Assiut University Bulletin for Environmental Researches

VoI. 17 No. 1, March 2014

GIS modeling of water erosion in Jordan using "RUSLE"

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ABSTRACT

Jordan is a country dominated by arid climate and fragile ecological system, which makes land degradation, soil erosion and desertification important areas of interest. This study creates a soil erosion model based on the RUSLE erosion model, resulting in a national potential soil erosion map for Jordan. The objective of this study is to create a national potential erosion map for Jordan using the RUSLE erosion model. To meet the objective of this study a GIS database was created to support the application of RUSLE in Jordan. The R, K, LS, and C factors have been created from RUSLE model using local data. The C factor was estimated from previous studies, and expert's evaluations. According to RUSLE model, the regions with high erosion rates are the northern highlands, Jordan Valley escarpment and some parts of Araba Hills in the southern Jordan. These regions have steep slope with precipitation rates ranging from 50 mm to 100 mm in the south to 550 -600 mm in the north. The model shows that the annual soil loss ranges between 0 - >100 tons/ha.yr.

Keywords: Erosion, desertification, RUSLE, GIS, modeling

INTRODUCTION

Soil erosion is the process of dislodgement and transport of soil particles from the surface by water and wind. The soil particles can be moved by the energy expended at the soil surface by the raindrops and then transported by water, wind or the force of gravity. (***Brooks et al. 2003***). When the rate of rainfall exceeds the infiltration rate on slopes, surface runoff occurs potentially causing rill erosion when it is combined with the raindrops splashing erosion and sheet erosion can results in a large amount of soil loss. Soil erosion implies loss of soil fertility and productivity as well as increasing the sedimentation that would affect the water quality.

Recently, the impact of climate change has caused damage in different parts of the world. In Jordan, the dry climate prevents expanding agricultural areas resulting in increasing the pressure on the existing agricultural land. High intensive rainfall events are considered a real threat to farm livelihood, wildlife and water quality. This manner of soil loss can be dramatic on steep unobstructed slopes exposed to heavy rain, where soil loss can be observed clearly in dry lands with sparse vegetation cover due to poor land management practices (***Brooks et al. 2003***). Other man made factors that contribute to accelerated erosion land degradation in Jordan are the population growth, overexploitation of water resources, plowing practices, overgrazing and deforestation.

The mapping and estimation of soil erosion in Jordan is crucial for the soil conservation. These products can support strategies aimed at preventing further erosion and land degradation. Many methods have been developed to estimate the soil loss quantitatively including USLE (Universal Soil Loss Equation), MUSLE (Modified Universal Soil Loss Equation), RUSLE (Revised

Universal Soil Loss Equation), WEPP (Water Erosion Prediction Project) and RHEM(Rangeland Hydrology and Erosion Model).

This study estimates the soil erosion by water using RUSLE method to create a potential erosion map for Jordan. The RUSLE model was chosen because it represents the affects of rainfall, soils, terrain and management practices on soil loss, uses data that are available in Jordan, and can be applied in a geographic information system (GIS) (***Brooks et al. 2003***).

MATERIALS AND METHODS

Study Area

Jordan is located in a dry region, where 85 % of its land is classified as arid and semi arid. The country is divided into four physiographic regions (Figure 1)

1) The Jordan Rift Valley (JRV) along the western border of the country, starts at lake Tiberius in the north (212m below sea level) and continues south through the Jordan valley into the Dead Sea on the West bank –Jordanian border (417 m below the sea level), from the Dead Sea southwards, it is occupied by Wadi Araba, then the Gulf of Aqaba and then the Red Sea .

2) The Highlands run from north to south, they consist of ranges of mountains and plains at an altitude between 600 and 1600 above sea level and many wadis sloping towards the JRV.

3) The Plains have a total area of 10 000 km^2 and extend from north to south along the western borders of Al Badia desert region.

4) Al Badia desert region in the east with a total area of 69 000 km^2 is an extension of Arabian Desert.

The dry climate of Jordan prevents increasing the agricultural areas leads to increasing the pressure on the existing agricultural land. Many factors contribute to land degradation in Jordan such as population growth, overexploitation of water resources, plowing practices, overgrazing and deforestation which affect the soil characteristics and make it fragile and susceptible to erosion.

Data Sets for RUSLE

Soil erosion is affected by different factors including rainfall intensity, soil types and texture, topography and land use. These factors can be represented using the GIS techniques. In order to predict the soil erosion, the following spatial and temporal datasets are used:

1. DEM (Digital Elevation Model) of 30 m resolution (Source: http://www.gdem.aster.ersdac.or.jp/search.jsp).

2. Soil map (1:250,000) (Source : National Soil Map and Land Use Project - JOSCIS - Ministry of Agriculture)

3. Land Cover Map (1:250,000) (Source : Royal Jordanian Geographic Center - RJGC)

4. Long term of annual rainfall precipitation of 31 rainfall station (Source: Jordan Climatological Handbook 2000).

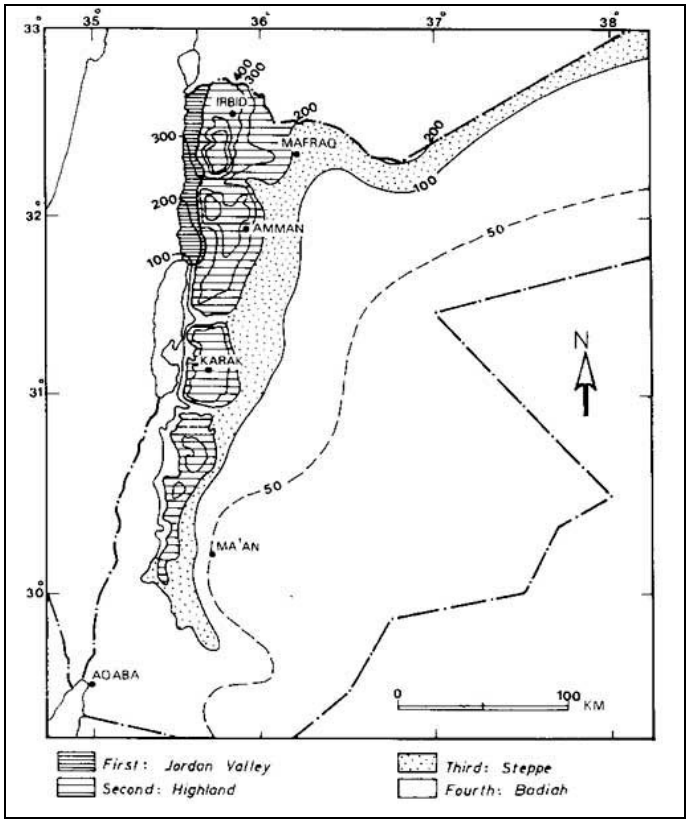


Figure 1: Physiographic Regions

(Source: http://www.fao.org/ag/AGP/AGPC/doc/Counprof/Jordan/Jordan.htm)

DEM Digital Elevation Model (DEM)

The DEM of 30 m resolution is shown below in Figure (2). The DEM shows that the elevation of Jordan ranges from -453 to 1812 m. From the DEM, we derived flow accumulation and the slope gradient in degrees which are used in slope length and steepness factors (LS) calculations.

