Potential and Actual soil losses assessment in Abjubeha, Sudan using USLE, RS and GIS analyses

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Abstract

The natural and human induced effect on landscape changes in study area were analyzed. Aster image was used to classify landscape by supervised classification.

Grain Size Index (GSI) was applied as indicator of the vulnerability level of topsoil to the erosion.
Erosion risk assessment at sub-regional level was measured using modern digital techniques and the well-known Universal Soil Loss Equation (USLE).
According to the result the area is subdivided into very low, low, moderate, high and severe erosion rates. The annual soil loss is greater than one tonne per hectare, at an averag of 1.23t/ha/year across the most of stuy area.

Set of maps of study area were produced for different erosion rates. Subtle different between the actual (human induced) and potential (natural) erosion rate was recognized.

The effect of individual soil erosion factors on erosion events as well as the erosion rate at different location within the study area were measured.

The impact of landuse practice on erosion could not be fully undertaken due to a lack of spatial information

Rationale

The USLE is a simple empirical model, based on regression analyses of soil loss rates on erosion plots in the USA. The model is designed to estimate long-term annual erosion rates on agricultural fields. Although the equation has many shortcomings and limitations, it is widely used because of its relative simplicity and robustness (Desmet & Govers, 1996). It also represents a standardized approach.

Soil loss in the study site is principally due to water erosion, is heightened by practice that reduce surface cover. A rough approximation of the areas as affected by soil degradation was reported by GLASOD data (Oldeman *et al.*, 1990), provides an overview of the extent of soil degradation in Sudan. About 64 million ha were affected by degradation in the Sudan, 42% of them are affected by water erosion (27milliom ha).

The most dominant effect of the loss of topsoil is often inconspicuous but nevertheless potentially very damaging. However, with a very slow rate of soil formation, any soil loss of more than 1 t/ha/yr. can be considered as irreversible within a time span of 50-100 years.

Different soil losses rate as recoded worldwide, i.e., 30 to 40 t/ha/y in Africa and 20 to 40 t/ha to more than 100t/ha in extreme events in Europe (Morgan, 1992) while the loss average is 100 t/ ha /y in China.

Extremely importance in term of its vital consequences, soil degradation may take some time before the effects of such erosion become noticeable, especially in areas with the deepest and most fertile soils. At a time the effects have become obvious; it is usually be too late to do to be mange.

Ayoub, (1998) and Yassoglou *et al.*, (1998) reported that the main causes of soil erosion are still inappropriate agricultural practices, deforestation, overgrazing, construction activities and the highly variable rainfall and recurrent droughts. As Breman et al., (2001) mentioned that nutrient depletion are the most widespread soil degradation types, it's a major biophysical cause of low per capita food production in Africa, nutrients depletion in the Sudan has steady increase through removal of large quantities of nutrients from soils without applying sufficient quantities of manure or fertilizer to replenish the soil, (Kapur etal 2002). Henao et al, (2006) revealed that nutrient mining across Africa ranges from 9 to 88 kg NPK/ha per year.

The evidence leaves no doubt that the resources on which Sudanese farmers are being undermined by soil degradation caused by nutrient mining and associated factors such as deforestation, use of marginal lands, and poor agricultural practices.

This paper assume that the environmental (Potential soil loss) and human impacts (Actual soil loss) of soil loss didn't vary greatly. Locations and human induced processes presume a causal relationship between grazing and cropping and soil erosion according to soil types and landuses.

Increasing the awareness among farmers, scientists and policy makers about the soil degradation problem in Sudan is now an urgent need. Since mechanized rained agriculture in the Sudan was based on the assumption that the wet conditions of the 1950s and 1960s were the norm. (Walsh, et al. 1988)

Rather more; such mistaken assumptions were due to misunderstanding of the dryland environments and lack of long-term data.

