



## Quantitative Estimation of Annual Soil Loss by Integration of Remote Sensing, GIS and Universal Soil Loss Equation (Case Study: Tartus District, Syria)

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**Abstract:** This paper describes the procedures employed to integrate Remote Sensing (RS) and Geographic Information System (GIS) techniques in an effort to characterize the spatial distribution of the risk of soil erosion by water on lands of *Tartus* district, Syria. The universal soil loss equation (USLE) is used to calculate the annual soil loss rates for Tartus soils. Mainly Landsat Enhanced Thematic Mapper (ETM) dated 5/2009, thematic maps such as land capabilities, landuse, digital elevation model (DEM) and climate data were used to determine USLE factors. Integration of these data sets resulted in a map of polygons with unique combinations of USLE factor values. The study showed that water erosion mainly threatens those soils on hilly lands where vegetation is sparse or absent and exposed to heavy rainfall. Mostly these lands extend around these towns and villages of Tiro, Jwibat, Hrison, Shiekh Bader, HamamWasel, Dulbeh and Safasif, where these soil loss was about  $150 \text{ t h}^{-1} \text{ y}^{-1}$  which account for 0.13% of the soil loss. These quantities of annual soil loss can be considered as a very severe amounts and if this water erosion persists at these high rates, the soil will be eroded and the parent material will be exposed in these regions. The study also mentioned a package of remedial measures so as to combat land degradation in the study area.

**Key words:** Water erosion, USLE, Landsat ETM, GIS, Sustainable land use, Tartus.

Extensive literature exists on soil erosion estimation by means of remote sensing data. The GIS/Remote Sensing integration with the USLE is a widely used approach in soil degradation assessments, Jurgens and Fander (1993) generated GIS layers of classes of length of slope factor (L factor) and steepness of slope factor (S factor) from DEMs, cropping and management factor (C factor) from Landsat Thematic Mapper (TM) and soil erodibility factor (K factor) from soil maps and used them in the USLE equation to create a map of soil erosion rates. In another study, Songcai and Wenqing (1999) used TM image to calculate land cover rate for estimating cropping and management (C) and supporting conservation practice (P) factors in an effort to estimate soil erosion. In addition to the soil loss, rates of water erosion for Latakia province in Syria was estimated by (Abed, 2000) using integration of USLE with RS/GIS.

The Tartus district (Syria) has been selected as the study area due to its excellent agricultural conditions. However, it faces various types of land degradation, excessive

deforestation primarily due to improper utilization of resources. Therefore, it is of crucial importance to monitor soil erosion rates and their distribution. In this study, the USLE was used to estimate soil erosion rates on Tartus lands with support of GIS and remote sensing techniques. Additionally, a Landsat images were used to determine the land cover conditions. It is expected that the study will determine the soil loss rates on Tartus lands, locate the most degraded areas, shows which soils are more subject to be eroded by water and help to plan land use and their management, in order to keep soil losses to a practical limit.

### Environment of the Study Area

Tartus province is located in the north west of Syria. With total area  $1900 \text{ km}^2$  bordered on the west by the Mediterranean Sea of 90 km coast. Tartus landform is characterized by very complicated mountains system. The north eastern slope is very steep, while the western one is gentle and broad towards the littoral plain. The climate of coastal area has good humidity conditions, mild winter and warm rainless summer. The amount of the rainfall increases with altitude in the region

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and the barren mountains and steep slopes lead to heavy soil erosion. Soils can be divided into main five groups (GORS 1991): Coastal Plain Soils, Alluvial Soils, Colluvial Soils, Mountainous Soils and Forest soils. Besides the natural vegetation cover, which consists mainly of various forest species (i.e., Pine, Cedar, Fir and Oak), one may find fruit trees, vegetables and various crops. Recently, afforestation practices are being adopted (GORS 1991).

**Materials and Methods**

The materials include spatial and attribute data. The spatial data consist of Landsat ETM multispectral image dated back to May 2009, Digital Elevation Model DEM (syria\_aster\_dem30m\_utm), along with the following maps in 1:50000 scale: current land use map and land classification/land capability maps. The attribute data includes the annual agricultural statistical abstract 2009, as well as precipitation data since 2009 for 19 meteorological weather stations. The main software packages used in the study include ArcGIS, ArcView and ERDAS image processing software.

