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Original Article

The Use of Geographic Information System Soil Erosion Assessment in the North-east of Libya

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ABSTRACT

The aim of this paper is to predict annual soil losses in the North-east of Libya. The universal soil loss equation (USLE) and geographic information system (GIS) have been used to map and quantify annual soil loss in the study area. GIS were used to map USLE parameters which are: Rainfall erosivity (R), Soil Erodibility (K), Slope length factor (L), Slope steepness factor (S), Crop and management factor (C) and Conservation factor (P). Individual GIS files were built for each factor of the USLE and combined by utilising the grid-cell modelling function in GIS to predict soil loss in the spatial domain. The data which was used included: climate data, soil survey data and topographic maps. The results have shown that the study area is at erosion risk. Four main classes were found: low, moderate, high and intensive erosion. Most of the intensive erosion risk were on the best quality soils in the area. Therefore, soil conservation plans are needed to reduce erosion risks and improve crop yield. The outputs show that GIS and USLE can be applied to determine field-scale soil loss both quantitatively and spatially, and predict erosion hazard over large watersheds in Libya.The results prove that GIS permit more effective and accurate application of the USLE model for small watersheds provided that sufficient spatial data are available.

Key Words: North-eastern Libya, GIS, soil erosion, USLE.

Introduction

The effect of soil erosion on crop productivity has been recoginsed and studied for more than 50 years. The extent to which crop yield responds to soil erosion depends on several variables such as crop type, soil properties, management practices and climate characteristics. Erosion often results in a decrease of the soil supply functions in three several ways: (1) the removal of organic matter; (2) the change in depth to a possible root-barrier; and (3) the loss of structure and increased compaction (Bakker et al, 2004)

If crop growth is sensitive to drought, then it is likely that water deficit following erosion will

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become a factor behind yield reduction.With top soil removal, water availability is affected by three processes: (a) soil depth decrease, reducing soil water storage capacity; (b) loss of soil structure due to reduction in organic matter and increased compaction, which reduces the soil water holding capacity; (c) the exposure of more clayey soil material at the surface, which has a detrimental effect on the extent to which soil moisture is available to plants (Daiz-Zorita et al, 1999; Larson et al, 1985). Topsoil removal may often result in a nutrient deficit. In the absence of sufficient fertilizer application, a shortage of nutrients will cause a rapid decline in crops yield. If the top soil clay content decreases because of erosion, nutrients may still become a factor of yield reduction when fertilizer is applied. Nutrients are often strongly absorbed on to clay particles, which can lead to reduced nutrient availability (Rhoton and Lindbo, 1997).

According to Sevink (1988), accelerated soil erosion is a serious problem in the Mediterranean region. Climatic characteristics of the Mediterranean region include rare freezing; hot summer with at least one to three dry months and cool rainy winters; precipitation often falls as storms of high intensity which produce torrential runoff. Because of these violent storms, the Mediterranean climate is described as one of the most aggressive in respect of erosion (Bradbury, 1981). Also, in regions such as the southern Mediterranean, cracks can form by desiccation during dry summers, causing extreme dissection of the slopes. A major problem in the climate in this region is that the winter rainfall, which causes erosion, does not coincide with the vegetation cover that protects the soil surface, especially in cultivated cropland and heavily grazed pasture. The Mediterranean climates do not favour the development of a dense vegetation cover on most slopes, which are poorly stabilised at ground level. This is true in the study area where the environment is vulnerable, the variability of rainfall and the occurrence of occasional relatively-heavy showers characterised by high intensity can produce run off.

There have been some studies dealing with the influence of soil on agriculture potential, but the problem of soil erosion is mentioned only briefly in some pilot studies. However, there have been two major studies in Libya in general and in the study area. The first was a report by FAO (1959) made by a team of experts using the available information on water resources to advise on measures for development of water resources and water conservation in northern Cyrenaica (north-east of Libya). The second study was conducted by Selkhozpromexport (1980). It concluded that the north-east of Libya represents 70.7 % of the north-east. Selkhozpromexport (1980) distinguished two types of accelerated erosion: water erosion and wind erosion. Water erosion is common in the form of sheet washing, occurring mainly within the Jabal Akhdar Upland while wind erosion is found in the form of deflation within the littoral plain (Selkhozpromexport, 1980; Mahmoud, 1995).

