07 t ha h ha^{-1} MJ^{-1} mm^{-1} for coarse sandy loam, 0.13 t ha h ha^{-1} MJ^{-1} mm^{-1} for sandy loam and 0.26 t ha h ha^{-1} MJ^{-1} mm^{-1} for silty clay.

3.1.3. Topographic factor (LS)

The topographic factor is related to the slope steepness factor (*S*) and slope length factor (*L*) and is considered to be a crucial factor for the quantification of erosion due to surface run – off.

The combined *LS* factor was calculated by means of ArcGIS spatial analyst and Hydrotools extension tools. In this study the equation derived from [7] was adopted (Equation 5).

$$LS = \left(\frac{[FlowAccumulation * Cellsize]}{22.13} \right)^{0.4} * \left(0.0896 \frac{\sin slope}{0.0896} \right)^{1.3} \quad (5)$$

3.1.4. Practice factor (P)

Practice factor (*P*) is defined as the ratio of soil loss after a specific support practice to the corresponding soil loss after up and down cultivation. In order to delineate areas with terracing practices the two GeoEye-1 satellite images were used and the delineation was accomplished in GIS environment with extensive monitoring of the study area. Areas with no support practice were assigned with a *P* factor equal to 1. On the other hand the terrace areas which are considered to be less prone to erosion were assigned a 0.55 value according to expert’s opinion.

3.1.5. Cover management factor (C)

According to [6], the *C* factor represents the effect of soil-disturbing activities, plants, crop sequence and productivity level, soil cover and subsurface bio-mass on soil erosion.

The NDVI extracted from the study area (applied to GeoEye-1 image) has values that range from -0.65 to 0.99. The NDVI is used along with the Equation 6 in order to calculate the *C* factor values of the study area in GIS environment.

$$C = \exp[-a \frac{NDVI}{(b - NDVI)}] \quad (6)$$

where a and b are unitless parameters that determine the shape of the curve relating to NDVI and *C* factor.

According to the final results, the *C* factor values range from 0 to 2.7

3.1.6. Application of RUSLE methodology for soli loss estimation

The annual soil loss was calculated in GIS environment (Figure 3) according to Equation 1. According to the final results, the estimated soil loss ranges from 0 to 6394 t ha^{-1} yr^{-1} with a mean value of 20,95 t ha^{-1} yr^{-1}. The maximum value of 6394 t ha^{-1} yr^{-1} cannot be considered as appreciable due to the fact that only one pixel in a total of 1199 was attributed with this value. However the mean value of 20,95 t ha^{-1} yr^{-1} is representative of the current soil loss regime of the basin.

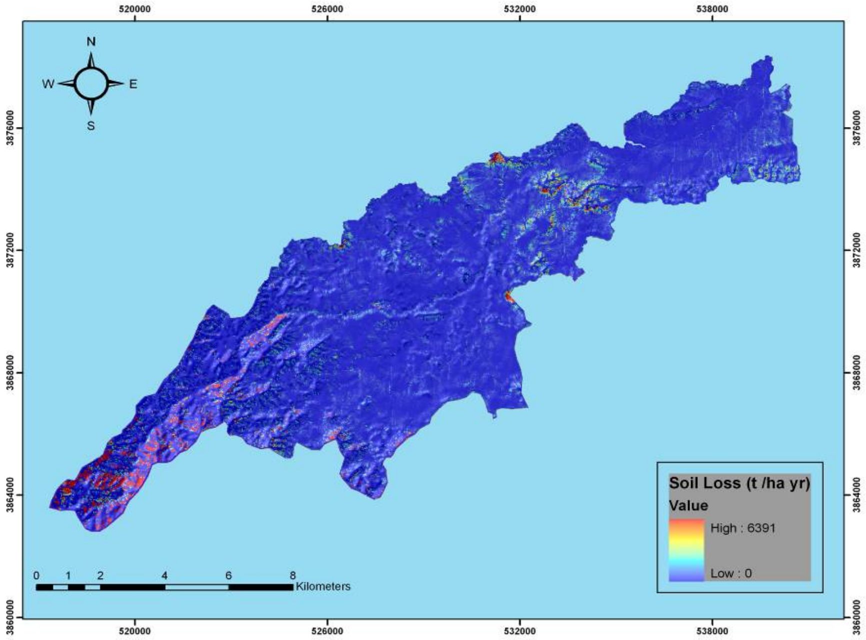

Figure 3: Map of the spatial distribution of soil loss after the application of RUSLE methodology in Yialias catchment area.

3.2. AHP methodology

In the AHP methodology interdependences and feedback between the factors are considered. The factors used in this methodology were: rainfall (*R*), soil erodibility (*K*), slope length and steepness (*LS*), cover management (*C*), support practice (*P)* and stream proximity. Six in total of seven factors had already been analysed in the RUSLE methodology. The additional agent to be analysed was the proximity to rivers and streams.

3.2.1. Proximity to rivers and streams

According to [8], an area of 50 m around rivers and streams was considered to be susceptible to flooding and, consequently, to the detachment of particles of soil by floodwaters. Thus, initially with the use of ArcGIS 10 Hydrotools module the drainage network of the basin was automatically extracted from the hydrological corrected DEM. At the next steps, a buffer zone of 50 m around was constructed around each drainage network segment.

According to AHP methodology, a pair-wise comparison of the contribution of each factor was established. Specifically, answers of several experts were collected on the reciprocal matrix, and the appropriate eigenvector solution method is then employed to calculate the factor weightings.

