Study of Soil Loss in Main Wadis of South Sinai

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Abstract: ***Universal Soil Loss equation (USLE) is a powerful tool that is widely used by conservationists in the Unites States and many foreign countries, it substantiated the usefulness and validity of (USLE) empirical erosion model for this purpose. It is also applicable to non-agricultural conditions such as construction sites. In this work, we need to predict the amount of soil loss occurs through the main wadis in South Sinai due to the flash floods occurs in this region by predicting the appropriate values for the (USLE) six factors like rainfall drop erosivity (R), slope steepness (S), slope length (L), soil erodibility (K), Crop management factor (C) and Support Practice Factor (P), using Geographic Information System (GIS) tools to facilitate the numerical computation for the (USLE) erosion model factors by using raster calculator algorithm based on remote sensing data. Global Precipitation Climatology Centre (GPCC) daily precipitation data used to estimate the rainfall drop erosivity (R) for a storm event occurs in twenty fifth of October two thousand and fifteen, where a field survey measurement for sediment loss volumes accumulated upstream two dams located on wadi watir to be used as a calibrated values for our model results, also the geological, morphological and land use remote sensing data used in estimating the other factors for our study area. The results estimated for soil loss volumes accumulated upstream the two dams are 10181.27 m^3 and 9926.068 m^3, while the field measurement volumes are 7440 m^3 and 8478 m^3 respectively. Thus, the calibration factors range between 0.73 to 0.85 for the sediments values results from the USLE model which should be taken into consideration. The present results provide a vital database to control soil erosion which effect on the ecosystem and the effect of control structures constructed on the main wadis on the sediments which arrive to shorelines.***

Keywords: Soil Erosion, Erodibility, Erosivity, USLE, Remote Sensing, GPCC and South Sinai

1. Introduction

During the last four decades, Sediment loss is an important social and economic problem that takes many concerns from hydrologists, as it is an essential factor in assessing ecosystem health and function. Sediment yield from a basin is that portion of the eroded soil which leaves the basin. In almost every case the real need is to forecast future conditions, because of land use, rainfall, and runoff are known for hindcasting, however, in forecasting future yields, all these parameters must be estimated. Moreover, hindcasting is the required technique for confirming that the procedure will be valid for the proposed study area. Estimation of erosion is essential to issues of land and water management, including sediment transport and storage in lowlands, reservoirs and irrigation and hydropower systems. Rates of soil erosion can be estimated using erosion prediction equations developed during the last four decades. Among these algorithms are Universal Soil Loss Equation (USLE) and its recent updated the Revised Universal Soil Loss Equation (RUSLE) or Modified University Soil Equation (MUSLE).

Erosion, the detachment of particles of soil and surface sediments and rocks, occurs by hydrological processes of sheet erosion, rolling and gully erosion, and through mass wasting and the action of wind erosion, both Morphological and Metrological are essential factors in sediment erosion process, this problem is generally greatest in arid and semi-arid regions, where soil is poorly developed and vegetation provides relatively little protection. Soil erosion effect on the ecosystem as it reduces the levels of the basic plant nutrients needed for crops, trees and others plants, and decreases the diversity and abundance of soil organisms, also it has a side effect on the shoreline erosion and Marine organisms as by increasing soil erosion this process decreases the shore line erosion. In the last decades the hydrological studies take place by hydrologists to avoid flash floods to protect the development areas and also for water resources management by constructing hydrological protection structure like dams which act as a trap for sediments which eroded due to flash floods, so this effect on the predicted amount of sediments which arrive to shorelines [5].

The objectives of the present investigation are:
1) Estimate annual soil loss potential rate on 90 m x 90 m cell bases by extracting the values of USLE factors using spatial data (i.e., DEM, GPCC data, soil map/information, and land use/cover maps) for South Sinai area.
2) Recognize areas of high-erosion loss in the study area.

