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Review of Soil Erosion Assessment using RUSLE Model and GIS

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Abstract
Soil erosion is one of the world environmental problems the world is facing in the 21st century affecting human society and is listed amongst the top environmental issues facing the world including increasing human population, water shortages, loss of biodiversity, energy and human diseases. An estimated 10 million hectares of agricultural lands are degraded and turned into un-farmable areas due to soil erosion thus resulting in reduced food production for the 3.7 billion malnourished people as reported by World Health Organization. Estimation of soil erosion loss and evaluation of soil erosion risk has become an urgent task by many nations before implementing soil conservation practices. There is now a large published literature on the application of the Revised Universal Soil Loss Equation known as the RUSLE model in combination with GIS technology for predicting soil loss and erosion risks in different regions. This review paper assesses the current literature on the combined application of RUSLE and GIS, examining new developments in deriving the five RUSLE components. The literature review shows that using the traditional RUSLE model in mapping out soil erosion in large watersheds poses challenges. The combined effect of RUSLE and GIS provides a useful and efficient tool for predicting long-term soil erosion potential and assessing soil erosion impacts. However, there is a need to further investigate better ways of deriving the conservation and management factor (P) in the RUSLE for better on future studies. Data source and quality is also another key issue in GIS application, thus great care must be given in checking and pre-processing GIS data, including conversion to different formats, geo-referencing, data interpolation and registration. Finally, validation of the soil erosion loss using reference data is also a valuable input towards improving the quality and correctness of the results.
Keywords: Soil erosion, RUSLE, watershed, GIS

1. Introduction

Soil erosion is define as a process in which topsoil on the soil surface is carry away from the land by water or wind and transported to other surfaces. It is considered the second prevalent environmental problem the world faces after population growth. Pimentel et al., (2009) revealed shocking figures about the erosion phenomenon, that is, most of the soil from farmlands is washed away about 10–40 times faster than it is being replaced, citing examples that United States was losing soil 10 times faster than the regular replacement rate, China and India are said to be losing soil 30–40 times faster. Soil erosion trend has increased throughout the 20th century. The land degradation in the world is about 85% which is associated with soil erosion, most of which occurred since the end of World War II, causing a 17% reduction in crop productivity (Angima et al., 2003).

The extent of soil erosion shows that it's a worldwide environmental problem with some areas such as Southern Europe and the Mediterranean region being extremely prone to erosion due to prolonged dry periods and heavy erosive rainfall, falling on steep slopes with fragile soils, causing in considerable amounts of erosion (Onori et al., 2006). Mitasovaet al., (1996) reported that in Greece, soil erosion affects 3.5 million hectares (26.5%) of the country's total land area. In countries like Malaysia, heavy rainfall is a frequent occurrence which causes soil erosion and landslides especially in steep areas where massive development occurs due to heavy pressure from agricultural and urban development (Khosrokhani and Pradhan, 2013; Pradhan et al., 2012). Himalayas in Southeast Asia and the Andes in South America, suffer some of the world's highest erosion rates because of the mountainous regions (Ismail and Ravichandran, 2008).

Literature has shown that eroded soils transport pesticides, nutrients, and other harmful farm chemicals into streams, rivers, pollute surface and groundwater resources (Gallaher and Hawf, 1997), reduce productivity and crop yields (Renard et al.,1997), caused air pollution through emissions of gases such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) (Cox and Madramootoo, 1998). Due to erosion over the past 40 years, 30% of the world's arable land has become unproductive. The erosion occurs when soil is left exposed to rain or wind energy thereby raindrops hit the exposed soil with great energy and easily displace the soil particles from the surface. Soil erosion has three-stage process involving detachment, transport and deposition as mentioned by Merritt et al., (2003). The impact intensified on sloping land, where often more than half of the surface soil is carried away as the water splashes downhill into valleys and waterways. The rate of erosion is thus influenced by the soil composition, slope of the land, and extends of vegetative cover.

Thus, timely and accurate estimation of soil erosion loss or evaluation of risk has become imperative for many countries. It is also useful to make estimate of how fast the soil is being eroded before affecting any conservation strategies. Due to the nature of the erosion process, erosion control requires a quantifiable and qualitative evaluation of potential soil erosion on a specific site, and the knowledge of terrain, cropping system, soils, and management practices. Many researchers involved in soil erosion research for quiet long time, and effort was put in understanding the mechanism of soil erosion, predicting the rate of soil erosion and soil loss both at catchment scale or plot (Fu et al., 2004; Fu et al., 2005; Kang et al., 2001), and at a regional scale. Several sediment transport and soil erosion models have been developed around the world to estimate rates of sediment and nutrient transport under different land use systems. There are three categories of model: the empirical models, the conceptual models and physically-based models as suggested by Merritt et al., (2003). These include the USLE and GIS based USLE, WEPP, AGNPS, LISEM and EUROSEM models. These models, however, vary significantly in their complexity, inputs and requirements, the processes represent and the manner in which these processes are represented, the scale of intended use and the types of output information they provide (Ismail and Ravichandran, 2008; Merritt et al., 2003).