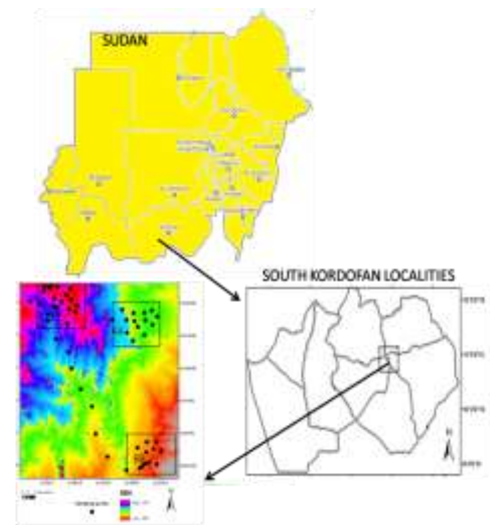
So the purpose of this paper is to:
To quantify the actual and potential soil erosion risk using USEL and GIS.
To produce set of erosion maps and its different aspects
To define what are the most factors affecting the soil erosion?

Material and Methods

Characteristics of the study area

The study area is a part of vast undulating forested region, underlain by the Precambrian Basement Complex in Abujubeha area (10° 52 48.17 -11° 23 08.79 N and30° 00 05.99 -31° 28 04.91' E) in Northeast Nuba Mountains, South Kordofan region, Sudan. The area has been one of the famous areas for traditional and broad mechanized cultivation in the Sudan especially for rainfed cotton and sorghum. The study area covered a total of about 250,000 ha

Fig.1: The study area, Location and Elevation Characteristics.

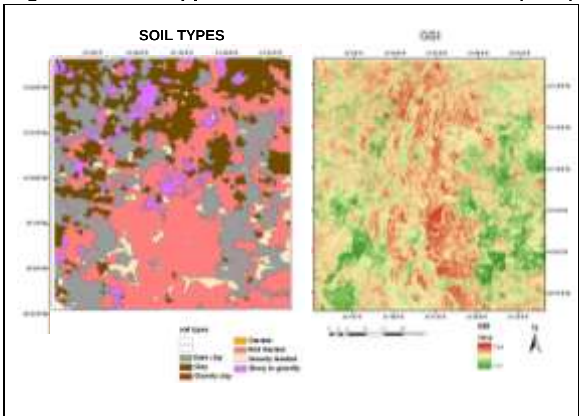


The study area is subdivided on physiographic basis into three landscape ecological zones Fig (1) according to altitude and soil drainage: zone AA (>550 m asl) represent the undulating physiographic system, zone BB (350-500 m asl) and zone CC (550-500 m asl) were taken along the slope to represent the down and upper slope respectively.

Soil Degradation Status: using (GSI).

Grain Size Index by Xiao. et al. (2005), was used as indicator for grain size distribution of topsoil which in turn represents the vulnerability level of topsoil to the erosion. The result was strongly corresponded with soil types, (Fig2). The relatively highest GSI value were recorded at the Rough soils texture (Stony to gravelly, Gravelly Gardud and Gravelly clay soils) followed by the Red soil (Red Gardud and Gardud soils) and lately came the Clayey soils (Dark clay and clay soils). The Clayey soils are less vulnerable to erosion at down slope and undulating position than that at the upper slope in far Northeast of the study area.

Fig4.18: Soil types and Grain Size Index (GSI)



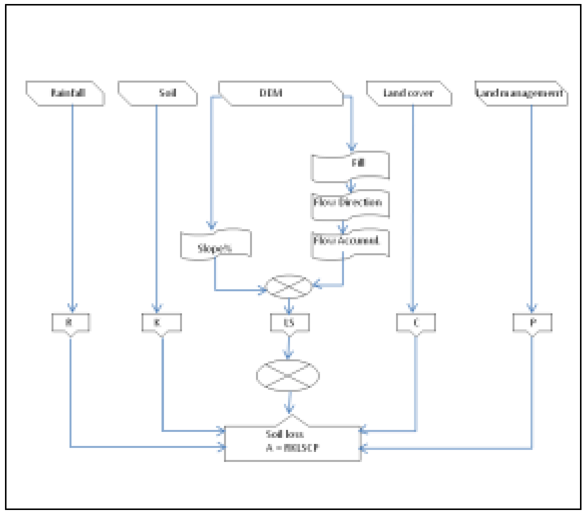
Erosion risk assessment

The assessment of soil erosion was carried out based upon principles and parameters defined in the Universal Soil Loss Equation (Wischmeier and Smith, 1978)