The methods used were aimed at establishing mathematical relationships between various soil, landscape and vegetation features and the rate of soil degradation. The most well-known example is the USLE by Wischmeier and Smith (1978). USLE equation is:

$$A=R \times K \times L \times S \times C \times P \dots(1)$$

where, A = the average annual soil loss (t km<sup>-2</sup> yr<sup>-1</sup>); R = rainfall erosivity factor (EI units yr<sup>-1</sup>); K = soil erodibility factor (t km<sup>-2</sup> EI units<sup>-1</sup>); L = length of slope factor (in meter); S = steepness of slope factor (in per cent); C = cropping

and management factor; and P = supporting conservation practice factor (contouring, terracing, strip-cropping).

The following flow chart present the general steps of the methodology for calculating the USLE factors (Fig. 1).

*Rainfall erosivity factor (R)*

R factor expresses the capacity of the locally expected rainfall to erode soil from an unprotected field (FAO, 1965). The rainfall erosivity factor, E, was calculated by applying the following equation (Dong Liang, 1997):

$$E_i = 1.735 \times 10^{(1.5 \times l \times g \frac{P_i^2}{P} - 0.8188)} \dots(2)$$

where, E<sub>i</sub> = monthly average of erosion (mm); P<sub>i</sub> = monthly amount of rainfall (mm); and P = annual amount of rainfall (mm).

The annual and monthly amount of rainfall was considered for each month of 2009 for the 19 meteorological weather stations distributed overall Tartus district by applying equation 2, R values were then calculated by taking the average of the monthly average of erosion. The R values for the study area were between a range of 7.28 to 266.74.

*Soil erodibility factor (K)*

Some soils erode more readily than others, even when other factors are the same. Wischmeier *et al.* (1971), found that by knowing only soil particle size distribution, organic matter content, a soil structure index and profile permeability class, the soil erodibility factor (K) could be estimated. Considering the soil texture and the organic matter content, the K factor was determined based on research

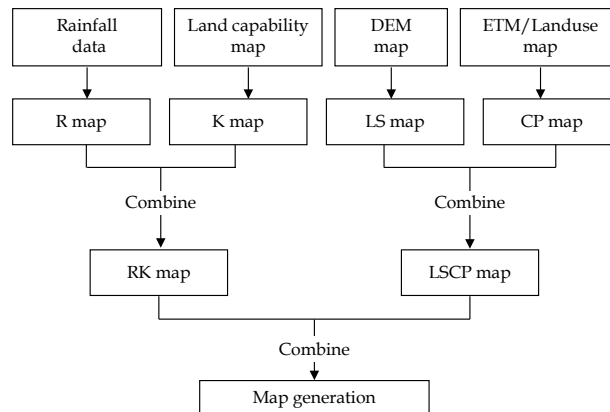


Fig. 1. General steps for estimating soil loss rates.

Table 1. K values based on soil organic matter

Organic matter content (g kg <sup>-1</sup> )	K values
< 40	1.0
41-60	0.9
61-80	0.8
81-100	0.7
101-120	0.6
> 121	0.5

Table 2. K values based on soil texture

Soil texture types	K values	Soil texture types	K values
Sand	1.00	Silt loam	1.00
Fine sand	0.17	Silt	0.52
Very fine sand	0.50	Sandy clay loam	0.21
Loamy sand	0.12	Clay loam	0.25
Loamy fine sand	0.19	Silty clay loam	0.32
Loamy very fine sand	0.47	Sandy clay	0.13
Sandy loam	0.15	Silty clay	0.14
Fine sandy loam	0.22	Clay	0.10
Very fine sandy loam	0.39	Heavy clay	0.04
Loam	0.31		

works done by Dickinson *et al.* (1989) and Bu Zhaohong and Quanying (1995) as shown in Table 1 and 2 wherein the K values ranged between 0 to 0.520

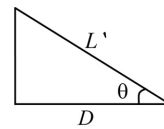
*Length and steepness of slope factors*

The main slope components that have significant effects on runoff and water erosion are: Slope length (L), slope steepness (S) and slope shape. The two most common methods for expressing slope are: as an angular measurement in degrees, or as a percentage. Slope length (L) and steepness (S) were calculated based on equations of (Bu Zhaohong *et al.*, 1994) as well as (Wischmeier and Smith, 1978) as presented in equation 3.