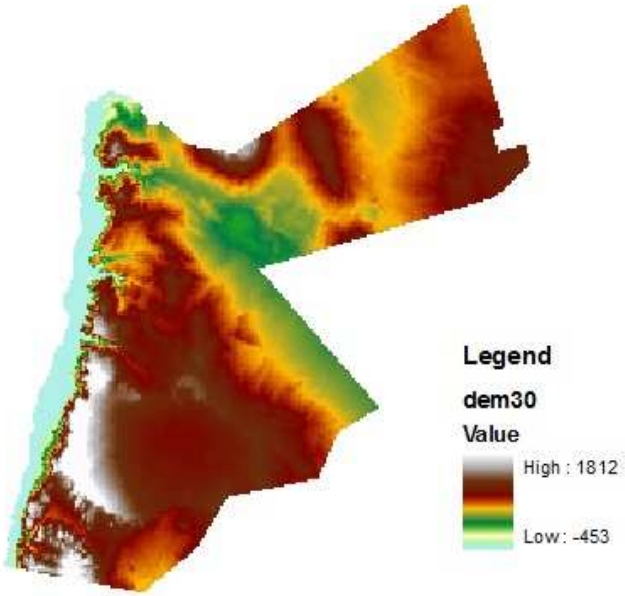


Figure 2: The Digital Elevation Model of Jordan (DEM) 30-m Resolution.

Soil Classification Map

The systematic soils survey and land classification in Jordan started in 1989, where a combined team of expatriate consultants and Jordanian staff mapped the soils of Jordan at different levels of details, through a project that lasted for a period of about 72 months, (**Al Qudah, 2003**). A soil map at a scale of 1: 250,000 were created. This map represents the soil of Level 1, where a careful analysis of LANDSAT remotely sensed imagery and aerial photography were substantiated and expanded by field observation in sample areas and traverses of an overall density of one observation site every 7.6 km2 Broad soil types thus were defined and grouped into appropriate mapping units and shown on a 1: 250,000 scale map (Baker al Qudah, personal correspondence). Figure (3) is the soil classification for Jordan. A supervised classification of Landsat 5 Satellite image of 30 m resolution had been conducted by Royal Jordanian Geographic Center (RJGC) Staff in 2005.

Precipitation Data

In this study, records from 31 rainfall gauging stations were used to estimate the R factor. These stations cover the entire country and allow for R values to be computed on all the regions.

METHODOLOGY and PARAMETERS ESTIMATION

This section of the study describes the basic concepts, the RUSLE model procedures, and the methodology we used to estimate the six parameters of the RUSLE. The parameters of RUSLE were estimated mainly based on the DEM, soil type map and land cover map.

RUSLE Parameters Estimation

According to **Shen and Julien (1993)** a complex interaction between topology, geology, climate, soil vegetation, land use and man–made developments affects the extent of erosion, specific degradation and sediment yield from a watershed. USLE was developed by **Wischmeier and Smith (1965)** based on long term of data from about 10,000 test plots throughout the US. Each test plot represented a different soil, terrain and management situtation and hence allowing the soil loss measurements to be combined into a predictive tool, to predict the long term rates of inter-rill and rill erosion from field or farm units treated by different management practices. RUSLE was developed to add new research results to the earlier USLE released in 1978 (**Wischmeier and Smith 1978**).

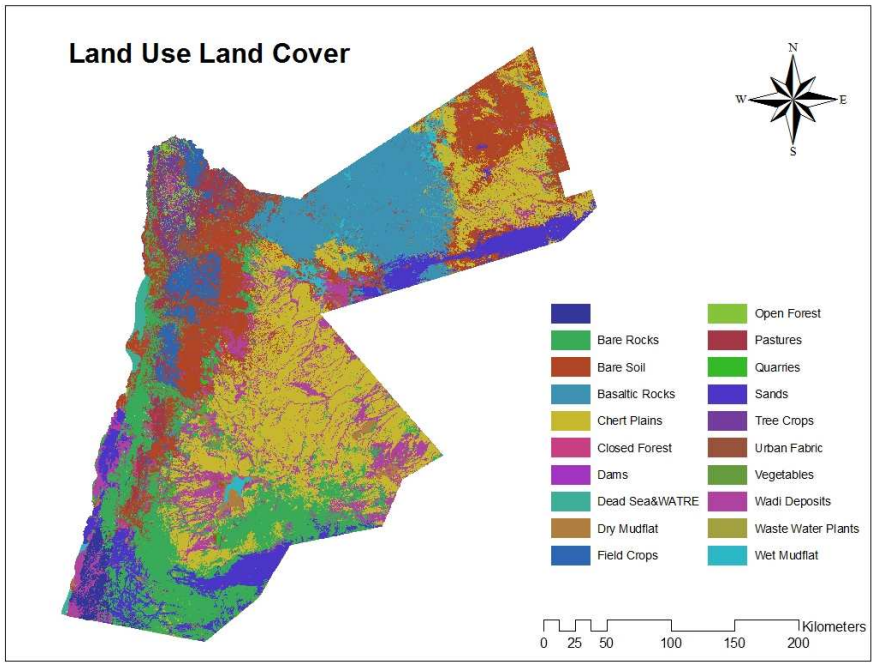


Figure 3: Land cover /Land use classification of Jordan. Source (**RJGC, 2005**)

Both the USLE and the RUSLE calculate the predicted annual erosion from the hillslopes according to the following equation:

$$A = R \times K \times L \times S \times C \times P$$

Where:

A = computed spatial average soil loss and temporal average soil loss per unit of area;

R = rainfall-runoff erosivity factor;

K = soil erodibility factor;

L = slope length factor;

S = slope steepness factor;

C = cover management factor;

P = support practice factor.

The L and S factors express the dimensionless impact of slop length and steepness, and C and P factors express the dimensionless impact of cropping and management practices on soil loss estimation. The RUSLE is a standard tool for prediction erosion not only in the US but also through the world (**Meyer, 1984**).

Rainfall-Runoff Erosivity Factor (R)

The rainfall – runoff erosivity factor is defined as the mean annual sum of individual storm erosion index values, EI30, where E is the total storm kinetic energy and I_{30} is the maximum rainfall intensity in 30 minutes. To compute storm EI30, continuous rainfall intensity data are needed. **Wishmeier and Smith (1978)** recommended that at least 20 years of rainfall data be used to accommodate natural climatic variation. In some parts of the world there is lack of long-term rainfall intensity data makes applying RUSLE more difficult.

In 1977 Arnoldus found a relationship to estimate R factor based on monthly and annual precipitation data using Fournier Index equation. He started his work in Morocco and he concluded that relations obtained using the modified Fournier index should be applied only to locations within homogeneous climatic regions (**Renard and Freimund 1994**). The following relation was used to develop an isoerodent map for Morocco (**Arnoldus, 1977**) where p_i is monthly precipitation and P is total annual precipitation:

$$F = \frac{\sum_{i=1}^{12} p_{,}^{2}}{P}$$

Then the R factor is computed as:

$$\textbf{R factor} = 0.264F^{1.50}$$

Monthly rainfall data from 132 sites in the continental United States were used to estimate *R* factor, with both mean annual rainfall amount and the modified Fournier Index (*F*mod) used (**Renard and Freimund 1994**). Based on their results two equations where suggested to approximate *R* values using precipitation amount (*P*):

When *P* is less than 850 mm: $R = 0.0483P^{1.610}$

When *P* is greater than 850 mm: $R = 587.8 - 1.219P + 0.004105P^2$

El Taif et al. (2010) developed an equation to estimate R-factor for Jordan using 18 weather stations north Jordan. Good fit was achieved between *R* values and the mean annual precipitation *P*:

$$R = 23.61 \times e^{0.0048P}$$

In this study we used the equation developed by ***El Taif et al. (2010)***. The results from **Renard and Freimund (1994)** equation $R = 0.0483P^{1.610}$, under estimation the R values compared to El ***Taif et al. (2010)*** equation (Figure 4). According to ***Al Taif et al. (2010)*** a good fit was achieved between *R* values and the mean annual precipitation (Figure 5).

According to ***El Taif et al. (2010)*** the proposed equation in their study showed sufficiently reliable results and could be most applicable for prevailing conditions in Jordan (Table 1).