Universal Soil Loss Equation (USLE) has emerges as a leading model and has been broadly used both in United States and all over the world in both agricultural and hilly watersheds owing to its simplicity of obtaining parameters (Wilson and Lorang, 1999). This model was first developed by Wischmeier and Smith (1978) and collected soil erosion data in 21 States in United States, analyzed and assessed various dominating factors of soil erosion, and introduced USLE to assess soil erosion by water. The USLE predicts the long-term average and annual rate of erosion on a field slope based on rainfall pattern, soil type, topography, crop system, and management practices (Kouli et al., 2009). For many decades now, comprehensive research on soil erosion by water has been conducted using this model. The model was then improved and replaced by the revised version now known as Revised Universal Soil Loss Equation (RUSLE) by additional data and incorporating recent research results to further enhance its ability to predict water erosion by integrating information made available through research of the past 40 years Renard et al., (1997). RUSLE is still widely used, as some of the models such as the WEPP are difficult to use for most users. In addition, the combination of remote sensing and GIS techniques with soil erosion models, such as RUSLE, proved to be an effective approach for estimating the magnitude and spatial distribution of erosion by other researchers. GIS is a tool efficient to integrate various datasets and assess dynamic system such as soil erosion.

The aim is to review the current state of erosion assessment and GIS applications in the literature. This will include; 1) the traditional application of the RUSLE model in assessing erosion, 2) and the application of GIS and remote sensing techniques in predicting and estimating the magnitude and spatial distribution of erosion at catchment or regional scales using RUSLE.

2. Traditional Methods of Soil Erosion Loss using RULSE

The historical background of erosion-prediction technology started with analyses as reported by Renard et al., (1997) to find the major variables that affect soil erosion by water. They listed three major factors: potential erosivity of rainfall and runoff, susceptibility of soil to erosion, and soil protection done by plant cover. Zingg (1940) published the first equation for calculating field soil loss as reported by Moore and Burch, (1986). They described mathematically the effects of slope steepness and slope length on erosion. Smith (1976) also gives additional factors for support practices and cropping system to the equation. The concept of specific annual soil-loss limit and the resulting equation to develop a graphic method for selecting conservation practices for certain soil conditions in the Midwestern United States were added.

Browning and associates (1947) as reported by Renard et al., (1997) added soil erodibility and management factors to the Smith equation and prepared extensive tables of relative factor values for different soils, crop rotations, and slope lengths. The approach emphasized the evaluation of slope-length limits for different cropping systems on specific soils and slope steepness with and without, terracing, contouring, or strip-cropping. Moore and Burch, (1986) reported a method for estimating soil losses from fields of clay pan soils. Soil-loss ratios at different slopes were given for contour farming, strip-cropping, and terracing. The recommended limits for slope length were presented for contour farming. Also, the equation is of limited value since it cannot provide information on the fate of sediment once it is eroded. The USLE model is not able to predict deposition or the pathways taken by eroded material and sediments as it moves from hill slope sites to water bodies. In European context, the most important consequences of erosion are pollution and sedimentation downstream rather than loss of productivity on-site. Policy-makers need to know more about the location of sediment sources and sinks. Similarly, the design of strategies to control pollution associated with erosion runoff and on agricultural land requires knowledge of what happens in individual rainstorms, seldom on a minute-by-minute basis, in order to forecast the size and timing of peak discharges of water and sediment from hill slopes to rivers. The USLE cannot provide this because it predicts only mean annual soil loss. The need for an alternative approach was recognized by improving on the USLE.

3. Application of GIS techniques for facilitating erosion estimation

Traditionally, the RUSLE model was developed to assess soil erosion risk for small local-scale watersheds. However, with the spatial widespread occurrence and acceleration of the soil erosion process and water quality problems, the use of RUSLE model poses inherent drawback with respect to costs of applying it, representativeness of site, and on reliability of predicted results (Lu., 2004; Wilson and Lorang, 1999). Thus, mapping of soil erosion spatial distribution is often problematic with the traditional RUSLE model (Lu et al., 2004).

The advent of GIS technology stimulated an explosive increase in GIS based models applications on regional scale. The combination of GIS technology with erosion models such as the RUSLE has improved the efficiency for estimating spatial distribution and magnitude of erosion risk with reasonable costs and better accuracy as documented by several researchers in the literature (Dziewonski et al., 1975; Mitasova et al., 1996; Cox and Madramootoo, 1998; Molnár and Julien, 1998; Millward and Mersey, 1999; Wilson and Lorang, 1999; Yitayew, 1999; Gibbs et al., 2003; Lewis et al et al., 2005; Fu et al., 2006; Erdogan et al., 2007; Neshat et al., 2014).

3.1. General methods for estimating RUSLE factors in a GIS environment.

The application of RUSLE in a GIS framework has been employed in various circumstances such as mountainous tropical watersheds, large scale watersheds, in agricultural dominant watersheds, in areas with distinct wet and dry seasons, and also in areas with dynamic changes such as in land cover patterns, agricultural farmlands and developments. The RUSLE model consists of three main databases: 1) Climatic and survey database which contains information such as monthly temperature and precipitation and contours that is required for the calculating the erosivity factor as well as slope length and steepness factors (LS). 2) Crop database contains information necessary for determining the surface cover factor (C). 3) The soil data contains soil survey and soil characterization data which is responsible determining the soil erodibility factor (K).