$$LS = (L'/22.1)^m (65.41 * \sin^2\theta + 0.065) \dots(3)$$

For adjacent cells, GRID calculates from the center of one cell to center of other cell. The distance, D, between the centers of two adjacent cells perpendicular to the x- or y- axis is the cell resolution size, 30. If a cell is diagonal from another cell, the distance, D, is the cell size times 1.412. As shown in equation 4. The development of USLE was based on a standard

plot length of 22.13 meters (Wischmeier *et al.*, 1965). Therefore, the slope-length factor has been defined by equation 5:



$$L' = \frac{D}{\cos \theta} \dots\dots (4)$$

$$L = \left(\frac{L'}{22.13}\right)^m \dots\dots (5)$$

where, L = slope length factor; L' = slope length, meters and m = exponent.

Current recommendations for the exponent m are listed in Table 3 (Wischmeier and Smith, 1978).

Table 3. Current recommendations for the exponent m

m	Slope %
0.5	>= 5
0.4	5-3
0.3	3-1
0.2	< 1

By applying equation 3, the Ls values were between 0 to 113.8 m, based on the following model (Fig. 2) which was used to compute L and S Values.

*Cropping factor*

This factor represents the ratio of soil loss from a specific cropping or cover condition to the soil loss from a tilled, continuous fallow condition for the same soil and slope and for the same rainfall. This factor includes the interrelated effects of cover, crop sequence, productivity level, growing season length, cultural practices, residue management and rainfall distribution (Kent Michell *et al.*, 1980). In order to determine the C values, the Normalized difference Vegetation Index (NDVI) is a commonly used vegetation index for depicting vegetation distribution. NDVI values of Landsat Image were determined, then the C values were calculated based on equation 6 (ACSAD, 2009). C values are between 0.10 and 0.76.

$$C = 0.431 - (0.0805 * NDVI) \dots (6)$$

*Support conservation practice factor*

The erosion control practice is the ratio of soil loss using the specific practice compared with the soil loss using up-and-down hill culture. The erosion control practices usually

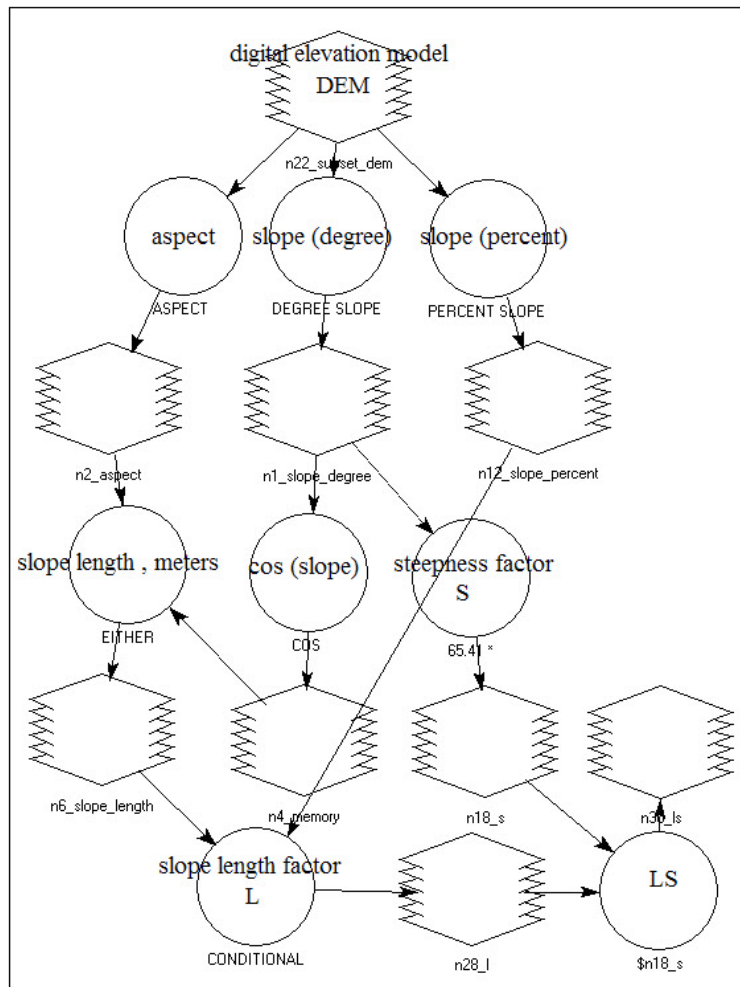


Fig. 2. Model used to calculate LS factors.

included in this factor are contouring, contour strip cropping and terracing. Conservation tillage, crop rotations, fertility treatments and the retention of residues are important erosion control practices (Michell and Bubenzer, 1980). The *P* values for Tartus were determined based on study (Table 4) done by Songcai and Wenqing (1999) and then adjusted according to conditions of the study area as shown in Table 5.