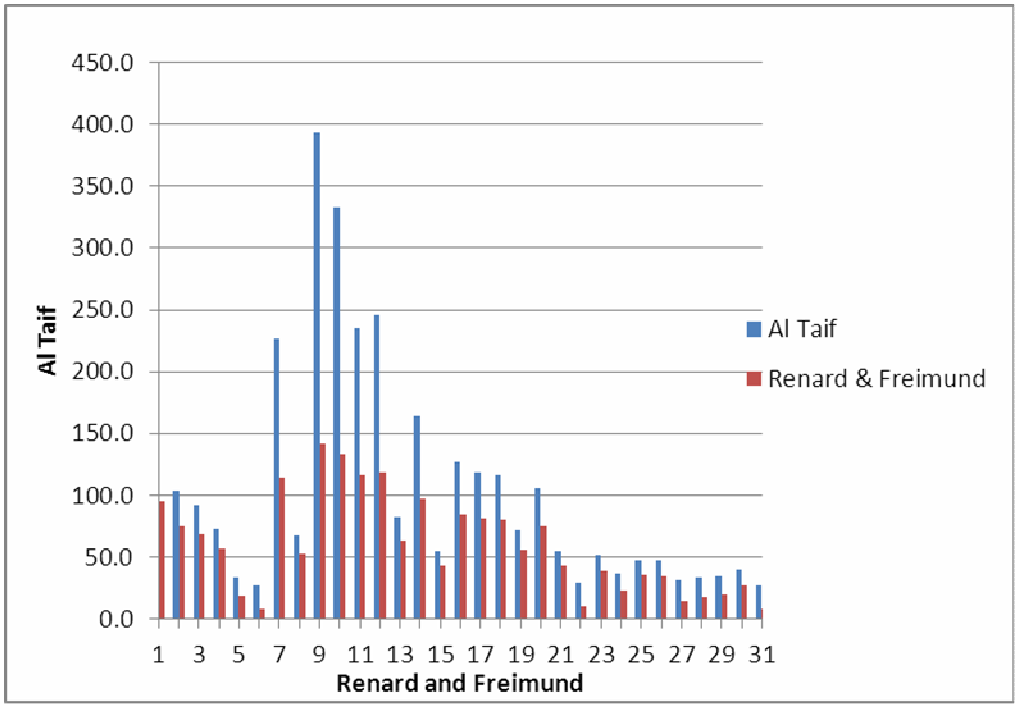


Figure 4: *El Taif et al. vs.* Renard and Freimund method for estimating R values

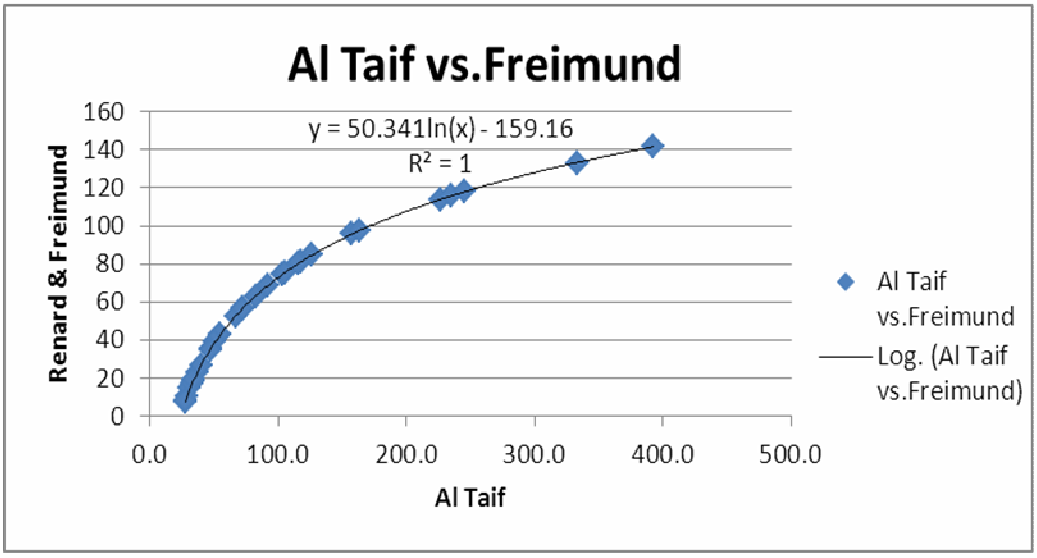


Figure 5: *El Taif et al. vs.* Renard and Freimund relationship

In terms of GIS representation, each rain gauge station is a point, so it needs to be interpolated to spatially match the same grid representation of the other thematic maps. The method of interpolation used in this process was the Inverse Distance Weighted (IDW) interpolation method supported in the ArcGIS 9.3. The interpolation was done using power of 2 and variable search radius selecting the 12 nearest gages. Figure 6 is the interpolated surface of R values in metric units (MJ mm ha^{-1} h^{-1} $year^{-1}$). The R _value ranges from 26.7 into 404 MJ mm ha^{-1} h^{-1} $year^{-1}$.

Table 1: Erosivity factor of each rainfall station based on the *El Taif et al. (2010)* equation.

Station	Average annual precipitation (P) mm	R factor MJ mm ha−1h−1 year−1	R factor (English units) 100ft.tonf.acre-1.yr-1
Baqura	393.4	156.0	9.17
Wadi El rayyan	308.2	103.6	6.09
Dei Alla	277.7	89.5	5.26
University farm	235.0	72.9	4.29
Ghore Safi	78.8	34.5	2.02
Aqaba Airport	26.4	26.8	1.57
Irbid	478.1	234.3	13.77
Ramtha	224.5	69.4	4.07
Ras Muneef	591.6	404.0	23.74
Salt	550.8	332.1	19.51
Jordan University	495.1	254.2	14.94
Swaileh	478.6	234.9	13.80
Amman Airport	265.7	84.5	4.97
Roman -Amman	399.6	160.8	9.45
Q.A.Airport	169.2	53.2	3.13
Madaba	331.3	115.8	6.80
Er-Rabbah	328.1	114.1	6.70
Muta University	332.5	116.5	6.84
Al Hasan Tafileh	227.8	70.5	4.14
Shobak	282.0	91.4	5.37
Wadi Mousa	177.2	55.3	3.25
Ma'an	38.0	28.3	1.66
Mafraq	156.4	50.0	2.94
Al-bayt University	93.4	37.0	2.17
Wadi Dhuleil	140.1	46.2	2.72
Zarqa Rifinery	142.7	46.8	2.75
Azraq South	61.4	31.7	1.86
Safawi (11-15)	70.0	33.0	1.94
Rweished(114)	79.9	34.6	2.04
Qatraneh	106.4	39.4	2.31
Aljafer	32.5	27.6	1.62

Soil Erodibility Factor (K)

K value reflects the susceptibility of soil to be eroded as well as the ability of sediments to be transported and the amount and rate of runoff given a particular rainfall input, as measured under a standard condition and it reflects the rate of soil loss per rainfall-runoff erosivity (R) index. The standard condition as it is expressed by **Weesies (1998)** is the unit plot, 72.6 ft (22.1 m) long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hillslope.

It is been found by **Romkens (1985)** that rainfall simulation studies are the least accurate and therefore their predictive relationship are the less accurate than direct measurement from field plot which have been studied for more than 5 years (***Loch et al. 1998***).

Therefore, soil characteristics such as percent of organic matter, particle size and density of eroded soil should be used to estimate soil erodibility (***Wischmeier et al., 1971***).