RUSLE model calculates the average annual soil erosion loss by considering the five factors as defined in equation 1 (Renard et al., 1997). Based on the plethora of literature, the general methodology of applying the RUSLE is to estimate each of the factors in the model. Several techniques for estimating these factors have been developed by previous researchers ranging from use of climate data, soil and geological maps, remotely sensed satellite images, empirical formulas and digital elevation model (DEM) obtained from various sources. The techniques used to generate the model factors and the results obtained are described in the next sections of this article.

$$\mathrm{A = RKLSCP} \qquad 1)$$

Where;

A = predicted long − term average of annual sheet and rill soil loss, $\mathrm{t\ ha^{-1}yr^{-1}}$

R = rainfall − runoff erosivity factor, $\mathrm{MJ\ mmha^{-1}h^{-1}yr^{-1}}$

K = soil erosivity factor, $\mathrm{Mg\ h\ MJ^{-1}mm^{-1}}$

L = slope length, m

S = slope steepness, %

C = cover and management factor

P = support practice

3.1.1. The rainfall erosivity factor (R)

Rainfall erosivity is the potential ability of rain to cause soil erosion (Lal, 1990). R factor is the most important parameter in erosion estimation by RUSLE as suggested by several researchers and its correlation with soil loss is high in many region and world rainfall site stations Fu et al., 2006; Millward and Mersey, 1999; Renard and Freimund, 1994; Wischmeier and Smith, 1978).

The general procedure employed by researchers in determining the erosion factor involves using observed historical rainfall data as well as application of several different formulas depending on the prevailing conditions of the area. The estimation of R factor poses a challenge in data poor areas or in situations where climate stations are extremely sparse. Fu et al., (2006) developed an equivalent R factor ($\mathrm{R_{eq}}$) for the Inland Pacific Northwest (IPNW) region in the USA by relating the R factor linearly with the local annual precipitation $\mathrm{P_r}$, mm as shown in equation 2.

$$\mathrm{R_{eq}} = -823.8 + 5.21\mathrm{P_r} \qquad 2)$$

Where;

$\mathrm{R_{eq}}$ = Equivalent R factor for unique climatic condition

$\mathrm{P_r}$ = annual precipitation, mm

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Millward and Mersey, (1999) also faced similar conditions of sparse climate data when assessing erosion risk in a particular watershed in Mexico. They employed a rather more improved technique in generating rainfall data. They used remote rainfall stations and rainfall was interpolated from the remote stations using interpolation methods such as kriging and inverse distance. Interpolation was done in IDRISI using an algorithm INTERPOL and the R factor was then estimated using the EI_{30} measurement. The technique used improved the results of their analysis. The simplest technique is the one used by Yitayew et al., (1999) where they converted on-site rain gauge data to energy intensity (EI) values and multiplying it by the maximum 30-min rainfall intensity expressed as I_{30}.

Renard and Freimund (1994) propose using the monthly and mean annual rainfall in environments with available long-term rainfall data, in the modified Fournier index, F, previously introduced by Sauerborn et al., (1999) which is defined by equation 3.

$$F = \sum_{i=1}^{12} \frac{p_i^2}{P} \qquad 3)$$

Where;
F = Modified Fournier index
P = mean annual rainfall depth, mm
p_i = mean rainfall amount in mm for month i

This equation was used by Kouli et al., (2009) in Crete watershed in Greece to estimate the modified Fournier index (MFI) for thirty five rainfall gauge stations as shown in Figure 1(a). The erosivity factor was then determined on the basis of the estimated MFI using the kriging interpolation method. Five classes of the R factor were established ranging from low to high erosivity range. Their showed high values from (3020–3687 MJ mm/ha year^{-1}) to medium to high erosivity (2353–3019 MJ mm/ha year^{-1}) in the Crete watershed area. A rasterized erosivity map was then constructed as in Figure 1(b) showing the spatial distribution of the rainfall erosivity. Pradhan et al., (2012) employed the same formula in their work of the correlation of soil erosion with landslide events in Malaysia.

(a) (b)

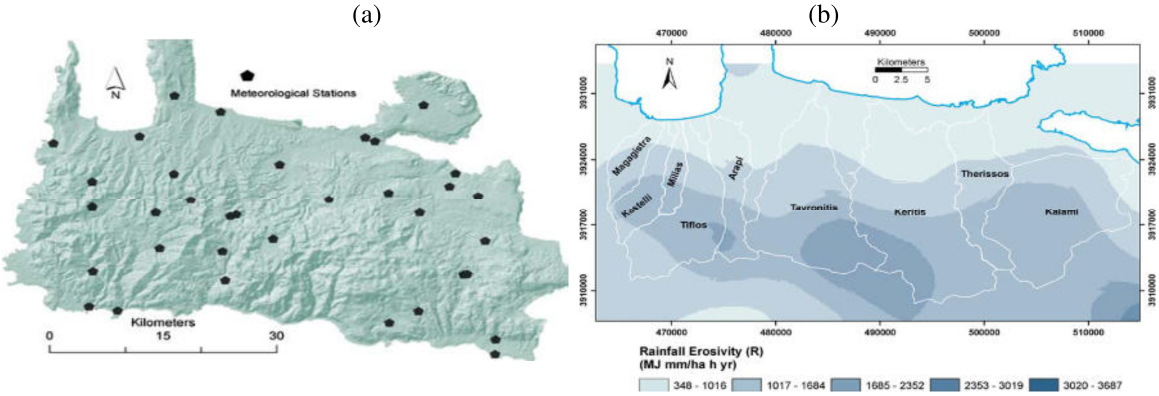

Figure1: (a) Spatially distributed rain-gauges; (b) Erosivity factor in the study area (Crete, Greece)