2. Study Area

Sinai Peninsula is a triangular plateau (61,000km^2) occupying the north eastern corner of Egypt. South Sinai area is about 28,400km^2, 46.6% of the total area of Sinai Peninsula (South Sinai Governorate, 1997). The study area is located between latitudes 28^{o}10'and 29^{o}10'N, and Longitudes 33^{o}15' and 34^o 39'E (Figure 1). The Study area covers South Sinai region with different vegetation types, altitude variations, landform types and climatic variations (Figure 2).

Figure 1: Satellite image of Egypt showing Sinai Peninsula

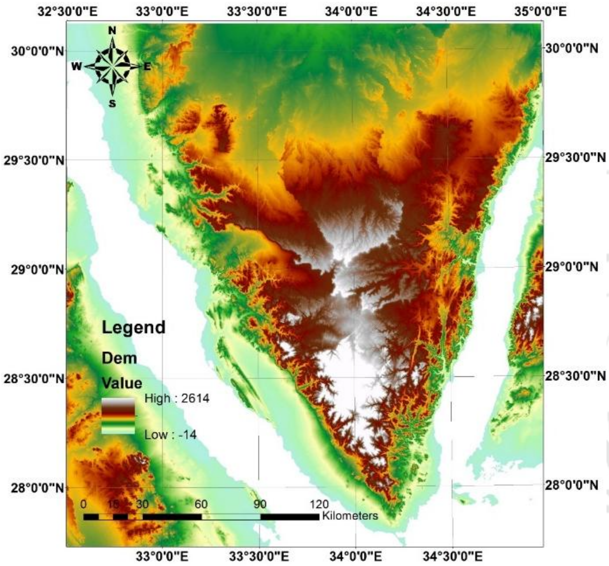

Figure 2: Digital Elevation Model (DEM) for study area

The northern part of Sinai is almost entirely covered by sedimentary rocks, mostly limestone. In the southern part the basement rocks occupy about 7000km^2 surface areas, forming a triangular mass of mountains with its apex at Ras Mohammed to the South. The Sinai massif contains much granite and other magmatic and metamorphic rocks (Hammad, 1980). The study area has six main landform types: slopes, terraces, gorges, wadis, fans, and plains. Slopes comprise all land surfaces, ranging from the horizontal to vertical (Holmes, 1984; and Moustafa and Klopatek, 1995). They originate by a combination of tectonic and erosion activity, thus uplifting or faulting provides slopes. Terraces comprise platforms of bedrock whether mantled with a sheet of gravel and sand, or rocky surface notched in circular lines. Gorges originate from joints or faults. Joints are fracture surfaces along which there has been unpredicted movement, and along which adjacent slabs and masses of bedrock join (Davis, 1984). The term wadi designates a dried riverbed in a desert area (Kassas, 1954), Watercourse after heavy rain (Kassas, 1954). Wadi bed is covered with alluvial deposits with different thickness and structure from location to another. The soil is usually composed of the same composition as the parent rocks and varied in texture from fine silt or clay to gravels and boulders (Kassas, 1952 and 1954; and Kassem, 1981). A wadi may be transformed into a temporary. Plains are flat expanses of desert where deep alluvial deposits are found. The desert plains represent a very late stage in the arid erosion cycle (Kassas, 1952).

3. Material and method

The methodology presented in this paper for estimating the average annual erosion expected to occur in South Sinai Region using universal soil loss equation (USLE) numerical model developed by (Wischmeier and Smith 1965, 1978) shown in equation (1):

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

Where;