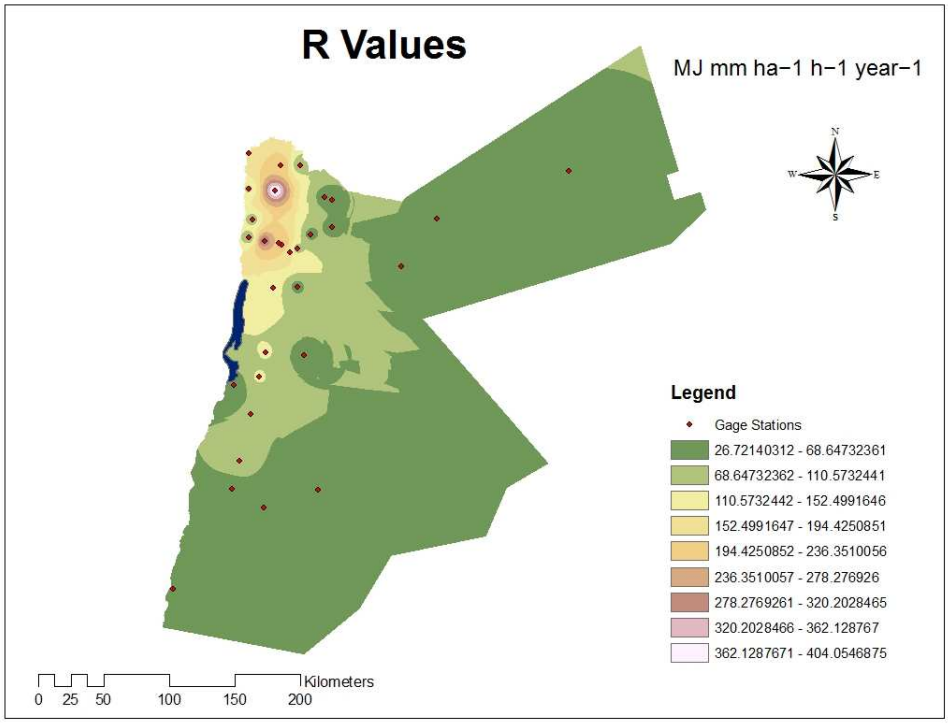


Figure 6: Interpolated R Values using the IDW method.

In this study, the soil erodibility factor was calculated using the nomograph (Figure 7) developed by **Wischmeier and Smith (1978)** based on soil texture; % silt plus very fine sand, % sand, % organic matter, soil structure, and permeability. According map units available in National Soil Map and Land Use Project, we obtained the soil texture, % silt +very fine sand, % sand. A map representing the organic matter (OM) was added to work as a crucial component in determining the K value, this map shows the percentage of OM ranging from 0.39 – 1.71%, Figure 8. The permeability was determined based on soil structure and texture (Table 2, from ***Edmonds et al. (1998)***).

Table 2: Soil permeability based on soil texture and structure (***Edmonds et al. 1998***).

Texture	Structure	Permeability
Sand, loamy sand	Single grain	Rapid
Sandy loam, loam, silt loam*	all	Moderately rapid
Clay loam, sandy clay loam, clay, sandy clay, silty clay	Blocky	Moderate
Clay loam, sandy clay loam, clay, sandy clay, silty clay	Prismatic, platy, massive	Slow
*A dense, brittle, platy layer known as a hardpan or fragipan may occur in some sub-soils with these textures. The occurrence of a frgipan indicates slow permeability, regardless of soil texture.		

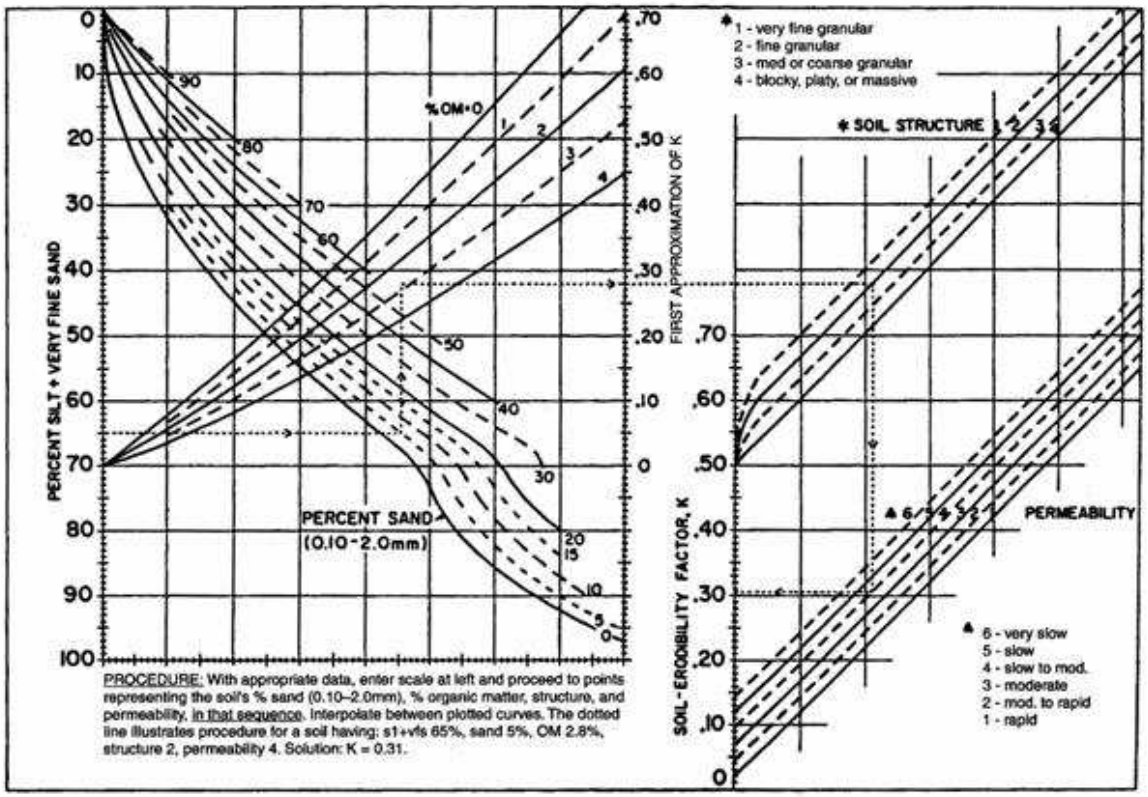


Figure 7: Soil erodibility nomograph (**Wischmeier and Smith, 1978**).