The Libyan Journal of AGRICULTURE. Volume (25), No. (1-2) 2020: 89 - 102

The aim of this study is to predict annual soil losses in the north-east of Libya using USLE and GIS in order to quantify and map soil erosion.

Materials and Methods

The Study Area

Location:

The study area is located in the strip of the coastal territory and Jabal Akhdar Upland bounded by the following coordinate's lat 31° 30′ – 33° 00′ N; long 19° 50′ - 22° 45′E (Figure 1). As shown in Figure (1) , This area of the country is known as North East and includes the Benghazi region and the Jabal Akhdar highlands).

Climate:

The study area is situated in a Mediterranean type climate, in the belt of subtropical alternate atmospheric circulation. In the summer the climate is determined by a stable high pressure zone situated over the Mediterranean Sea, i.e., by the Azores maximum spur with descending tropical air currents. In the autumn-winter-spring period, climate conditions are determined by the cyclonic activity of the ascending air masses in the temperate latitude zone. The mean air temperature in winter is two or three times lower than the summer. The amount of total rainfall precipitations from October to March is 85-90 per cent of the annual precipitation, its maximum evidently being in winter. The contrast in seasonal climatic indices increases due to two factors: orographics (Atlas Mountains), and baric (the high pressure zone in summer).

The climatic conditions in the study area are unstable and depend on the distance from the sea and the altitude of the territory. Further inland, the mean annual air temperature increases, while the precipitation amount decreases. With an increase of absolute elevation in the Jabal Akhdar Upland, the mean annual air temperature drops abruptly and the amount of precipitation increases. The orographic temperature gradient equals 3.8°C, that of precipitation being 345 mm (Selkhozpromexport.1980; Mahmoud, 1995).

Soils:

Soils and their characteristics in the study area are affected to great extent by the nature and conditions in which these soils were formed. Generally, aridity is the main characterises of such soils. Most of these soils are undeveloped or partly developed. Aridisols and Entisols are the main soil order in the study area (Selkhozpromexport.1980; Mahmoud, 1995).

Soil Erosion Predictions:

Prediction methods of soil erosion were described by Foster (1988) as a package of scientific knowledge that effectively transfer technology from research to the user. A model is a method of predicting soil loss under a wide range of conditions (Morgan, 1995). Three types of models can be identified: black box, grey box and white box.

Most of the models used in soil erosion studies are the empirical grey-box type. They are based on defining the most important factors and through use of observation, measurement, experiments, and statistical techniques, relating them to soil losses (Morgan, 1995).

In recent years significant advances have been made in the understanding of the mechanics of erosion. As a result a great emphasis has been placed on developing white-box and physically-based models. Hudson (1995) classifies the models into four different models: empirical or black-box models; process-based or physically based models; productivity models and watershed models. Morgan and Hudson (1995) descriped the models and their theoretical background.

There are many models which have been developed to predict soil loss casued by erosion. For instance , WEPP (Water Erosion Prediction Project) and EUROSEM (European Soil Erosion Model). WEPP is a process-oriented model, based on modern hydrological and erosion science, designed to replace USLE for the routine assessment of soil erosion by organisations involved in soil and water conservation and environmental planning and assessment.

European Soil Erosion Model (EUROSEM) is an example of the European effort to develop more process-based models of rainfall erosion (Quinton and Rickson, 1994; Morgan, 1995). However, these process-based models have data and computer requirements that cause difficulties when efforts are made to apply them beyond the small catchment scale. Data constraints mean that, for practical purposes, the USLE provides the basis for modelling rainfall erosion in catchments (Kinnell, 1998).

The Universal Soil Loss Equation (USLE):

The Universal Soil Loss Equation (USLE) was applied in the GIS to determine the average annual soil loss in the study area. The USLE is designed for predicting soil loss at a field scale, as a basis for the selection of conservation practices for specific sites, but it is not intended for predicting soil loss from a watershed or other larger areas. It can, however, be used for the latter purposes by subdividing the area under consideration into sites with similar characteristics, and by calculating the soil loss for each of these, and multiplying by their relative extent proportionately.