- **A** = computed spatial average soil loss and temporal average soil loss per unit of area, expressed in the units selected for K and for the period selected for R. In practice, these are usually selected so that A is expressed in ton. acre^{-1}. yr^{-1}, but other units can be selected (that is, t. ha^{-1}. yr^{-1}).
- **R** = rainfall-runoff erosivity factor, the erosivity factor in the USLE is the product of storm's total kinetic energy and its maximum 30 min intensity.
- **K** = soil erodibility factor, the soil loss rate per erosion index unit for a specified soil as measured on a standard plot, which is defined as a 72.6 ft. (22.1 m) length of uniform 9% slope in continuous clean tilled fallow.
- **L** = slope length factor, the ratio of soil loss from the field slope length to soil loss form a 72.6 ft. length under identical conditions.
- **S** = slope steepness factor, the ratio of soil loss from the field slope gradient to soilloss from a 9% slope under otherwise identical conditions.
- **C** = cover management factor, the ratio of soil loss from an area with specified cover and management to soil loss from an identical area in tilled continuous fallow.
- **P** = support practice factor, the ratio of soil loss with a support practice like contouring, strip-cropping, or terracing to soil loss with straight row farming up and down the slope.

3.1 Calculation of USLE parameters

a) Rainfall erosivity (R factor)

The rainfall erosivity (R) factor express the product of storm's total kinetic energy and its maximum 30 min intensity [2] shown in equation (2). Thus, the R value is greatly affected by the volume, intensity, duration and pattern of storm event whether for single or a series of storms.

$$R = \frac{1}{n}\sum_{j=1}^{n}\sum_{k=1}^{m_j}(EI_{30})_k \qquad (2)$$

Where R-factor is average annual rainfall erosivity (MJ mm ha^{-1} h $^{-1}$ yr^{-1}), n is the number of years of records, m_j is the number of erosive events of a given year j, and EI_{30} is the rainfall erosivity index of a single event k.

The energy of a rainstorm is a function of the amount of rain and of all the storm’s component intensities. The median raindrop size generally increases with greater rain intensity [3], and the terminal velocities of free-falling water drops increase with larger drop size [3]. Since the energy of a given mass in motion is proportional to velocity squared, rainfall energy is directly related to rain intensity. The relationship, based on the data of Laws and Parsons (1943), as shown in equations (3) & (4).

$$e_m = 0.119 + 0.0873 \log_{10}(i_m) i_m 76\ mm.h^{-1} \quad (3)$$

$$e_m = 0.283\ i_m > 76\ mm.h^{-1} \quad (4)$$

Where e_m has units of mega joule per hectare per millimeter of rainfall (MJ.ha-1.mm-1). A limit of 76 mm.h-1 is imposed on intensity because median drop size does not continue to increase when intensities exceed 76 mm.h-1 (Carter et al.1974).

According to the previous equations we need to calculate the max 30 min intensity during a storm which needs a short duration rainfall data which is unavailable in our case study area. Thus, Using Remote Sensing data takes place in our study to achieve the short duration rainfall data needed in our case study. Global Precipitation Climatology Centre (GPCC) daily precipitation data was used to estimate the max 30 min intensity for a storm event occurs in twenty fifth of October two thousand and fifteen (Figure 3).

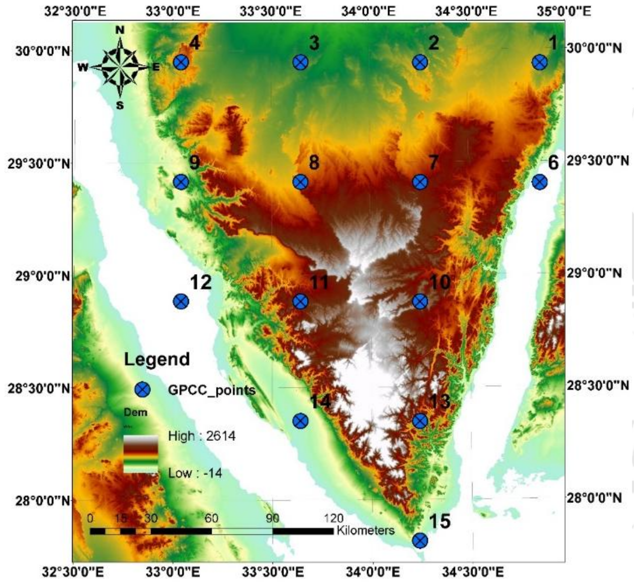

Figure 3: Global Precipitation Climatology Centre (GPCC) points cover the study area