3.1.2. Soil erodibility factor (K)

K factor measures the erodible-ness of soil as affected by soil properties. According to Fu et al., (2006) and Millward and Mersey (1999), it characterizes the long term reaction of the soil to heavy erosive precipitation events. To measure the erodibility factor, Wischmeier and Smith (1978) proposed a simple procedure measuring five soil properties such as percent organic matter (OM), sand, silt, soil structure and permeability. The best methods in determining these soil properties as input to soil erodibility include field sampling and testing of the site of interest as employed by Yitayew et al., (1999). They then used the nomograph method to determine the erodibility factor from soil characteristics found by sampling. However, the downside of this method is its time consuming and laborious nature.

The general trend by many researchers is to utilize existing soil maps in areas where soil maps are available from government departments in hard copy format and digitize them to produce a vector coverage map. The soils are then grouped into soil classes extracted from sources such as the Agricultural Handbook as recommended by Shamshad et al., (2008) or the FAO soil classification system as employed by Millward and Mersey (1999).

A raster map was then produced by converting the vector soil map using ArcGIS tools. Ozcan et al., (2008) applied the USLE and GIS methodology in their study in Kazan watershed in Turkey where they computed soil loss from this agricultural watershed. The generated soil map of the Kazan watershed is shown in

Figure 2 and their results indicated high soil erodibility of about 88.9% containing textures of very fine sandy and silt loam soils within the watershed.

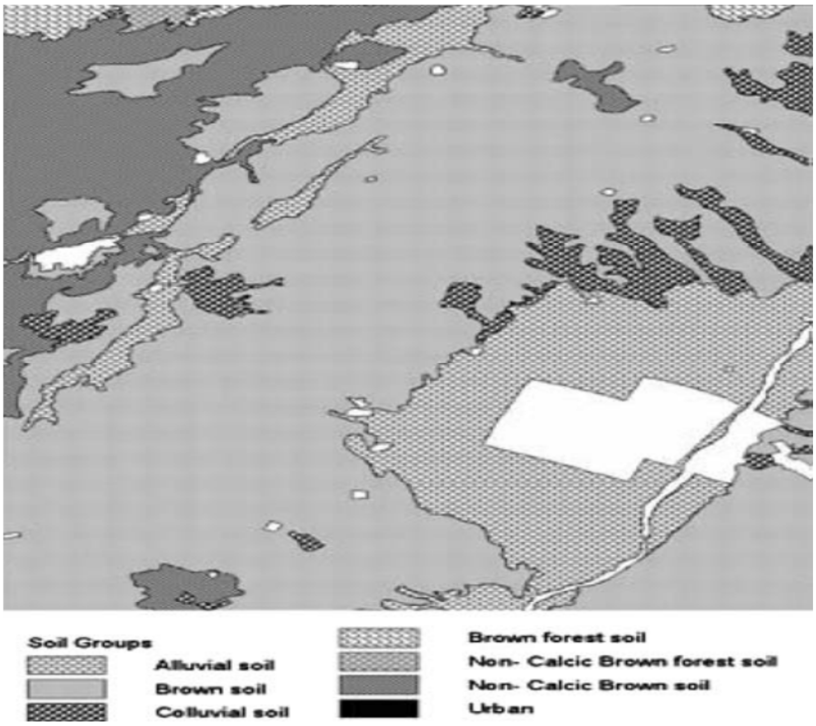

Figure 2: Map of land use for Kazan watershed in Turkey

To determine the soil erodibility factor for the watershed, the soil map serves as a base for deriving the erodibility factor layer. Erodibility factor values were assigned to corresponding soil types within the watershed. K factor was derived using equation 4 proposed by Römkens et al., (1995) and later by Renard et al., (1997).

$$K = 0.0034 + 0.0405 \text{ x } \exp\left[-0.5\left(\log D_g + 1.659\middle|0.7101\right)^2\right] \quad 4)$$

Where;
K = factor layer

$$D_g = \exp\left(\sum f_i . \ln\left(\frac{d_{i+}d_{i-1}}{2}\right)\right) \quad 5)$$

Where;
d_i = is the maximum diameter(mm)
d_{i-1} = is the minimum diameter(mm)
f_i = is the corresponding mass fraction for each particle size of clay, silt, and sand

Kouli et al., (2009) applied this formula in their study for predicting erosion with RUSLE in a GIS framework in Chania watershed in Greece. A rasterized layer of K was generated as shown in Figure 3. Their results indicated that erodibility values range from 0.02 ton ha MJ^{-1} mm^{-1} in a large areas of sandy soils to 0.04 ton ha MJ^{-1} mm^{-1} for the loamy and silt loamy soils of the study area. Their results also show that the highest values of the erodibility factor are spatially correlated with the areas which revealed quaternary and neogene sediments.