The USLE predicts soil loss for a given site as the product of six major factors (Equation .1) whose value in a particular location can be expressed numerically (Wischmeier and Smith, 1978).

$$\mathbf{A = R \times K \times L \times S \times C \times P} \quad \mathbf{(1)}$$

A = Annual soil loss in t ha^{-1} y^{-1}

R = Rainfall erosivity factor (J mm.m^{-2} h^{-1})

K = Soil erodibility factor (t J^{-1} $mm^{-1)}$

L = Slope length factor

S = Slope steepness factor

C = Crop and management factor

P = Conservation-supporting practices factor

The data for the model were obtained from Benina weather station, soil survey data and topographic maps. Individual GIS files were built for each factor of the USLE and combined by utilising the grid-cell modelling function in ArcGIS (ESRI, 2000) to predict soil loss in the spatial domain.

Determining Rainfall erosivity (R):

Rainfall erosivity constitutes an important factor for the understanding of the geomorphological processes that are taking place in a territory. However, this parameter is often difficult to estimate, due to the lack of the necessary pluviometric records. Therefore, some other equations such as the Fournier index can estimate, with good accuracy, monthly and/or annual values of rainfall erosivity by using pluviometric records, such as annual and monthly rainfall averages. The Fournier index presented in (Equation 2) represents an equation widely used for this purpose:

$$\mathbf{Cc = M^2x/P} \quad (2)$$

Cc = Fournier index

M = Monthly value of precipitation (mm) for month x

P = The annual values of precipitation (mm)

Rainfall erosivity was determined using data from the Benina meteorological station in Benghazi, for which monthly and annual values of precipitation records were available.

Determining Soil Erodibility (K):

The aim of the soil erodibility assessment is to provide a factor K which is spatially interpolated for the whole study area, for the calculation of soil loss within the USLE. Figure (2) shows a flow diagram of the steps taken in determining the K-factor of the soil in the study area.

The relation between erodibility and the physical and chemical properties of some Libyan soils are studied by (El-Asswad and Abufaied, 1994). Fifteen equations were produced expressing the relation between soil physical and chemical properties (Clay%, Sand%, Silt%, EC, pH, CaCo3 %, organic matter, bulk density and permeability). The findings of the study were in agreement with findings by Wischmeier and Smith, (1971; 1978).

Figure 2 shows a map of the K-factor values present in the study area. The K – factor was calculated for each soil sub-type. The map in figure (2) shows a classification for k- factor to get an indication about the k- factor distribution. The K-factor has been grouped together into classes in Figure (3) to give a general overview. A more detailed map could be created for smaller areas showing the individual K-factor for each soil sub-types.

Determining Crop and management factor (C) and Conservation factor (P)

The factors C and P are derived from the specification of land utilisation type (for each of the selected crops). For each crop, there is a land use factor and value which is used in the estimation of soil loss.

Compared to the other factors of USLE, research on the P factor has been rather limited. Thus, P-factors have been taken from the original values developed in the USA by Wischmeier and Smith (1978). The values of P range from about 0.05 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices (Wischmeier and Smith, 1978).