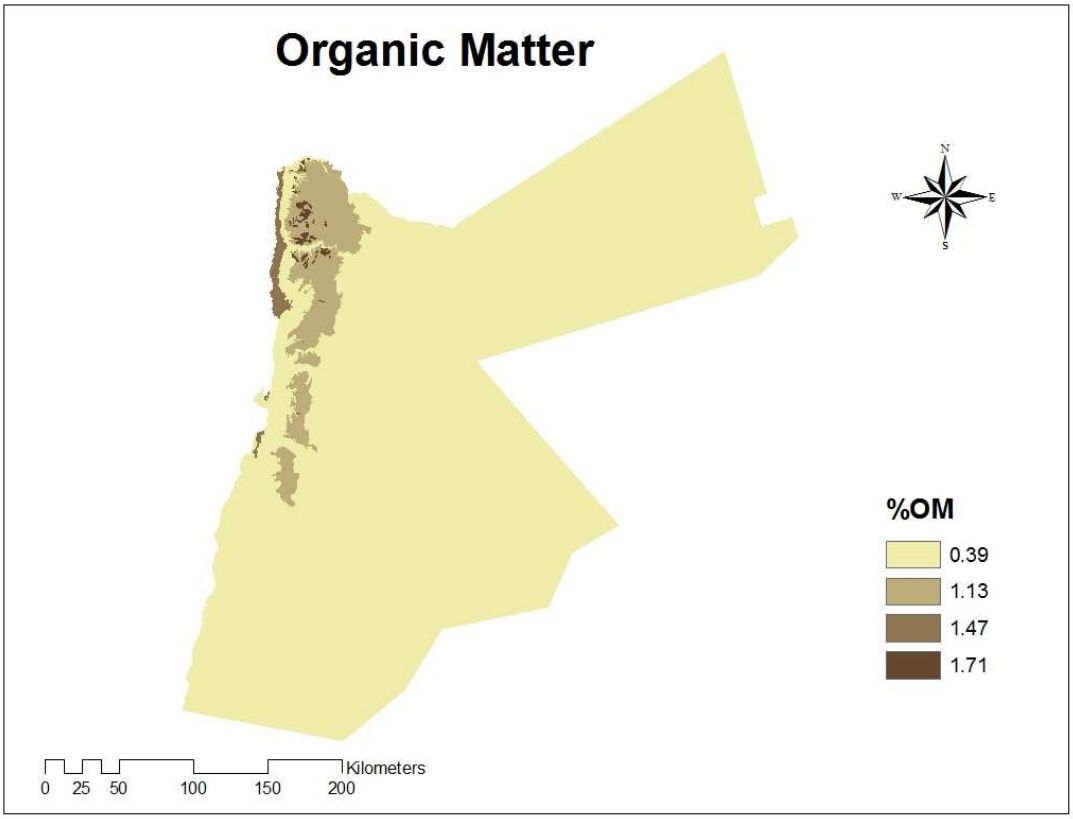


Figure 8: Percent of organic material Map

According to the OM map the average organic matter does not exceed 2%, although in some places northern Jordan the organic matter exceeds 2%. In this study we assumed that the maximum average of OM does not exceed 1.7 based on OM map (Figure 8).

According to the soil map of Jordan, there are 160 map units covering the whole country. However, there is missing information in almost 60 map units. Where we couldn't find the percentages of sand, silt and clay for those map units, so the K factor is based on textural class and OM %, (Table 3; ***Schwab et al. 1981***).

Table 3: Soil erodibility factor (K) (***Schwab et al., 1981***)

Texture	Organic Matter Content (%)	
	0.5	2
Fine sand	0.16	0.14
Very fine sand	0.42	0.36
Loamy sand	0.12	0.10
Loamy very fine sand	0.44	0.38
Sandy loamy	0.27	0.24
Very fine sandy loam	0.47	0.41
Silt loam	0.48	0.42
Clay loam	0.28	0.25
Silty clay loam	0.37	0.32
Silty clay	0.25	0.23

Slope Length and Steepness Factor

Slope length is the ratio of soil loss from the field slope length to that from a 72.6 ft length under otherwise identical conditions. LS in RUSLE factor reflects the effect of topography on soil erosion, and it combines the effect of slope length factor L and a slope steepness factor S. In general as the slope length L increases, the total soil loss and soil erosion per unit increases as a result of progressive accumulation of runoff in the down slope. As the slope steepness increases the soil erosion increases too as a result of increasing the velocity and erosivity of runoff.

L is calculated for crop land by the equations used in RUSLE (***McCool et al. 1997***) with

$$L = (X_h / 72.6)^m$$

where:

X_h = the horizontal slope length in ft

m = a variable slope length exponent.

m is related to the ratio ϵ of rill erosion to interrill erosion by the following equation

$$m = \varepsilon / (1 + \varepsilon)$$

ϵ is calculated for conditions when the soil is moderately susceptible to both rill and interrill erosion using the following equation:

$$\varepsilon = \frac{\sin\theta}{0.0896 \times \left[3.0 \times (\sin\theta)^{0.8} + 0.56\right]}$$

where:

Θ = the slope angle

The slope steepness (S) is the ratio of soil loss from the field slope gradient to that from a 9% slope under identical conditions. The RUSLE slope steepness equation is the following (**Renard et al. 1997**):

$S = 10.8 \times \sin\Theta + 0.03 \qquad \sigma \leq 9\%$

$S = 16.8 \times \sin\Theta - 0.50 \qquad \sigma > 9\%$

Where:

Θ = the slope angle;

σ = the slope gradient in percentage.

The slope length and slope steepness (S) can be defined from the Digital Elevation Model (DEM) (***Hickey et al. 1994; Van Remortel et al. 2001***) using equations above. In this study, we used the DEM of 30 m, to calculate the LS factor based on ***Mitasova et al. (1996)*** equation presented below that uses the flow accumulation grid to compute the slope length.

Procedure to calculate the LS Factor in ArcGIS

First we calculated the slope for the DEM in Degrees (Figure 9) using the Spatial Analyst Tool. The LS factor (Figure 17) was then computed as follows:

1) From the Hydrology Toolkit in Spatial Analyst, we calculated the flow direction

Figure (10) and then the flow accumulation Figure (11).

2) In this study we are interested in calculating the soil loss from only the hill-slope which requires extracting the channels from our model. Using Raster calculator we extracted the channels with a threshold of 100 (the number of weighted cells higher than 100 were excluded from the study, which represents an area of 90 hectares and it was chosen using trial and error to evaluate the best threshold representing the known channel systems and then calculate the LS factor for the remain cells.

3) Using the Raster Calculator to compose the following expression based on the ***Mitasova et al. (1996)*** equation :

LS=Pow([FlowAcc] * cellsize/22.1, 0.6) * Pow (sin([SlopeDegree]) * 0.01745)/0.09, 1.3)

Cover Management Factor

The cover management C Factor reflects the effect of vegetation management on soil loss. Like other factors of RUSLE, the C value is a ratio of the existing surface conditions at a site to the standard conditions of unit plot. C values can be found in USDA Agricultural Handbook 530-540 under "Predicting Rainfall Erosion Losses: A Guide to conservation Planning," or it can be calculated requiring more details that are not available for the whole countries.