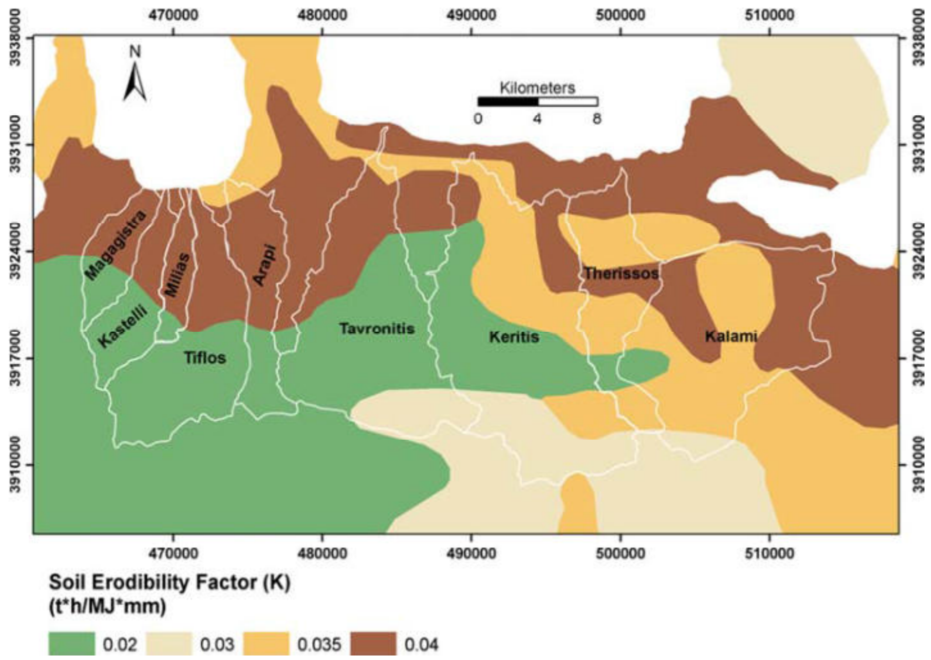

Figure 3: Soil erodibility map for Crete watershed, Greece

3.1.3. The Topography/slope factor (LS)

The Length and Slope factor in RUSLE model characterizes the influence of topography on erosion. Previous researchers in the field of soil erosion have defined slope length as the distance from the point of origin of overland flow to the point where either the slope gradient decreases enough where deposition begins or the flow is concentrated in a defined channel (Renard et al., 1997; Wischmeier and Smith, 1978). Haan et al., (1994) revealed that when the length of slope is increased there is a corresponding increase in erosion owing to increased velocity of the water flow. Thus soil loss increase proportionately with increase in length and incline of slope (McCool et al., 1987). The combined effects of slope length and slope incline give a good estimate of soil erosion rate. Rill and inter-rill erosion are the most common types of erosion and the former is as a result of surface runoff towards the direction of slope. The latter is a result of the impact of rain falling on the ground. The RUSLE represents both types of erosion and does not differentiate between these two.

The general procedure adopted by several researchers for computing the topographic effect on erosion is calculating both factors (Land S) together. Nowadays with GIS technology, many researchers have adopted using the DEM for generating topography data. The DEM is drawn from existing or digitized contours with known interval. There are many formulas capable of computing topography. Several researchers have adopted the technique as suggested by Moore and Burch (1986). This technique requires flow accumulation and slope steepness as shown in equation (6).

$$\text{LS} = \left(\text{Flow accumulation x}\frac{\text{cell size}}{22.13}\right)^{0.4}\left(\frac{\sin(\text{slope})}{0.0896}\right)^{1.3} \qquad 6)$$

Where;
LS = Slope length and steepness factor

Lim et al., (2005) developed a GIS integrated prototype version of the Sediment Assessment Tool for Effective Erosion Control (SATEEC) to provide an easy-to-use GIS interface to estimate soil erosion and sediment yield without additional input parameter data other than those for the USLE model. They applied the method suggested by Moore and Burch (1986) in the prototype SATEEC to compute the topography factor from the DEM by providing an upper bound of slope length of 122 m. Although the prototype was not validated in their study, it gave acceptable results.

Kouli et al., (2009) applied similar technique with the RUSLE version 4 in which the Arc- Info Grid was used to perform the computation steps of flow path based iterative slope-length accumulation. Each slope value was assigned in each 20 m cell of the grid surface of the watersheds. The results as shown in Figure 6 shows the topographic factor ranges from 0 in flatter zones to 118 at the steeper slopes. The results also indicate that extended areas of steep slopes are prone to severe erosion compared to smaller extents which show less proneness to erosion.

Similar consistent results were also reported by Erdogan et al. (2007) in their application of USLE and GIS models in the Kazan watershed in Turkey. They found that the combination of steep and long slopes resulted in the accumulation water with high higher erosive velocities. Overall, the application of the USLE/GIS methodology resulted in a consistent pattern of soil erosion for different land use purposes, slope incline, and soil classes. They predicted annual soil losses well showing areas that are highly susceptible to erosion due to highly concentrated flow in certain areas within the watershed. The topography of this particular agricultural watershed mostly favored less erosion.