Based on the daily precipitation depth values for each point we estimate the short duration depths specially the thirty-minute precipitation depth using bell's ratio equations shown in Table 1. Bell's method (1969) was developed after an analysis of rainfall data from the United States, the USSR, Australia and South Africa. His method is based on the assumption that the most intense short duration storms are caused by convective storm cells and that such storms have similar characteristics wherever they occur in the world [4]. For this reason, his method is only valid for storms of up to 2 hours duration shown in equation (5).

$$P_t^T = (0.54t^{0.25} - 0.5)P_{60}^T \quad 5\ min < t < 120\ min \quad (5)$$

Where P_t^T is the rainfall depth in mm at T-years and t-min; and P_{60}^T is the rainfall depth in mm at T-years and 60 min storm duration.

It is known that the use of specific time periods to measure precipitation amounts can lead to a reduction in the estimation of the maximum amounts of the real precipitation during the specified period. Many studies recommend modifying measured quantities using fixed intervals [1], usually using a multiplier. Hirschfeld (1961) proposed multiplying the results of the frequency analysis of the annual maximum measured by using one fixed time interval for any period from 1 to 24 hours by factor 1.13 to give these amounts almost to the maximum real value. On the basis of probability theory, Weiss (1964) determined theoretical value 1.143 for this factor, since the adjustment is lower if the fixed time periods available are shorter than the specified duration [1]. Based on that, adjustment multiplier factor used to adjust the valus of the daily precipitation GPCC data used in this case study and assumed to be 1.14.

Table 1: GPCC daily precipitation depth values for each point and the estimated short duration depths using Bell's ratios equations

GPCC Point No.	Estimated Rainfall max 30 min intensity for Storm Event 25/10/2015					
	P daily (mm) from GPCC data	P 24hrs (mm)	P 60min (mm)	P 30min (mm)	I 30min (mm/min)	em (MJ/ha. mm)
1	8.53	9.72	5.83	4.46	0.15	0.20
2	4.05	4.62	2.77	2.12	0.07	0.17
3	4.05	4.62	2.77	2.12	0.07	0.17
4	1.35	1.54	0.93	0.71	0.02	0.13
5	0.59	0.68	0.41	0.31	0.01	0.10
6	6.31	7.20	4.32	3.30	0.11	0.19
7	5.12	5.84	3.50	2.67	0.09	0.18
8	5.12	5.84	3.50	2.67	0.09	0.18
9	4.21	4.80	2.88	2.20	0.07	0.18
10	5.12	5.84	3.50	2.67	0.09	0.18
11	5.12	5.84	3.50	2.67	0.09	0.18
12	4.21	4.80	2.88	2.20	0.07	0.18
13	3.27	3.73	2.24	1.71	0.06	0.17
14	3.27	3.73	2.24	1.71	0.06	0.17
15	3.27	3.73	2.24	1.71	0.06	0.17

According to the previous table rainfall energy em was estimated based on the data of Laws and Parsons (1943) using equations (3) & (4). Thus, the R factor values for each point was calculated based on (Brown and Foster, 1987) equation. Applying GIS ver.10.1 interpolation algorithm tools a raster map of R factor was generated using Inverse distance weight interpolation (IDW) Method (Figure 4).

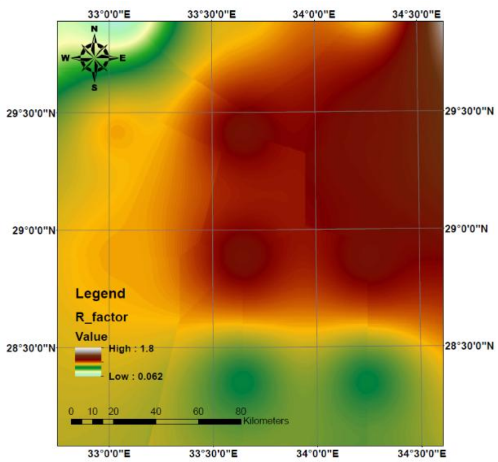

Figure 4: R-Factor raster cover the study area

b) Soil erodibility factor (K)