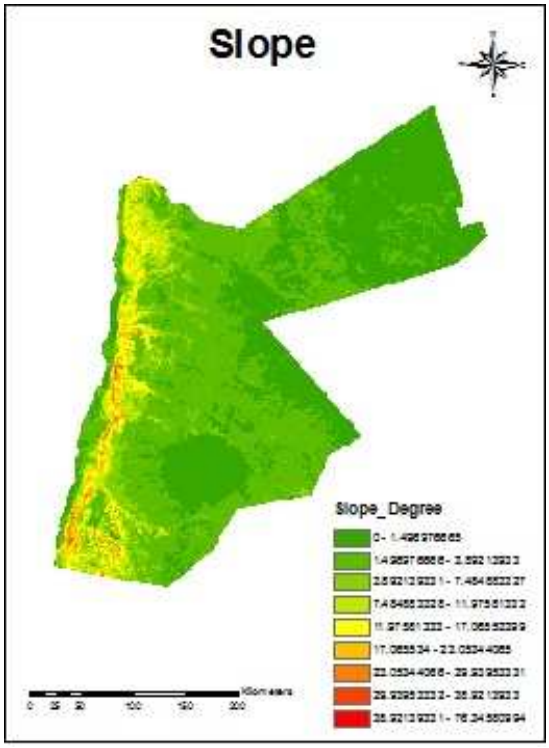


Figure 9: Slope in degrees

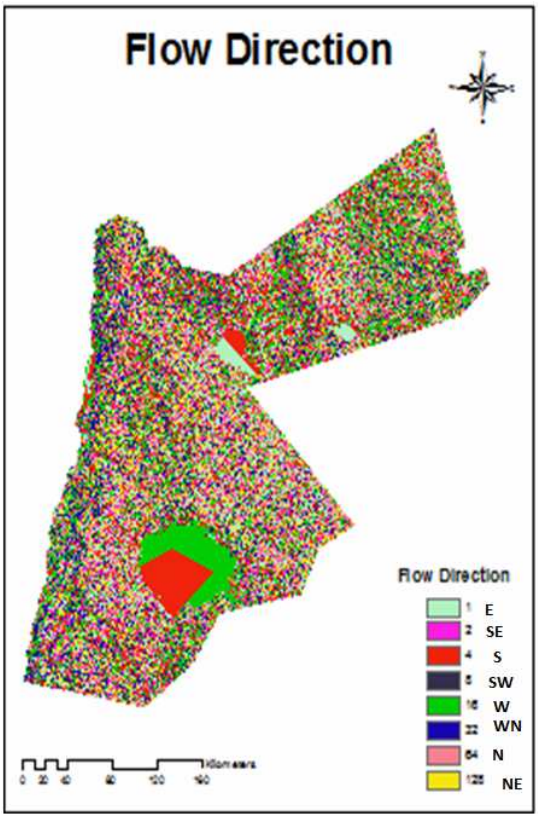


Figure 10: Flow direction Map

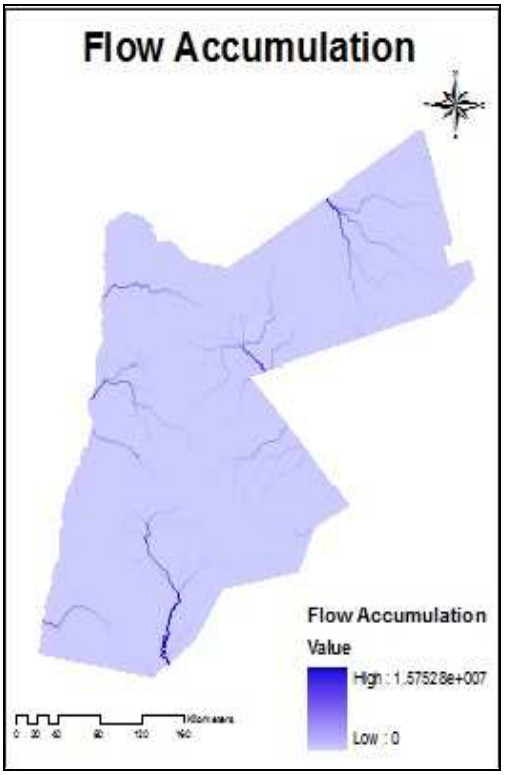


Figure 11: Flow accumulation Map

In this study the C values were assigned based on recent study made in Northern Jordan in 2006 by Eng. Fajer Al- Zitawi for wheat, the major crop type in Jordan, and it came up with C values of 0.234, 0.232, 0.205 for the Kufranjeh, As-Salt and Gumaiam states in northern Jordan. Essa (2004) suggested using a C value of 0.35 for rangelands in Jordan. The other C Values were assigned based on recommendations from Jordanian experts and scientists.

In order to create a C factor layer in ArcGIS, a land cover map must be obtained. Next , C values were assigned to each land cover type and then using the Look Up tool in ArcGIS reclassified the land cover map according to its C values. Table 4 shows each land cover class and its C value. Figure 16 is the C factor map for Jordan.

Support Practice Factor (P)

The support practice is the ratio of soil loss with a specific support practice to the corresponding soil loss with straight row upslope and down-slope tillage. The P factor consider the control practices used to reduce the erosion potential of the runoff by their effect on drainage patterns, runoff concentration, runoff velocity, and hydraulic forces exerted by runoff on soil. The mechanical support practices include contouring, strip-cropping, or terracing. In terms of GIS, a database of geo-referenced support practices with assigned P factor values would need to be developed. Since this type of GIS data was not available at the time of this assessment, values of P factor were not evaluated as part of calculation and all Land use /Land Cover were assigned a value "1" for P factor.

Table 4: C values

code	Name	C_VALUE
1	Dead Sea Water	0
2	Pastures	0.35
3	Vegetables	0.22
4	Sands(treated as bare soil)	0.5
5	Tree Crops	0.20
6	Basaltic Rocks (treated as a bare soil)	0.5
7	Chert Plains(treated as bare soil)	0.5
8	Dry Mudflat(treated as a bare soil)	0.5
9	Wet Mudflat(treated as a bare soil)	0.5
10	Dams (treated as urban) (most attenuation)	0.01
11	Urban Fabric (most attenuation)	0.01
12	Open Forest	0.05
13	Wadi Deposits (treated as bare soil)	0.5
14	Bare Soil / Bare soils (plowing along slope (0.85)	0.5
15	Closed Forest	0.001
16	Field Crops	0.22
17	Waste Water Plants (trial and error ,horticulture)	0.06
18	Quarries	1

RUSLE Model of Jordan

Figure 12 illustrates the application of the RUSLE model for Jordan based on the factors R, K LS and C. Figure 18 are the model results and Figure 19 are the results reclassified into erosion categories.

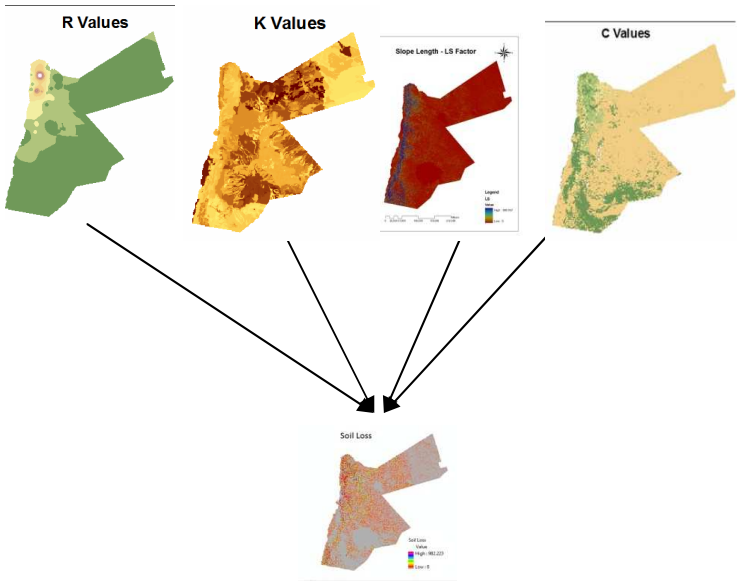


Figure 12: Application of the RULSE model.

RESULTS AND DISCUSSION

Rainfall and Runoff Erosivity Factor

The R values were calculated from rainfall records showing the monthly average of rainfall for periods of different long term ranges. In RUSLE the R factor is modified to account for water ponding so it takes into account the relation between R values and slope. But it should be taken into account that regions with higher elevation receiving low rainfall amount will result in low R values since there no significant effect of rainfall at that point (Figure 13 and 14) and this explains having areas with higher elevation and low R values compared to areas with lower elevation and higher R values.

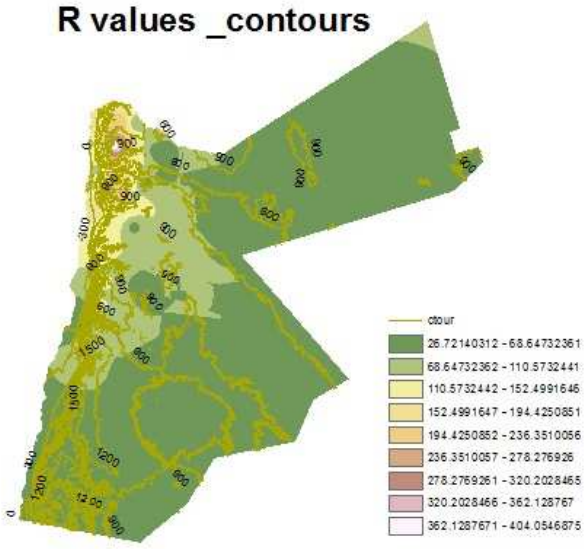


Figure 13: R values along with isolines.