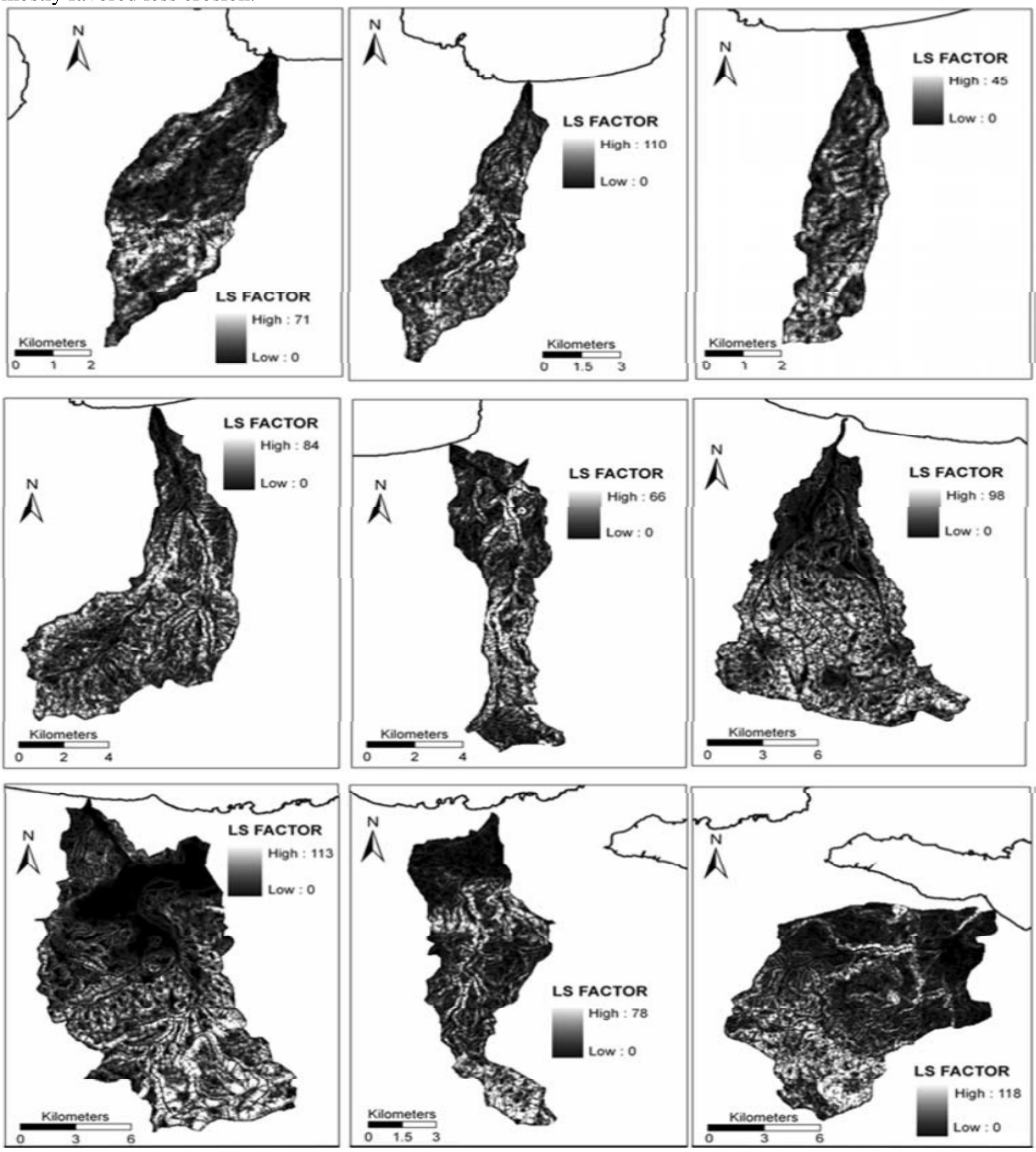

Figure 4: The topography maps covering nine subwatersheds in the Crete watershed, Greece.

3.1.4. Vegetative cover and management factor (C)

The vegetation cover and management factor represent the influence of ground cover, be it by crops in the agricultural environment and their corresponding management practices in reducing soil loss, as well as ground cover by trees and grass in non-agricultural situations (Renard et al., 1997). Ground cover tends to dissipate the raindrop erosive power prior to hitting the soil surface, as the vegetation cover increases, the soil loss decreases. Thus, vegetation cover as well as crop cover types plays an important role in controlling erosion and runoff rates. Soil erosion can be restricted with appropriate management of residues from vegetation and plant remnants (Lee, 2004). According to (Benkobi et al., 1994) in their evaluation study on refined surface in controlling erosion, noted that the surface cover and slope length and steepness are crucial in controlling soil loss.

Traditionally, the surface cover factor is derived using empirical equations based on the measurements of many variables related to ground covers collected in the sample plots. It can also be derived from weighted average soil loss ratios (SLRs) that are determined from a series of sub-factors that include prior land-use, canopy cover, surface cover and surface roughness (Renard et al., 1991). Knowledge of these sub-factors can be obtained from various sources including site visits. However, a quick and easier technique for determining the C factor is estimating a constant cover management value. A cover management factor of 0.0013 was estimated by (Yitayew et al., 1999) in their study in which they used GIS technique for facilitating erosion estimation in the Walnut Gulch experimental watershed in Arizona, although they highlighted that caution should be used in applying this technique.