Soil erodibility factor (K) is defined as the rate of soil susceptibility to detachment and transport of soil particles under an amount and rate of runoff for a specific storm event, measured under standard plot. It is a function of inherent soil properties related to soil profile parameters [6] such as: percent silt (0.002– 0.01 mm), percent sand (0.1–2 mm), and percent organic matter in the sample, soil structure, and permeability. The K factor rated on a scale from 0 to 1, with 0 indicating soil with least susceptibility to erosion, and 1 refers to soils which are highly susceptible to erosion by water. The K factor was computed using Williams (1995) equation (6).

$$K_{USLE} = f_{csand} * f_{cl-si} * f_{orgc} * f_{hisand} \qquad (6)$$

where fcsand is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with little sand, fcl-si is a factor that gives low soil erodibility factors for soils with high clay to silt ratios, forgc is a factor that reduces soil erodibility for soils with high organic carbon content, and fhisand is a factor that reduces soil erodibility for soils with extremely high sand contents.

The factors are calculated:

$$f_{csand} = 0.2 + 0.3 * exp\left[-0.256 * m_s * \left(1 - \frac{m_{silt}}{100}\right)\right] \qquad (7)$$

$$f_{cl-si} = \left(\frac{m_{silt}}{m_c + m_{silt}}\right)^{0.3} \qquad (8)$$

$$f_{orgc} = \left(1 - \frac{0.0256 * orgC}{orgC + exp[3.72 - 2.95 * orgC]}\right) \qquad (9)$$

$$f_{hisand} = \left(1 - \frac{0.7 * \left(1 - \frac{m_s}{100}\right)}{\left(1 - \frac{m_s}{100}\right) + exp\left[-5.51 + 22.9 * \left(1 - \frac{m_s}{100}\right)\right]}\right) \qquad (10)$$

Where ms is the percent sand content (0.05-2.00 mm diameter particles), msilt is the percent silt content (0.002-0.05 mm diameter particles), mc is the percent clay content (< 0.002 mm diameter particles), and orgC is the percent organic carbon content of the layer (%).Soil percentages for all types of soil required in the previous factors that cover the study area was collected from The World Soil Information Service (WoSIS) that contain a harmonized soil remote sensing data for all the world in form of digital maps. Applying GIS ver.10.1 raster calculator algorithm tool on the previous soil percentage digital maps to estimate the previous factors for Williams equation, a raster map of K factor was generated (Figure 5).

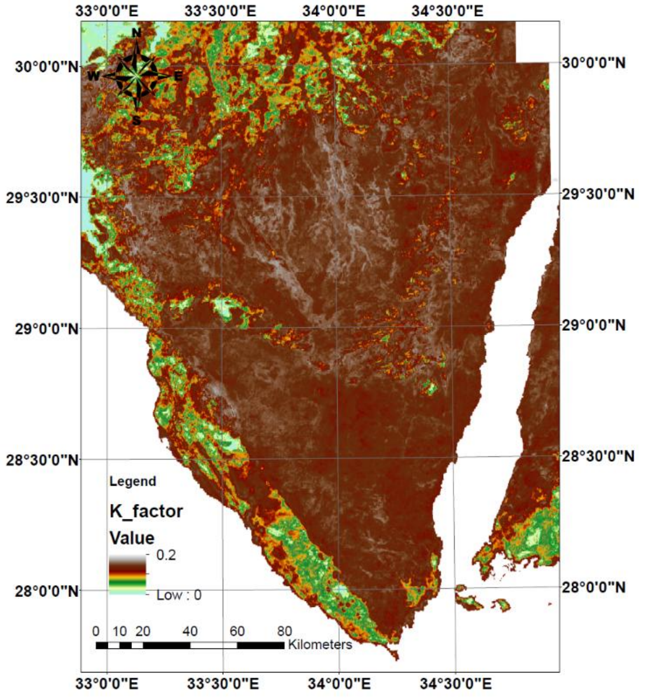

Figure 5: K-Factor raster cover the study area

c) Slope length and steepness factor (LS)