Table 4. *P* values under different land use classes

Land cover	<i>P</i> values
Drainage basin	0.15
Intensive paddy	0.15
Paddy and other crops	0.35
Brush	1.00
Trees	1.00
Unknown	1.00
Water	0.00

Table 5. Adjusted *P* values under different land use classes (adapted from CSAR, 1995)

Code	Landuse type	<i>P</i> values
1	Urban land	0.00
2	Intensive irrigated agriculture	0.15
3	Irrigated agriculture	0.35
4	Non-irrigated agriculture	0.35
5	Trees	1.00
6	Brush	1.00
7	Water	0.00
8	Barren land	1.00

## Results and Discussion

The six GIS layers for the R, K, L, S, C and P factors were multiplied together within ArcGIS package to construct the USLE equation and to obtain the annual soil loss map. The annual soil loss values for the study area were between 0 to 250 t hectare<sup>-1</sup> as shown in Table 6. The soil loss

grades were classified based on classification presented by Bu Zhaohong *et al.* (1997).

The result shows that the soil erosion extent and severity mainly occurred on the high mountain regions on the eastern and northern high mountains, where the heavy rainfall, barren mountains and the steep slopes existed. Mostly these lands extend around these towns and villages of Tiro, Jwibat, Hrison, Shiekh Bader, Hamam Wasel, Dulbeh and Safasif, where soils loss was about 150 t h<sup>-1</sup> y<sup>-1</sup> and occupy an area of about 2.46 km<sup>2</sup> of total Tartus lands which is about 0.13% of 1900 km<sup>2</sup>. Such quantities of annual soil loss can be considered as a very severe amounts and if this water erosion persists at such high rates the soil will be eroded and the parent material will be exposed in those regions soon.

From the Table 6, it is clear that the area of land with very slight to light erosion is about 1361.96 km<sup>2</sup>, which constitutes about 71.25% of the area of the study area. While, the area of land with low to moderate erosion rates is about 480.88 km<sup>2</sup>, 25.16% of the study area. However, the high and very high erosion rates are about 66.31 km<sup>2</sup>, about 3.47% of the area. Whereas the severe and very severe erosion occupying an area of 2.46 km<sup>2</sup>, or 0.13%. The erosion rates obtained by the current GIS/RS based erosion model and measured soil loss (Kbebo *et al.*, 2015) and prove that the integration of GIS/RS with USLE is practicable and effective to monitor soil erosion on large areas.

Table 6. The annual soil loss, A, in Tartus district

Soil loss grade	Soil loss (t hm <sup>-2</sup> year <sup>-1</sup> )	Area (km <sup>2</sup> )	% of total
Very slight	0-1	763.6122	39.95
Slight	1-5	598.3497	31.30
Low	5-10	262.2051	13.72
Moderate	10-25	218.6757	11.44
High	25-50	56.5992	2.96
Very high	50-80	9.7146	0.51
Severe	80-150	2.2320	0.12
Very severe	150-250	0.2313	0.01
		1911.6200	

### Recommendations and Proposals to Combat Water Erosion

In general, areas with slight to moderate erosion or those that have not yet eroded are the most common and should be given

special attention. While, in severe eroded areas anti-erosion measures should be specified so that erosion is clearly defined and remedial action is applicable. The recommendations and proposals for reducing the water erosion can be summarized as follows:

- Observing those areas with high soil erosion rates by establishing monitoring stations dedicated to this purpose and taking advantage of remote sensing techniques for this purpose
- Support soil conservation projects, particularly in vulnerable areas and apply measures to combat soil erosion in the sloping areas, such as contouring, strip farming and terraces
- Directing urbanization and establishing tourist and industrial facilities away from arable and forest lands
- Limit the cutting of the vegetation cover, prevent grazing and igniting fires in or near forest lands
- Educate the local population about the danger of erosion and ways to combat it, importance of vegetation cover and to involve them in sustainable development plans

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