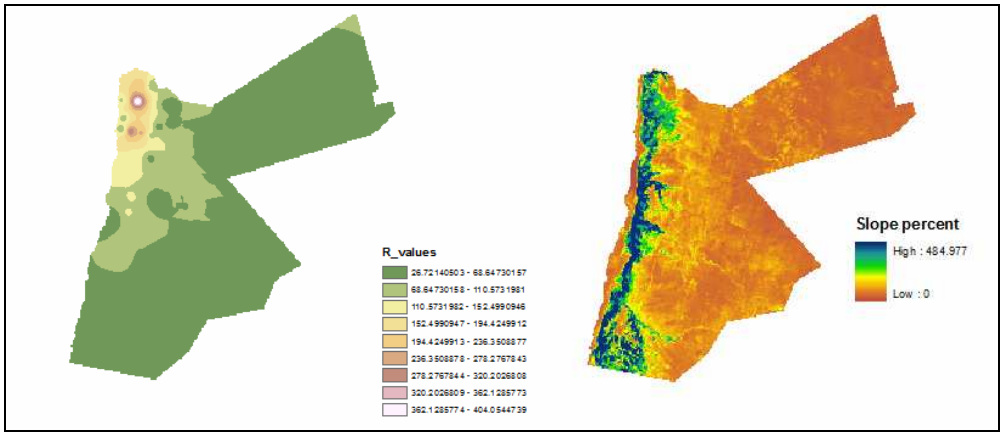


Figure 14: R values (right) and Slope in percent (Left).

Our model shows that regions with low slope degree have low erosivity R values which implies that flat areas increase the water pond over the surface and protect the soil particles from being eroded by raindrops. Figure (15) shows the equation used to calculate the R values in Jordan based on annual rainfall data.

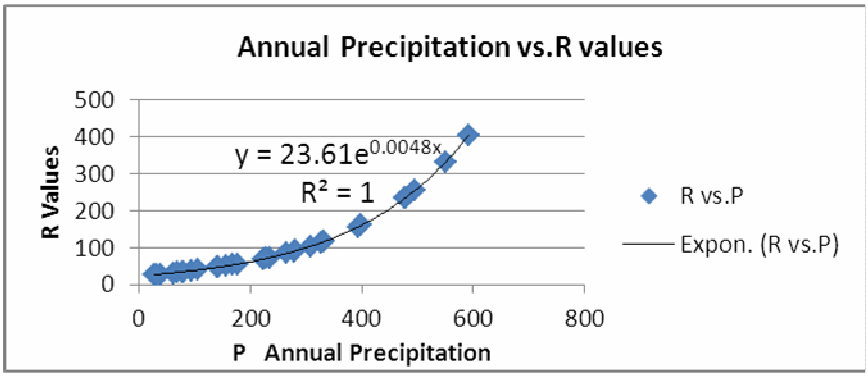


Figure 15: Relationship between P (Mean Annual Precipitation) in mm and R values.

According to our results, the highest R values are found to be 404 MJ.mm/ha.hr.yr in Ras Muneef where the mean annual rainfall is 591.6 mm and the lowest R value is found in Aqaba Airport 26.8 MJ.mm/ha.hr.yr with an annual precipitation 26.4 mm.

Soil Erodibility Factor (K)

The soil erodibility K Factor measures the soil susceptibility to water erosion based on its texture and structure and its content of OM. The K value given for each map unit indicate the amount and rate of runoff given a particular rainfall input, as measured under a standard condition and it reflects the rate of soil loss per rainfall-runoff erosivity (R) index. The standard condition as it is expressed by **Weesies (1998)** is the unit plot, 72.6ft long with a 9 percent gradient, maintained in continuous fallow, tilled up and down the hillslope. High K values are assigned to soil containing high percentage of silt and very fine sand that affects its permeability based on its structure (massive, blocky or platy) . Low K values usually assigned to soils of granular structure and containing high content of OM. In our model, the K values are estimated using the nomograph developed by **Wischmeier and Smith (1978)**.

Some of map units are estimated based only on OM and soil texture (***Schwab et al., 1981***) due to lack of the data attached to them which could have caused some inaccurate results in some regions compared to those estimated from soil profiles with available data. A map of OM covering the entire country was used, but it has been found that some map units lie spatially in two different OM classes and this may cause small errors in the results for some map units, but should not significantly affect the K values since Jordan

has low OM in general ranging from 0.39 – 1.17 % and the regions that overlap are close in their values.

Our model of K Factor shows highly variable K values, and it ranges between 0 for the Dead Sea and 0.088(t.ha.h/ha.MJ.mm). Altitudes range from -429 m at the Dead Sea to 1812 m according to our DEM 30m. The climate varies from sub-humid Mediterranean in the north-western part of the country with annual rainfall of about 630mm to desert conditions to the east over a distance of only 100 km. The geology (**Bender, 1974**) includes Basaltic rocks, sandstone, lime-stone, chalks, marls and cherts and various Pleistocene and Holocene deposits, both of alluvial and Aeolian origin. Extensive lava flows have occurred in the north of the country. This wide range in physical features has produced an equally wide range of soils and landscapes. This makes each map unit have a different texture and unique K values figure 16.

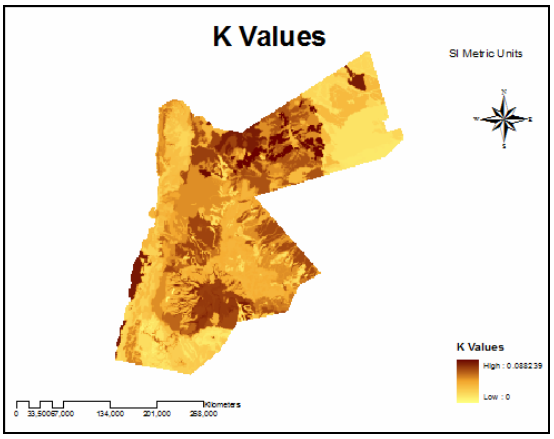


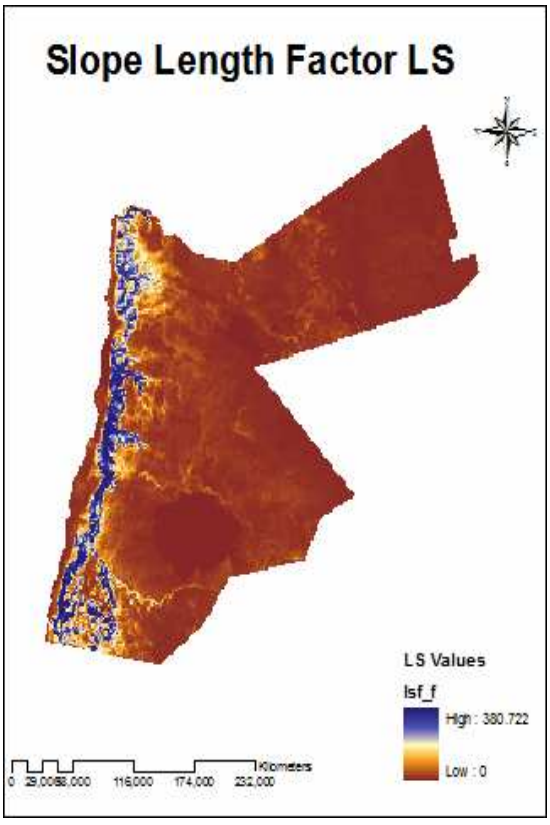
Figure 16: K Values in SI metric units (t. h. ha $^{-1}$.MJ^{-1}.mm^{-1}).

Soil Length and Steepness Factor

In RUSLE, new equations have been assigned based on the ratio of rill to interrill erosion .In our model the slope length and steepness were evaluated together using the equation:

LS = Pow ([Flow Acc]*cell size / 22.1,0.6)* Pow (sin([Slope Degree])*0.01745)/0.09,1.3) the values of LS varies from 0 – 380 (Figure 17).