The effect of terrain factor on soil erosion rates is expressed by the combined effect of slope length (L), slope steepness (S), and slope morphology on rill, inter-rill erosion and sediment production. As slope length increases (L), the total soil erosion loss per unit increases, as a result of progressive accumulation of runoff in downslope. As the slope steepness increases, the soil erosion also increases as a result of increasing the velocity and erosivity of runoff (Wischmeier and Smith 1978). Rill erosion is mainly caused by surface runoff and increase in a downslope direction because the runoff increases in this direction. Interrill erosion is the result of raindrop impact on soil surface and is considered uniform along a slope [7]. The (L) parameter expresses the ratio of rill erosion (initiated by flow) to inter-rill erosion (raindrop impact) to find the loss of soil in relation to the standard plot length of 22.1 m. Renard et al. (1997) define slope length as the horizontal distance traversed from the origin of overland flow to the point where deposition occurs, or runoff concentrates into a defined channel.

The slope steepness parameter (S) relates to the effect of the slope gradient on erosion in comparison to the standard plot steepness of 9%. The effect of slope steepness is greater on soil erosion loss compared to slope length. Therefore, (LS) is the predicted ratio of soil loss per unit area from a field slope from a 22.1 m long, 9% slope under otherwise identical conditions. The Digital Elevation Model (DEM) 90 m x 90 m cell size, was employed to derive the LS factor. L and S in the equation are generally combined as LS, representing the effect of the topography on erosion rates [8]. The equations for calculating LS in the USLE are:

$$LS = L * S \qquad (11)$$

$$L = (\lambda/22.13)^m \qquad (12)$$

$$m = \beta/(1 + \beta) \qquad (13)$$

$$\beta = (\sin\theta)/[3 * (\sin\theta)^{0.8} + 0.56] \qquad (14)$$

The slope steepness factor S is evaluated from (McCool et al., 1987).

$$\begin{aligned} S &= 10.8 * \sin\theta + 0.03 \qquad \theta < 9\% \\ S &= 16.8 * \sin\theta - 0.5 \qquad \theta \geq 9\% \end{aligned} \quad (15)$$

Where λ is the slope length (m), m is a variable length-slope exponent, β is a factor that varies with slope gradient, and θ is the slope angle (degrees). Applying GIS ver.10.1 raster calculator algorithm tool on dem 90 x 90 m to generate the previous equations parameters. A raster map of LS factor was generated (Figure 6).

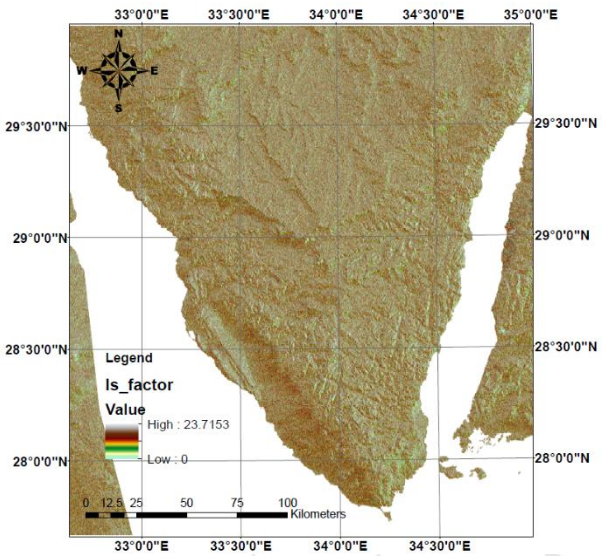

Figure 6: LS-Factor raster covers the study area

d) Cover and management factor (C)