$E = R.K.L.S.C.P$ [metric ton/ha/year]

The USLE was applied using the Geographic Information System (GIS) according to the flow chart (Fig 2)

Fig:2: Flow chart showing erosion assessment using GIS



3 The Universal Soil Loss Equation (USLE).

The Universal Soil Loss Equation (USLE) was employed to assess the amount of existed soil loss (Actual soil loss) and the Potential (Natural) soil loss. The following results were obtained using of Arc GIS tool.

3.1. Rainfall Erosivity Factor (R).

The modified Fournier index was used since there were no detailed data on storm intensity.

The index relates average annual precipitation to rainfall in the wettest month. Data was plotted using Arc GIS. (Fig.3)

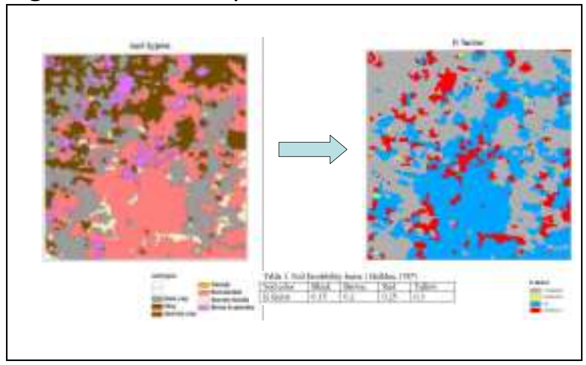
The result indicating that erosivity decreased from NW to SE approximately. The erosivity value at upper slope in the far North West of the study site of about 976MJ.mm. $ha^{-1}h^{-1}y^{-1}$, and it was declined at mid and lower slope in the South East and North East of about 816MJ.mm. $ha^{-1}h^{-1}y^{-1}$ Regardless the differences in values but they were not highly significant.

Fig3:R- Factor map

3.2. Soil Erodability Factor. (K).

The values of K-factor range from 0 to 1. Based on soil colors according to Heldden (1987) the soil map of the study site was converted into a new map having the K-factor values corresponding to each color. The new map consists of four erodability classes which was then after, rasterized using Arc GIS, (Fig.4)

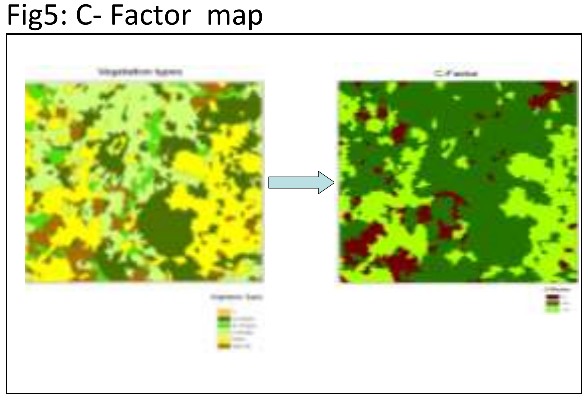
Fig4: K-Factor map



3.3. Vegetation Covers Factor (C).

C- Factor which was represents the soil loss under a given crop or vegetation cover is calculated using the produced vegetation classification map. The classified vegetation map was rasterized and then reclassified using standard C- value as delineated by USLE –model. C- Factor map of three C-Factor values was produced (Fig5)

Fig5: C- Factor map



3.4. Slope Length and Slope Steepness (LS).

Slope length and slope steepness (LS) was determined using LS method proposed by Moore and Burch (1986). The slope length (flow accumulation) and slope steepness (slope gradient) were driven from DEM. The following Fig(6) shows the steps as implemented in Arc GIS.