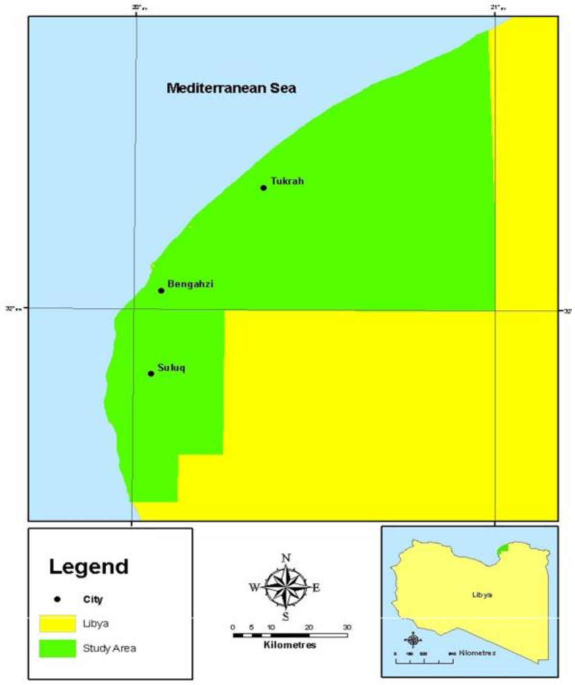

Figure 1. The location of the study area

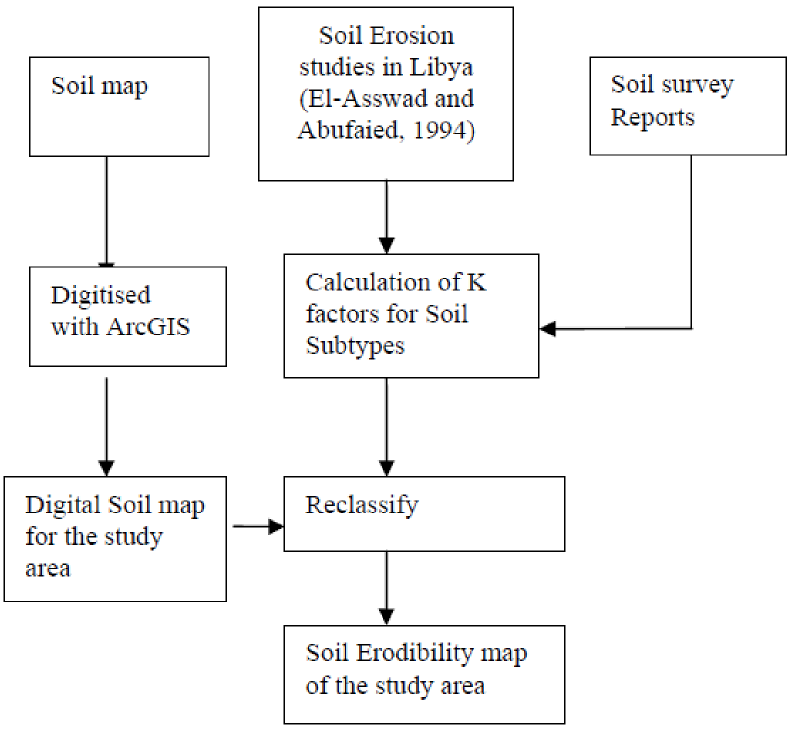

Figure 2. Determination of K factor of soil in the study area

The Libyan Journal of AGRICULTURE. Volume (25), No. (1-2) 2020: 89 - 102

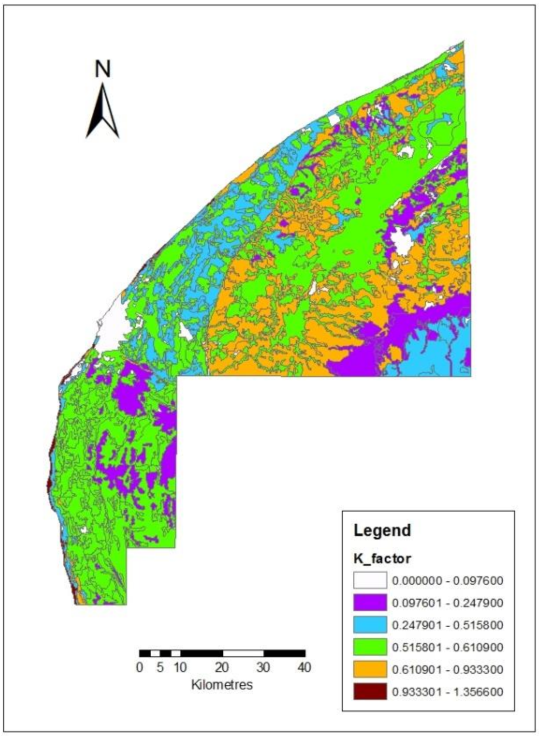

Figure 3. Soil Erodibility in the study area

Determining Crop and management factor (C) and Conservation factor (P)

The factors C and P are derived from the specification of land utilisation type (for each of the selected crops). For each crop, there is a land use factor and value which is used in the estimation of soil loss.

Compared to the other factors of USLE, research on the P factor has been rather limited. Thus, P-factors have been taken from the original values developed in the USA by Wischmeier and Smith (1978). The values of P range from about 0.05 for reverse-slope bench terraces, to 1.0 where there are no erosion control practices (Wischmeier and Smith, 1978).