However, the most widely used technique nowadays for deriving the surface cover factor is by employing remote sensing techniques in producing land use/cover classification from satellite. Lu et al., (2004) in their study of mapping soil erosion risk in the Brazilian Amazonia based their estimation of the surface cover on the fraction images from spectral mixture analysis (SMA) of Landsat ETM+ image. By using equation 7, the C factor was estimated on the assumption that abundant vegetation cover results in less soil loss and the corresponding higher losses are as a result of less vegetation cover. However, they caution that in the process of developing the C factor, there remains the need to calibrate obtained results using local (reference) data as surface characteristics is captured at the time of image acquisition.

$$C = \frac{f_{soil}}{1+f_{gv}+f_{shade}+f_{gv} x f_{shade}} \quad 7)$$

Where;

$C =$ Vegetative cover and Management factor

f_{soil}, f_{gv} and $f_{shade} =$ values of soil, gree vegetation, and shade endmembers

The three fraction values of soil, green vegetation, and shade endmembers. The values of $f_{soil}, f_{gv}, f_{shade}$ parameters range from 0 to 1 and their sum equals 1.

The most commonly used remote sensing technique is the Normalized Difference Vegetation Index (NDVI) for deriving the C factor. This index indicates the energy reflected by the earth for various conditions of surface cover type and is derived from the equation (8) for LandSat-ETM. NDVI values have two bands ranging between -1.0 to +1.0. When the measured spectral response of the earth surface is very similar to both bands, the NDVI values will approach zero. A large difference between the two bands results in NDVI values at the extremes of the data range (Kouli et al., 2009).

Vegetation that is actively growing represent a high reflectance in the Infrared portion of the spectrum (Band 4, Landsat TM), compared with the visible portion (red, Band 3, Landsat TM), thus the NDVI values for actively growing vegetation is positive. NDVI values for low vegetative surface cover range between -0.1 and +0.1, while clouds and water bodies show a negative or zero values (Kouli et al., 2009).

$$\mathrm{NDVI} = \frac{L_{\mathrm{TM4}} - L_{\mathrm{TM3}}}{L_{\mathrm{TM4}} + L_{\mathrm{TM3}}} \quad 8)$$

Where;

NDVI = Normalized Difference Vegetation Index

Kouli et al., (2009) used the NDVI technique to obtain the C factor in their soil erosion prediction study in Greece. The C factor surface was derived from the NDVI values using equation (7) as suggested by (Van der Knijff et al., 2000). Their results looked realistic showing that forest areas had the C values nearing 0 while for rocky terrain approaching 1. They also showed that the predicted slope values for the arable land are affected by crop type and management practices.

$$C = e^{(-\alpha((\frac{NDVI}{\beta - NDVI}))} \quad 9)$$

Where;

α and β are unitless parameters that determine the shape of the curve relating to NDVI and C factor

Recent work by Pradhan et al., (2012) also applied the remote sensing technique in their work on erosion and landslide study in Malaysia. They used SPOT 5 images of 2005 and 2010 with 10m spatial resolution to derive the C factor from a land cover map. The slope map was produced by assigning slope values to different classes as shown in Figure 5. Although their results are sufficient for general planning, they highlighted the need for further investigation of the C factor as it was difficult to account for actual values.

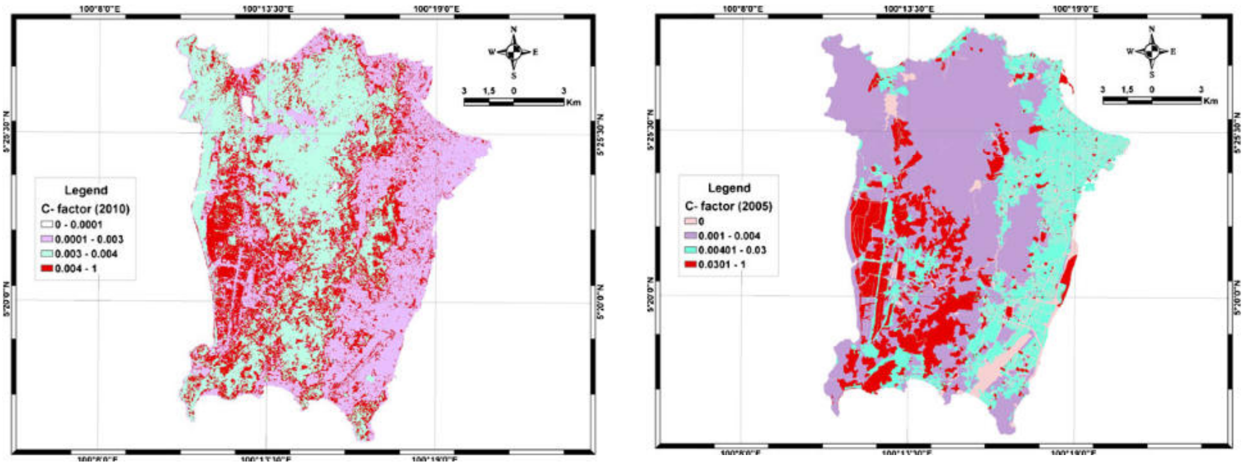

Figure 5: *C* factor layer of 2005 and 2010 of study area

3.1.5. Support practice factor (P)

Conservation and management practice factor (*P)* is a dimensionless ration accounting for soil loss under specific management practices (Renard et al., 1997; Wischmeier and Smith, 1978). Contouring and tillage practices can have significant impact on soil erosion as described by Millward and Mersey (1999). The general practice by many farmers in the agricultural sector is ploughing up and down without practicing contouring, strip cropping or terracing which results to higher P value. However, if conservation practices are incorporated, the *P*-value tends to be lower.