Fig6: LS- Factor extraction and map

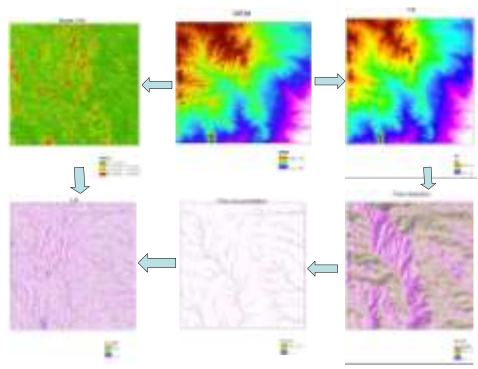
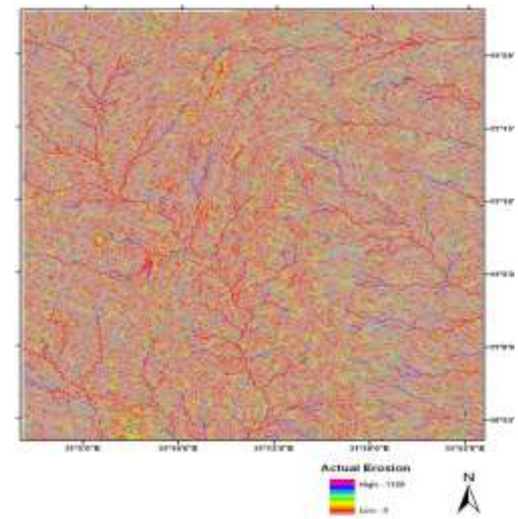


Fig7: Actual Soil Erosion Risk map (ton/area/y)



Soil Erosion Intensity.

All the factor maps of R, K, LS and C were integrated to generate a composite map of erosion intensity (Fig7). The map was classified into five classes.

The result showed that, the amount of soil loss in the study area is of about 240.320 ton/area/y. Soil loss at different parcel of land are ranging from 0 to 1159 t/ha/year.

The overall average of annual soil loss of the study site is 1.23t/ha/year.

Soil loss is typically greater along the steeper slope banks of tributaries. Other high soil erosion areas are dispersed throughout the site and are typically associated with high erosion potential land uses. The plain areas of the study area show the least vulnerable to soil erosion.

With the same context the Potential soil loss map was produced using R factor, LS factor and K factor only. The human- induced effect (C- factor) was excluded.

A comparison between the Actual and Potential soil loss in the area was generated. The result revealed subtle difference between the two soil loss values.

Very low rate of erosion class represent (66-60%) of the total area followed by Low rate (11-10%), Moderate (10-13), High rate (04-05%) and the Sever erosion rate comprised (9-12%) for both Actual and Potential erosion intensities respectively (Fig.8).

Fig8: Natural (potential) and Actual (human-induced effect) soil loss maps.

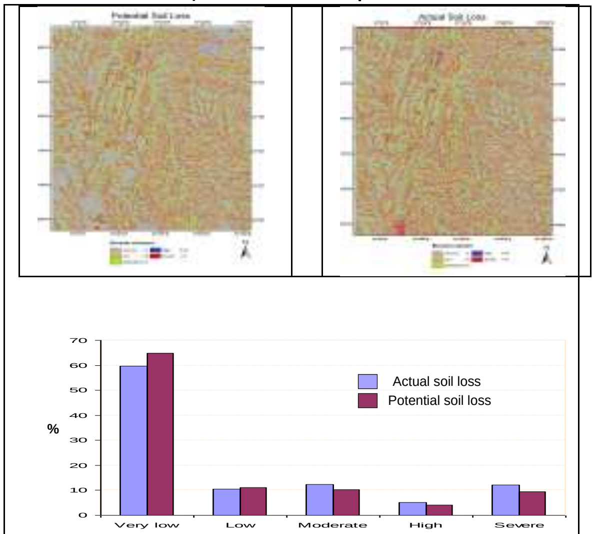
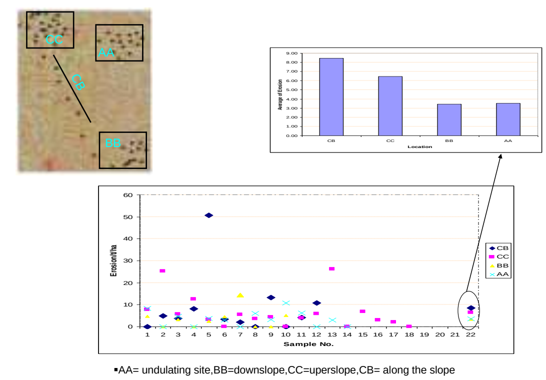