The factors of slope steepness (S) and length (L) can be calculated separately or they can be merged into a single index (LS), which expresses the ratio of soil loss under the steepness and length of slope, to the soil loss from the standard USLE plot conditions, The L and S factor can be obtained from the equations developed by Wischmeier and Smith (1978) (equation 3 and 4).

$$\mathbf{S = 65.41 \sin 2\,\theta + 4.56 \sin\theta + 0.065} \quad (3)$$

$$\mathbf{L = (\lambda / 22.13)\, m} \quad (4).$$

θ = angle of the slope

λ = Slope length in m

m = an exponent that depends on slope steepness and m is 0.5 for slope steepness exceeding 5 per cent slopes, 0.4 for 4 per cent slopes and 0.3 for slopes less than 3 percent. Equations 3 and 4 were developed for single uniform slopes. The topographic factor (LS) described will usually overestimate soil loss from concave slopes, and underestimate loss from convex slopes. To correct for irregular slopes, Foster and Wischmeier (1974) proposed the following adaption to the USLE equation:

$$\mathbf{A} = \mathbf{RKCP}\,[\boldsymbol{\Sigma}\,(\mathbf{Sj\,Xj\,1.5} - \mathbf{SjXj\text{ - }11.5})/\ \mathbf{Xe}\,(\mathbf{22.13})\,\mathbf{m}] \qquad (5)$$

Where,

Xj = distance from the top of the slope to the lower end of the segment (m)

Xj -1 = slope length from the top of the hill to the upper end of the segment (m)

Xe = Overall slope length (m)

Sj = the value of the slope–gradient factor for the j segment and A, R, K, C, P and m= are as defined previously (in equation 1).

For long slopes on which rill and interrill erosion occurs, the LS factor has been found to consist of two linear relationships with break points at the 9 percent and 1 percent slope. These relationships predict less erosion on slopes steeper than 9 percent and also on slopes flatter than 1 percent compared to the original Wischmeier's equation. The two equations are given as follows:

$$\mathbf{S = 10.Sin\,\theta + 0.03\ for\ slopes} < \mathbf{9} \qquad (6)$$

$$\mathbf{S} = \mathbf{10.Sin\,\theta\text{ - }0.50}\ \text{for slopes} > 9\,\% \qquad (7)$$

These relationships describe the increase in soil erosion as the slope steepness increases due to the formation of larger rills on the steep slope. The application of the USLE in a GIS environment has greatly benefited from the possibilities of generating digital elevation models (DEM) using contour maps (Burrough, 1992). Thus algorithms for automatically determining the USLE LS- factor in the GIS have been developed. In a simplified form, Moore et al (1991) developed the equation 6.8, for the LS factor in GIS:

$$\mathbf{LS} = (\mathbf{m+1}) \times (\mathbf{As}\,/\,\mathbf{22.13})\,\mathbf{m} \times (\mathbf{sin\,\theta}/\,\mathbf{0.796})\,\mathbf{n} \qquad (8)$$

n = 1.3

As = the specific catchment area, while m and θ are defined previously.

This equation was derived from the unit power theory proposed by Moore and Burch (1986), and is better suited to landscapes with complex topographies than the original given by Wischmeier and Smith (1978), as it explicitly accounts for flow convergence and divergence through the As term in equation (8). In applying the USLE for large catchments, the LS factor determination is very important. The Moore et al equation (1991) was used, as a very high resolution input DEMs was available

Digital topographic data for the study area were obtained from 50 sheets of topographic maps at scale of 1:50 000 digitised by the Survey of Libya. This work was done with PC ArcInfo (ESRI, 2000).

Creation of a DEM

The Digital Elevation Model (DEM) of the study area was generated using TOPOGRIDTOOL within Arc/Info (ESRI,1997).

The TOPOGRIDTOOL generates a hydrologically-correct grid of elevation data points from stream and elevation coverage. A grid cell size of 10 m was used (Figure 4).