By comparing the slope degree, slope length and steepness factors; we conclude that the LS factor has a significant effect on soil loss. The differences in topography plays an important role in soil properties, lower positions contain more organic matter received by runoff from upper position (***Hattar et al. 2010***). On the other hand, rainfall varies considerably with location, mainly due to the country's topography, which affects degree of soil susceptibility to water erosion. For example, the Jordan Valley escarpment, a long narrow escarpment runs from the Yarmouk River in the north to Wadi Hasa in the south and the slope percentage ranges from 0 – 325 % , xerochrepts and torriorthents dominating most of the region. By comparing the LS, R AND K models we conclude that there is a strong relationship between the distribution of rainfall, soil properties and topography presented by the slope length and steepness.



Figures 17: LS factor

Crop Management Factor

In RUSLE many factors should be taken into consideration to develop an accurate model for C values. RUSLE uses a subfactor method to compute soil loss ratios, which are the ratios at any given time in a cover management sequence to soil loss from the unit plot. Soil loss ratios vary with time as

canopy, ground cover, roughness, soil biomass and consolidation change. A "C" factor value is an average soil loss ratio weighted according to the distribution of R during the year. The subfactors used to compute a soil loss ratio values are canopy, surface cover, surface roughness, prior land use and antecedent soil moisture (**http://www.iwr.msu.edu/rusle/**).

According to **Wischmeier and Smith (1978)**, the C values for wheat ranges from 0.1 and 0.4 depending on cover percentage. Differences in C values are attributed to differences in rainfall effect and R values (Wischmeier and Smith 1978). In this study the C values have been estimated based on previous studies and experts opinions.

Areas covered with forests are given low values (0.001) since they protect soils from being eroded, while the bare soils exposed to plowing have been given a high value (0.85) and the natural bare soils have been given 0.5, for rangeland 0.35). The model shows good results after applying the assumed C values for each land cover class, but more field work measurements need to be implemented to calculate the C factor based on each subfactor in RUSLE Figure 18.

Soil Loss Using RUSLE

Our results shows (Figure 19) that the soil loss ranges from 0-5 ton/ha.yr in Badia and other regions with low slopes and low annual precipitation. Erosion starts to increase in steppe regions and some parts of highlands ranging from 5- 10 tons/ha.yr to 10-50 tons/ha.yr. In northern and central highlands and some parts of Jordan Valley escarpment erosion ranged between 50 – 100 tons/ha.yr and >100 tons/ha.yr in some parts of northern highlands of high precipitation and in some part of Jordan valley escarpment.

In 1979 FAO – UNDP cited in ACSAD Report of Desertification in Arab World (Arabic), 2004 estimated approximate values for the water and wind erosion (Figrue 24) in Jordan and it was as follows: 10 – 50 ton/ha.yr in Agricultural flat plains and from 50- 100 ton/ha.yr in moderate steep areas while they estimated the soil loss to Our model matches the results estimated by FAO, although further work needs to be implemented to better estimate the soil loss prediction.

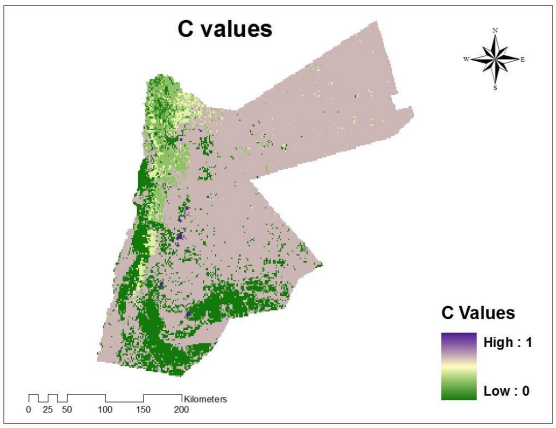


Figure 18: C Values

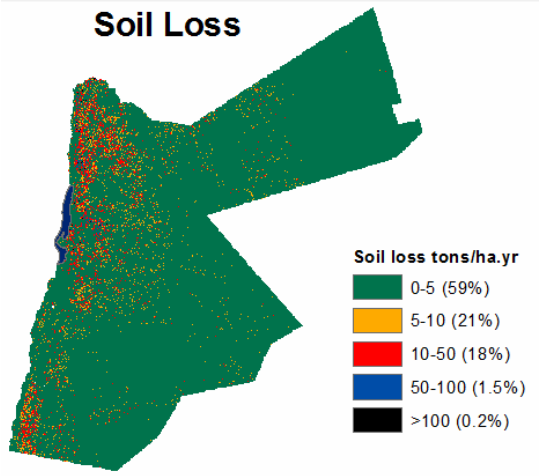


Figure 19: Soil loss classes (ton/ha-yr)

CONCLUSIONS

There is a wide range in physical features in Jordan that produce an equally wide range of soils and landscapes This makes each map unit have a different texture and unique K values, this result in different soil loss values that vary significantly with potential erosion estimates ranging from 0 to 982 tons/ha.yr. However, the potential erosion rate from water for most of the countries is less than 10 tons/ha.yr which is expected for a country with low rates of precipitation. We need to take into account that it is unrealistic to expect a model to predict values with great certainty than the likely variability around the measured value (**Nearing 2000; 2006**). Many of our modeled factors could produce

uncertainty. The use of guide values rather than measured can produce errors arising from predictions used to run the model like in our study, and the error could be multiplicative which explains the existence of values more than 100 ton/ha.yr.in some cases. Our model is also highly sensitive to LS factor derived from DEM, so the DEM accuracy is a crucial issue in modeling soil erosion at large scale areas.

ACKNOWLEDGMENTS

The authors acknowledge the assistance of soil Physist Dr. Alaeddin Tahboub (from Al Balqa' Applied University) during the fieldwork and data collection. I am also very grateful to Dr. Tarek Ammari (Associate Professor of Soil Chemistry) from Al Balqa' Applied University, and to Dr. Khaldoun Qudah (Associate Professor of Water Resources) from Yarmouk University for providing us valuable comments and revising our manuscript.

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الملخص العربي

نمذجة رياضية اعتمادا على نظم المعلومات الجغرافية لتعرية المياه في الأردن باستخدام نموذج RUSLE

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يسيطر على الأردن المناخ الجاف والنظام البيئي الهش، الأمر الذي يجعل مناطق تدهور الأراضي وتعرية التربة والتصحر محط الاهتمام. هذه الدراسة تبني نموذجاً رياضياً لتعرية التربة استنادا إلى نموذج تعريةRUSLE، للتوصل إلى عمل خارطة تعرية التربة المحتملة الوطنية للأردن. الهدف من هذه الدراسة هو إنشاء خريطة وطنية للتعرية المحتملة للأردن باستخدام نموذج تعريةRUSLE. لتحقيق الهدف من هذه الدراسة تم إنشاء قاعدة بيانات نظم المعلومات الجغرافية لدعم تطبيق RUSLE في الأردن. وقد تم إنشاء عوامل LS،K،R، وC من نموذج RUSLE باستخدام البيانات المحلية. تم تقدير عامل C استناداً إلى الدراسات السابقة وتقييم الخبراء. وفقا لنموذج RUSLE، تبين أن المناطق ذات معدلات التعرية العالية هي المرتفعات الشمالية، ووادي غور الأردن وبعض أجزاء من تلال وادي عربة في جنوب الأردن. هذه المناطق تمتاز بمنحدرات حادة ومعدلات هطول أمطار تتراوح بين٥٠ملم إلى١٠٠ملم في الجنوب إلى ٥٥٠-٦٠٠ملم في الشمال.يبين النموذج أن فقدان التربة السنوي يتراوح بين ٠-> ١٠٠ طن/هكتار في السنة.

الكلمات الرئيسية: تعرية، التصحر، RUSLE، نظم المعلومات الجغرافية نمذجة.