Fig9: Location as affected by soil loss



Erosion/Location

Soil Loss at Different Locations.

Soil loss within and between locations upper the slope (CC), down slope (BB) and the undulating location (AA) was measured. Within location the result revealed that there was a noticeable variation in location CC.

Soil loss variation becomes obvious between locations; along the slope (CB) showed the highest vulnerability to soil loss averaging to (8.2t/ha/y), followed by the upper slope(CC) with average (6.5t/h/y), the undulated location (AA) and down slope with average (3.6t/ha/y) and (3.00 t/ha/y) respectively. (Fig9)

erosion factors Effect on erosion intensity.

Correlation relations between the soil loss and its factor (K, C and LS) as affected by elevation, location and the whole area were examined to detect which is curial for erosion process.

The result as it shown in figure 10 revealed that:

-No correlation between the elevation and the soil loss (E) nor the soil erodability (K-factor)

-Soil erodability factor (k-Factor) and the LS factor showed strong effect on soil erosion loss (E) within the whole site, location AA, location CC and along the slope. With R^2 values range between 6.5 and 9.

-In location BB (down slope) the soil loss was strongly affected with the soil erodabilty (K-factor) (R^2 = 6). And with less correlation relation with vegetation cover factor (R2=4)

-K- factor, LS –factor and C- factor respectively, affecting the soil result.

Fig10: soil loss as affected by Erosion factor, location elevation

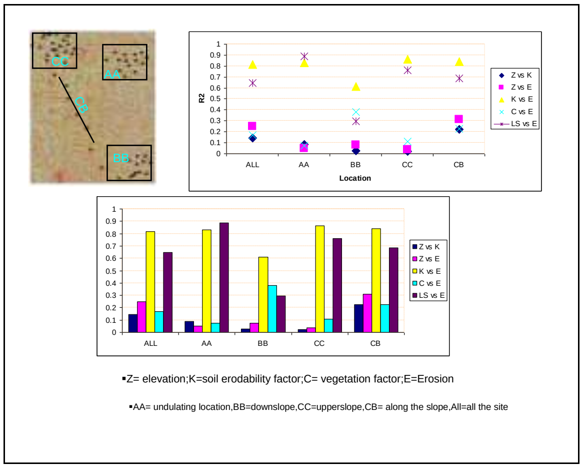
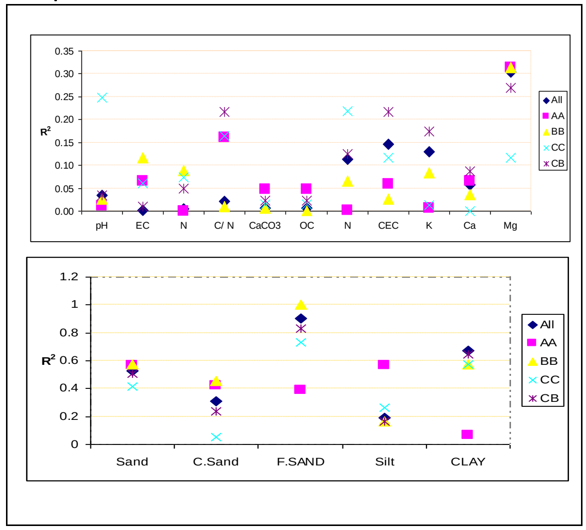


Fig4.27: Physical and Chemical Properties Response to Soil Loss



Impact of Soil Loss on Soil Properties.