The cover and management factor (C) represent the effect of cropping and management practices on the runoff and soil erosion rate [9], and is considered the second major factor after topography controlling soil erosion. Vegetation cover normally dissipates the kinetic energy of the raindrops before impacting the soil surface. Thus, vegetation cover and cropping systems significantly influence the runoff and erosion rates. Consequently, soil erosion can be limited with proper management of vegetation, plant residueand tillage (Lee 2004). Depending on available information, the cover and management factor can be estimated according to different methods. The crop management factor is largely controlled by surface vegetation, land use, surface roughness and soil moisture. A successful estimation of the cover factor can be carried out rapidly from satellite imagery. The (C) factor combines plant cover, the level of its production, and the associated cropping techniques. It varies from 1 on bare soil to 1/1000 under forest, 1/100 under grasslands and cover plants, and 1–9/10 under root and tuber crops [9]. According to the satellite imagery for the study area the (C) factor chosen for our study area equal 1 as the majority of the land cover is a bare soil, as shown in Table 2 the values for C factor for several types of land use generated from Evaluation and Conservation Online Manual in Purdue University.

Table 2: Cropping and management (C) factor of the USLE for several tillage/cover systems generated from Evaluation and Conservation Online Manual in Purdue University.

Tillage and cropping practice	Crop sequence	C - Factor
Forest	(permanent)	0.0005
Pasture	(permanent)	0.005
Rotation (1/6)	C-G-M-M-M-M	0.011
Rotation (2/5)	C-S-G-M-M	0.027
No-till, cover crop after soybeans	C-S (cover crop)	0.027
No-till	C-S	0.05
Ridge-till planting	C-S	0.1
Chisel (50% residue) on contour	C-S	0.16
Chisel (50% residue) and no-till	C-S	0.1
Chisel tillage (50% residue)	C-S	0.16
Chisel tillage (little residue)	C-S	0.35
Moldboardplow, spring	C-S	0.35
Moldboardplow, fall	C-S	0.39
Bare soil	none	1

C- Corn, M- meadow (forage crop); G-small grain; S – soybeans. The last three entries in the table are included in "Clean Tillage".

e) Conservation practice factor (P)

The conservation practice factor (P) in the RUSLE model is the ratio of soil loss using a specific support practice to the corresponding soil loss after up and down cultivation [9]. It is a measure of the effect of conservation practices that reduce the amount and rate of water runoff, which reduces erosion. It includes different types of agricultural management practices such as: strip cropping, contouring and terracing. Using Visual inspection of satellite image and field observations were used to recognize the type of land development and conservation practice (P). The conservation practice factor (P) chosen in our study area was 1, as the study area will not undergo any future development and conservation practice. As shown in

Table **3**the values for P factor for several types of different support practice factors [9].

Table 3: P values for different support practice factors (Kelvin K. K. Kuok et al. 2013)

Soil Conservation	P - Factor
None	1
Contouring	0.6
Contour strip - cropping	0.35
Terracing	0.15

4. Results and Discussion

After estimating each factor in USLE as illustrated in previous sections. Applying GIS ver.10.1 raster calculator algorithm tool by multiplying all the previous generated digital maps to generate the soil loss digital map which represent the average erosion expected to occur due to a storm event occurs in twenty fifth of October two thousand and fifteen in South Sinai Region. A raster map of average erosion was generated (Figure 7).