The final soil erosion risk map (Figur 4) was constructed by summing up (through Boolean operators) the product of each category (that had already been rated accordingly for its subcategories) with the corresponding weight of significance according to Equation 7.

$$LS = F1 * 0.025 + F2 * 0.09 + F3 * 0.146 + F4 * 0.059 + F5 * 0.38 + F6 * 0.3 \qquad (7)$$

The final erosion risk assessment map was reclassified to three soil erosion severity classes separated to low (pixel value 1), moderate (pixel value 2) and high risk (pixel value 3). The results showed that 77.5 % of the study area is classified as low potential erosion risk, 17.5 % as moderate potential risk and only a 5 % as high risk.

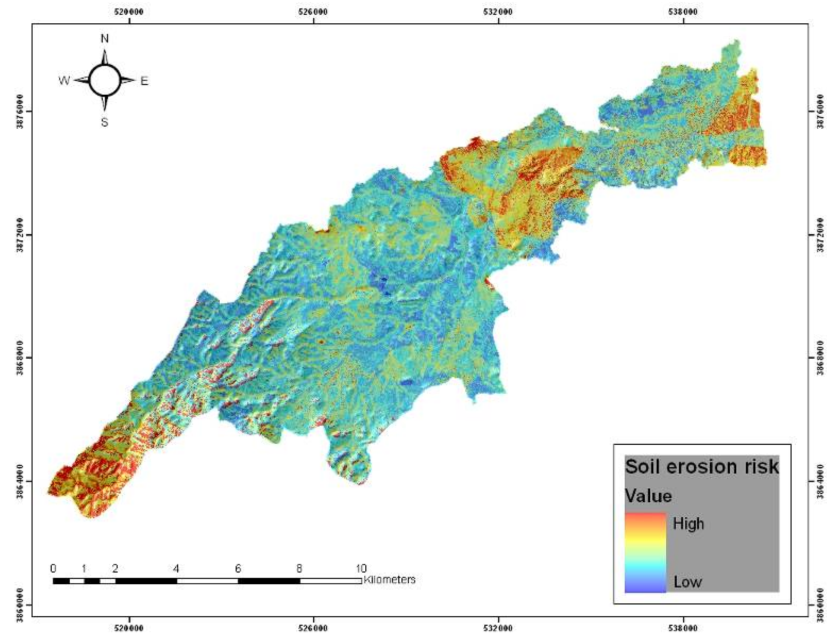

Figure 4: Final erosion risk map constructed with AHP method.

4. Evaluation of AHP and RUSLE

In the same way that the AHP risk assessment map was reclassified, the estimated soil loss percentage map was separated in 3 different classes according to experts opinion (1^{st} class 0-20 $t*ha^{-1}*yr^{-1}$ – pixel value 1- , 2^{nd} class 20-100 $t*ha^{-1}*yr^{-1}$- pixel value 2, 3^{rd} class 100-6391 $t*ha^{-1}*yr^{-1}$-pixel value 3). The two grid images were subtracted in GIS environment. Searching the extracted grid image it is obvious that there is considerable identification between the two methodologies (Figure 5).

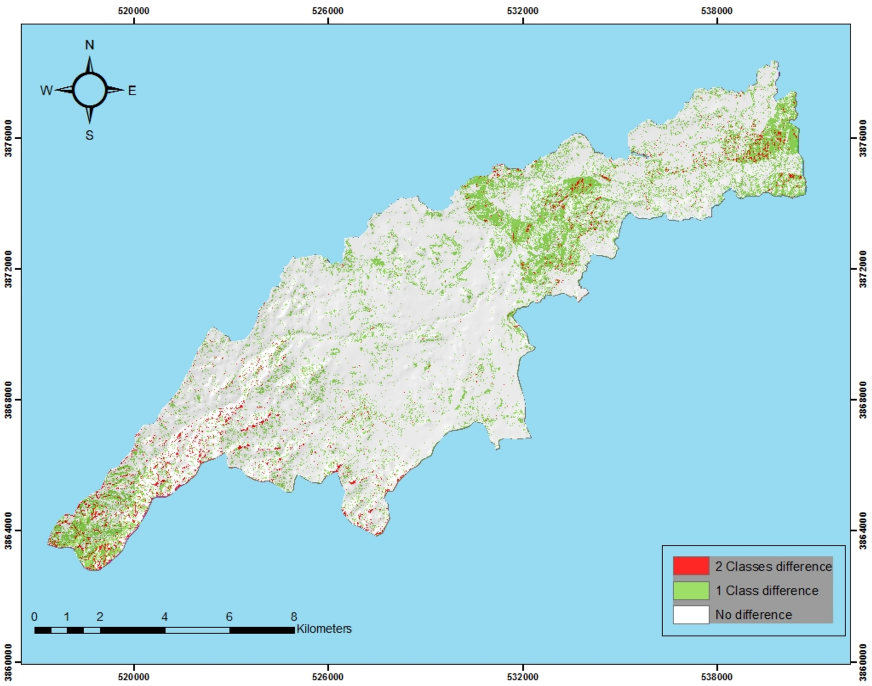

Figure 5: Image indicating the soil erosion severity class differences between AHP and RUSLE method.

5. Conclusions

This research demonstrates the integration of RS, GIS and precipitation data to model soil erosion potential. The current research proved that both RUSLE and AHP methodologies can be efficiently applied at basin scale with quite modest data requirements in a Mediterranean environment such as this of Cyprus providing the end users with reliable quantitative and spatial information concerning soil loss and erosion risk in general.

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