The generally followed approach for determining the conservation factor is by developing empirical equations. In China, Fu et al., (2005) used the Wenner method suggested by Lufafa et al., (2003) to derive the conservation factor values as given by the equation 8. The equation only requires slope which can be easily extracted from available DEM. Based on this equation, the P factor value can be applied in environments where there is no conservation and management practices.

Khosrokhani and Pradhan (2013) used this equation to obtain P values which ranged from 0.2 to 2.58, in their assessment of soil erosion in Kuala Lumpur city. Areas with greater slope were assigned the highest values, while minimum values corresponded to the regions with lower ($S = 0^0$) slope as shown in Figure 9.

$$P = 0.2 + 0.03 \text{ x } S \qquad 8)$$

Where;

$S = \text{slope grade}(\%)$

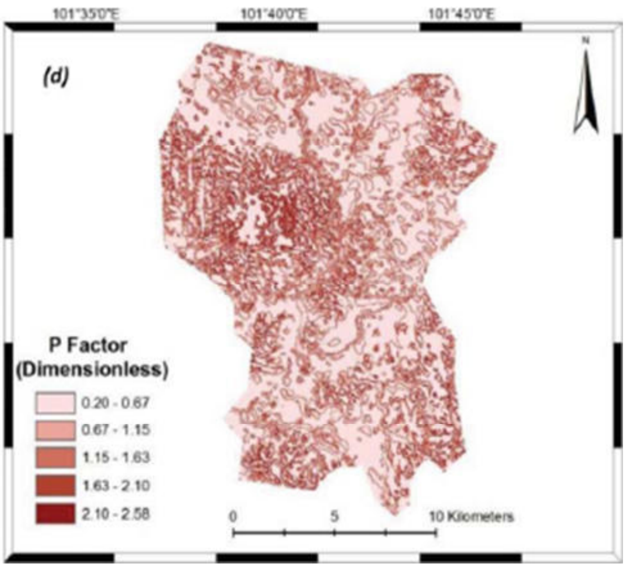

Figure 7: P factor computed from slope map of the study area

3.1.6. Overall Soil Loss

To compute the overall loss, the five gridded surfaces of the watershed were overlaid using GIS tools to produce the soil erosion potential and risk map. Typically, the map is categorized into several risk levels ranging from low to very high risks. The risk varies slope and surface cover. Lu et al., (2004) in their Brazilian Amazonia study found that the soil loss ranged from very low and low risk levels. Kouli (2009) in the Crete watershed found that there high correlation between steep slopes and poor surface cover within the watershed. Shi et al., (2004) in their application of RUSLE in the small watershed of Wangjiaqiao in China catergorized the soil loss into classes within the watershed as shown in Figure 9. They found that about 26 tonnes/ha of soil loss was from the flatter agricultural areas while 52 tonnes/ha represented cultivation occurring on steepy lands and the latter being the major contributor to sediment transport in the watershed.

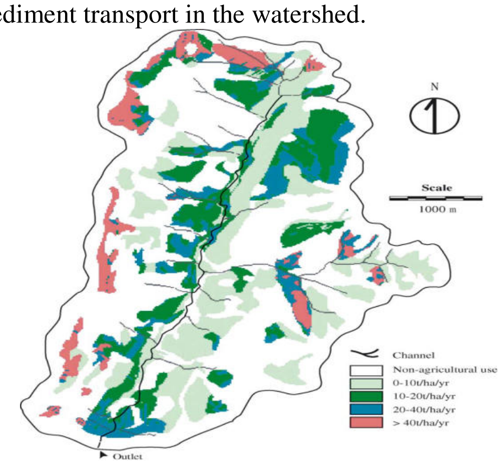

Figure10. Distribution of soil erosion loss map

4. Conclusion and Recommendations

The vast literature surveyed has shown that the RUSLE model has been applied extensively and also proven valuable in estimating soil losses as a result of erosion in many parts of the world. Although it is a suitable model for application at local (small) scale, the combination of RUSLE and GIS techniques has improved the assessment of spatially distributed of soil erosion in large catchment scales. Literature has shown that the five important components of the model can be derived from many sources (DEM, weather data, soil maps, and remote sensing images). Thus, the use of GIS technology allows for wider study area (large scale catchment) in soil erosion studies and provides the necessary tools to analyze these in order to improve the results.

The following recommendations are worth mentioning for future soil erosion studies with RUSLE model in a GIS framework:

- There is a need to further investigate better ways of deriving the conservation and management factor (P) for better on future studies.
- Data source and quality is key in GIS, therefore, great care must be given in checking and pre-processing of GIS data, including conversion to different formats, geo-referencing, data interpolation and registration.
- Validation of the soil erosion loss using reference (locally available) data is also a valuable input towards improving the quality and correctness of the results.
- Finally, other soil erosion models such as WEPP could also be applied with GIS to improve on their precision and extent of application.

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