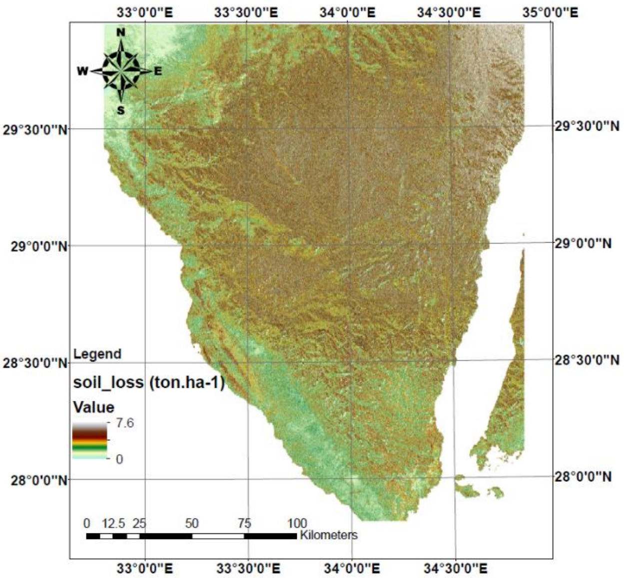

Figure 7: Soil loss values raster cover the study area

To calibrate the generated soil loss values estimated by the remote sensing data. Applying GIS ver.10.1 raster calculator algorithm tool by dividing the previous generated digital map of the soil erosion in (ton. ha^{-1}) by the density digital maps collected from The World Soil Information Service (WoSIS) multiplying by gravity acceleration to convert the density to specific weight of soil. Thus, soil loss digital maps generated in units of volume per hectare (m3/ha). After this step spatial analyst tools used to generate the final soil loss volumes accumulated upstream the two existing dams that generated from the two catchments attack each dam (AbiadBatno and Shebiha dams) (Figure 8). The two located dams with field soil loss measurements collected from water resources research institute (WRRI) used for calibration of the soil loss values generated by remote sensing Table 4.

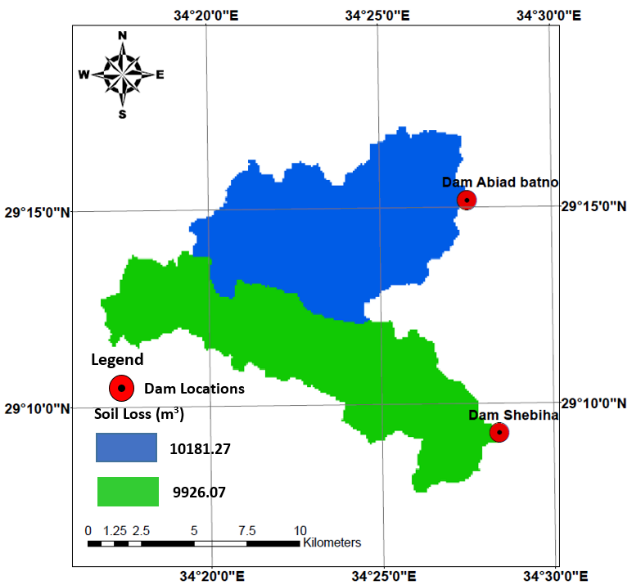

Figure 8: Soil loss values accumulated in the catchments upstream the two dams

Table 4: Calibrated factors for both sediment loss volumes resulted from remote sensing data.

Dam Name	Field measurement Volume (m^3)	Catchment area (m^2)	Remote Sensing Resulted Volume (m^3)	Calibration Factor
Dam Abiadbatno	7440	74556114.89	10181.27	0.73
Dam Shebiha	8478	74780546.09	9926.07	0.85

5. Discussion

The present case study explains the different parameters that effect soil erosion loss. The estimated soil loss using remote sensing could be employed for immediate applications in soil conservation planning and implementation. Moreover, the estimated soil loss and sediment yield seriously endanger the future life of constructed dams (Abiadbatno Dam) and (Shebiha Dam). Despite the fact that several dams had been already built to avoid flash floods to protect the development areas and also for water resources management which act as a trap for sediments which eroded due to flash floods, so this effect on the predicted amount of sediments which arrive to shorelines. The USLE model provides an efficient tool for soil erosion loss and soil erosion risk estimation, and therefore, areas vulnerable to soil erosion and landslides must be prioritized for conservation. However, further research is highly recommended on soil erosion factors in arid and semi-arid regions with a large scale of sediments field measurements as more data on rainfall and its duration and intensity provided the basis for calculating rainfall erosivity and also sediment loss volumes to increase the efficiency of using remote sensing data which is more available, simple and low cost techniques for modelling and assessing soil erosion risk in other comparable watersheds in the southern Sinai highlands.

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