The soil physical and chemical properties showed different response to the soil loss. Generally, the physical parameters were greatly responding in compare with chemical properties. The fine sand is highly affected (R^2=4-9.7) in all location and in the whole area. The chemical properties were less or weekly responding to soil loss (R^2< 0.3), location (BB) is relatively less respond and in the other hand along the slope showed the highest respond in respect to other location. Individual cations not respond to soil loss. But within this low response, exchangeable Mg showed relative high vulnerability to be eroded followed by the CEC and C/N respectively (Fig 11).

Discussion

A proper validation of the results is hardly possible at the scale used. Nevertheless, it is possible to make some comments on the general pattern of the map for some areas. Erosion rate seems to be overestimated in some areas within the landscape of the study area. The 90-m elevation model used to derive slopes is too coarse leading to slope estimates that are generally too high. Results of the spatial analyses presented might have some other limitations and shortcomings.

First of all, the Universal Soil Loss Equation only gives a very crude estimate of long-term expected soil loss. Its only predicts rill- and interrill erosion: gully erosion and deposition were not taken into account although it could be included if a sufficiently detailed elevation model would be available (Moore et al, 1986; Mitasova *et al.*, 1996).

Furthermore, some important factors influencing soil erosion are not taken into consideration, such as the effect of stones and rock fragments in the soil is not included. Römkens (1985) suggests that the effect of stones is best considered in the *C*-factor of the USLE, because stones protect the soil surface in a similar way as a surface Mulch.

Probably even more important than the problems mentioned above are the uncertainties associated with the various data sources. Some of the main sources of uncertainty are:

-The estimation of the rainfall erosivity factor (R), which is based on an approximate relationship with annual rainfall.

-The soil erodibility factor (*K*) is estimated from surface texture and soil colors, while the actual correlation between K and the texture parameters is rather weak as Van der Knijff, et al (1999) said.

-For the LS factor, slope angle was derived from an elevation model with a resolution of 90 m, which is rather coarse for erosion modeling. Because it was not considered feasible to estimate slope length (or specific contributing area) from the current DEM, an arbitrary constant slope length value was assumed, so in effect slope length is not taken into account. These and many other uncertainties propagate throughout the model, resulting in an uncertainty in the estimated erosion rate.

Despite these deficiencies and shortcomings, the methods outlined in this report have produced valuable information on soil erosion risk. The main value of the spatial analysis is to identify areas that experience erosion risk. Then, a more detailed assessment may be performed for these areas using more detailed data, more sophisticated erosion models and field surveys.

This study is an attempt to produce a map of soil erosion risk in sub-regional scale. The interpretation of the maps is complicated; it should be emphasized that these results should be used with caution. For example, it would not be advised to use the maps to predict soil losses on agricultural parcels or to predict soil loss for any individual year. Only soil erosion by water flow is taken into account.

In conclusion, the current soil erosion risk map of study area; nevertheless, the limitations outlined above; simply be close to the best that can be obtained with the available data. The results could be improved by using a more detailed digital elevation model, satellite data that have better spectral and geometric characteristics, more detailed soil information (especially texture and soil depth) and the inclusion of rainfall data from more meteorological stations.

It seemed that the degradation assessment not the end of the story, policies and decision should be tackled in a way that balance between increase production and sustain environmental resources and management.

Over the span of the last three decades or so, public sector have respond to the problems of soil degradation and environmental problems establishing public sector of soil conservation and natural resource management agencies with charters related to soil condition.

These agencies have generally not been well integrated with agencies promoting strategies to enhance agricultural productivity. In many instances these agricultural productivity strategies have had an adverse impact on the natural resource base.

However, the need to address soil erosion has been evident for at least 60 years; with adequate management practices to maintain good ground cover, retention of native vegetation, not undertaking agricultural activities on areas particularly susceptible to erosion, adjusting grazing pressure from both domestic and wild species, modifying grazing strategies (as distinct to grazing pressure), minimum tillage, soil conservation works and stubble retention is urgently needed.

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