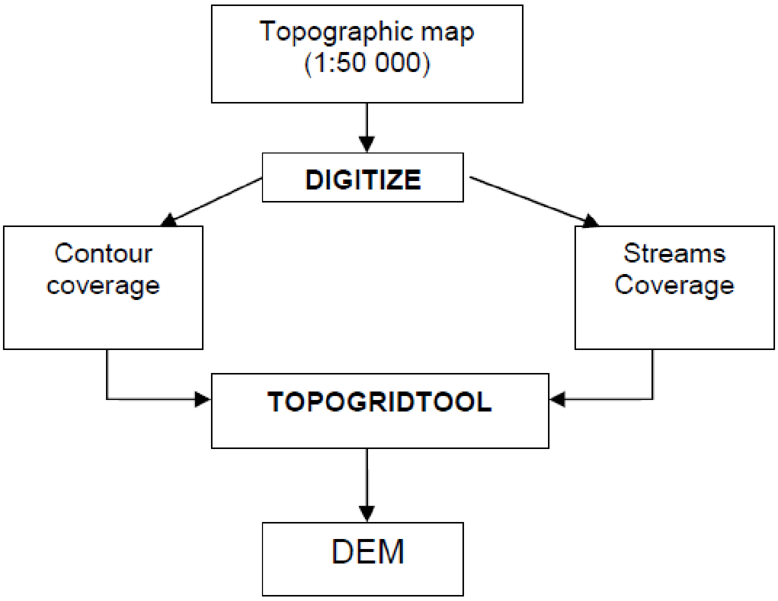

Figure 4. Procedures in the preparation of DEM and LS-factor maps

Results and Discussion

Calculation of Soil Loss

The calculation of soil loss for the erosion hazard map was done directly in ArcGIS, by multiplying the respective USLE grid files (Figure 5). The resulting output grid files contained actual calculated values of soil loss for each crop.

Tolerable soil loss rates (T)

The T- value is operationally defined in terms of the long-term averaged annual soil losses estimated with the USLE and is normally applicable to the agriculture field. It is a value based on renewal due to soil formation rates, as well as replenishment of fertility from added organic matter.Guide values of T have been developed in the USA which has been adopted by many other researches for the assessment of erosion hazard. In this paper the critical values used are the one developed in (Nwer,2005). The next Table shows these threshold values . Based upon these values a soil erosion map was prouduced (Figure 6).The amount of erosion was estimated using the USLE Equation (1). The source data were limited to rainfall studies and the soil map displaying only the representative values of the soil variables. The only available source of climatic data was the Benina meteorological station. Moreover, the R, L, and S factors were themselves derived through the use of several regression formulae. The equation therefore incorporates a series of discrete data sources, each of which has in itself a degree of uncertainty. In combining these data sources together, there is a concern that one is compounding the uncertainty, magnifying it in the result. The ambition is therefore to minimise as far as possible uncertainties in each constituent data source, whilst recognising the difficulties of limited, missing and incomplete input datasets. Examples exist in the literature as to how this approach can be recognised (Burroughs, 1992). In this research, the datasets available in the Libyan context effectively preclude such bracketing of uncertainty due to the limited nature of the source information available.

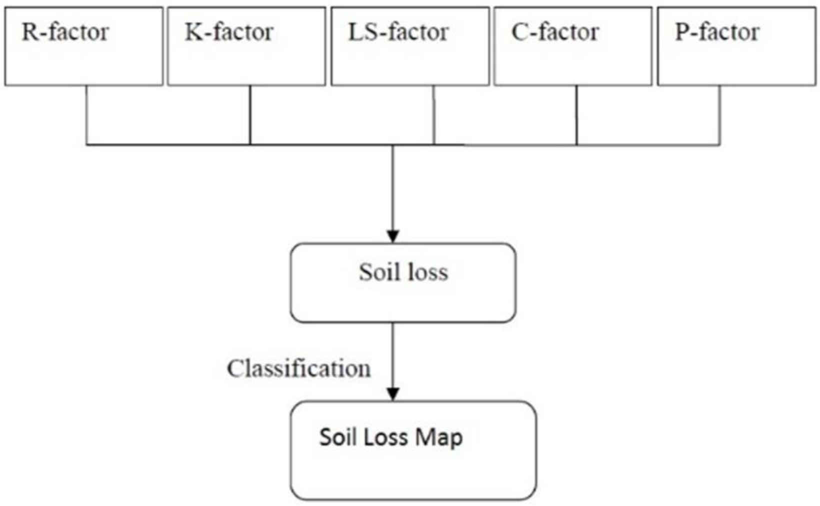

Figure 5. Application of USLE in GIS to calculate Soil loss

Table 1. Tolerabe soil loss values and classes

Soil loss classes		Potential Soil Loss (ton h^{-1} yr^{-1})
Low	0- 2	
Moderate	>2 – 5	
High	>5 – 7	
Intensive	> 7	

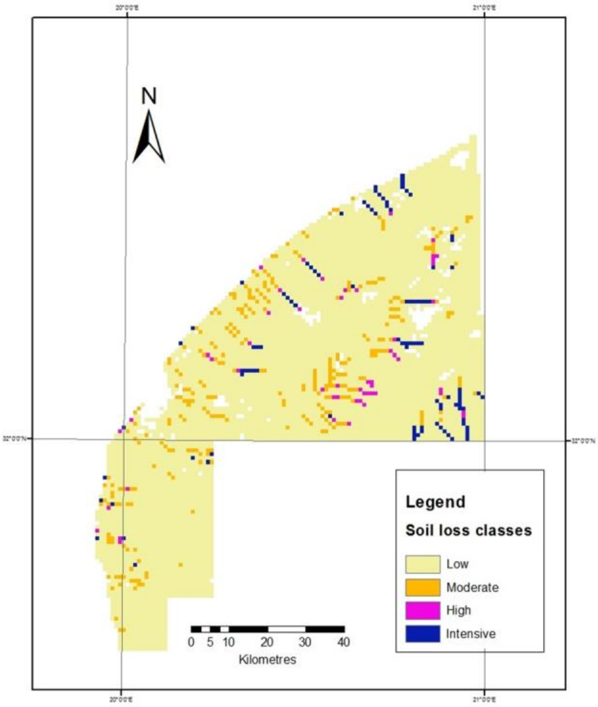

Figure: 6. Soil loss Classes in the study area

Conclusion

This study was done to assess and quantify the soil loss problem in the study aera . GIS was used to map USLE parameters R, K, LS, C and P factor. The integration of USLE in GIS environment was an effective tool to analyse and spatially map the soil loss. Therefore it was possible to creat a soil loss map for the study area average annual soil loss risk in the study area is moderately high from the acceptable limit. The methods and the predicted amount of soil loss and its spatial distribution of the study area described in this study which are useful to formulate and further implement conservation program that will reduce soil loss from the study area.

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The Libyan Journal of AGRICULTURE. Volume (25), No. (1-2) 2020: 89 - 102

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المجلة الليبية للعلوم الزراعية
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استخدام نظم المعلومات الجغرافية فى تقدير تعرية و انجراف التربة

بشير نوير

قسم التربة والمياه – كلية الزراعة – جامعة طرابلس

المستخلص

تهدف هذه الورقة إلى التنبؤ بكميات الفقد السنوي للتربة في شمال شرق ليبيا. تم استخدام المعادلة العالمية لتقدير فقد التربة (USLE) ونظم المعلومات الجغرافية (GIS) لتقدير وتخريط الفقد السنوي. وقد استخدمت نظم المعلومات الجغرافية لتخريط عناصرالمعادلة العالمية لتقدير فقد التربة والتي تمثلت في: قابلية التعرية بالأمطار (R)، وقابلية التربة للتعرية (K)، وعامل طول المنحدر (L)، وعامل درجة الانحدار(S)، وعامل إدارة المحاصيل (C)، وعامل الحفظ (P). تم بناء ملفات (GIS) فردية لكل عامل من المعادلة العالمية لتقدير فقد التربة، ودمجت باستخدام وظيفة نمذجة خلايا الشبكة في GIS للتنبؤ بفقد التربة في النطاق المكاني. شملت البيانات المستخدمة: البيانات المناخية، وبيانات التربة، والخرائط الطوبوغرافية. أظهرت النتائج أن منطقة الدراسة معرضة لخطرالتعرية. حيث وجدت أربع درجات رئيسية وهى: منخفضة، متوسطة، عالية، وشديدة. كانت معظم درجات التعرية الشديدة على الترب ذات الجودة العالية بالمنطقة. مما يستدعي خططا لحفظ التربة لتقليص خطر التعرية وتحسين إنتاج المحصول. أوضحت المخرجات أنGIS وUSLE يمكن تطبيقهما لتحديد فقد التربة على المستوى الحقلي معا كميا ومكانيا، والتنبؤ بمخاطر التعرية على أحواض أوسع في ليبيا. أثبتت النتائج أن نظم المعلومات الجغرافية تسمح بتطبيق أكثر فعالية ودقة لنموذج USLE للأحواض الصغيرة بشرط أن تتوفر بيانات مكانية كافية.

الكلمات الدالة :شمال شرق ليبيا ،نظم المعلومات الجغرافية، انجراف التربة، المعادلة العالمية لتقدير لفقد التربة.

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