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Evaluation of Spatial Soil Loss with the aid of Geo-information Techniques in the southern part of King County In Washington, USA

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Abstract:- This study is aimed at estimating soil erosion potential in response to variable annual rainfall in the south King County, Washington, USA. The thematic layers of soil erodibility (K-factor), rainfall (R-factor), slope length and steepness (LS-Factor), cover and management (C-factor), and the conservation support-practices (P-factor) are the main data required for computed soil loss per unit area. These layers were extracted and manipulated from the available topographic, soil maps, satellite image (TM in 1988 and ETM in 2014), and field survey data analyses. The spatial analyst function in GIS software was used for matching the thematic layers and assessing the land degradation by soil water erosion. In terms of statistical analysis 181.34 km^2 (72.7 %) of land area has slight to moderate land degradation, 65.10 km^2 (26.1%) has high to very high land degradation, and 2.99 km^2 (1.20%) of the total land area is facing a severe degradation. This study emphasizes that a supervised classification, vegetation index (NDVI) and revised Universal Soil Loss Equation (RUSLE) model coupled with GIS and remote sensing techniques are promising and cost-effective tool for mapping critical areas of land degradation in the study area.

Keywords:- Soil erosion; Geo-information Techniques; land use information; RUSLE

I. INTRODUCTION

Soil erosion is one of the most serious global environmental problems resulting in both on-site and off-site effects. Soil erosion has accelerated in most of the world, especially in developing countries, due to different socio-economic, demographic factors and limited resources [1]. For instance, Keiko [2] mentioned that increasing population, deforestation, intensive land cultivation, uncontrolled grazing and higher demand for fire often cause soil erosion. Soil erosion is generally more acute in tropical areas where rainfall is more intense and soils are highly erodible due to the relatively shallow depth and low structural stability [3].

Researchers have been involved in soil erosion research for a long time, and many models for soil erosion loss estimation have been developed [4-7]. Morgan [8] summarized some keynote papers about soil erosion in northern Europe, and Morgan [9] highlighted major empirical models for predicting soil erosion loss. The RUSLE (Revised Universal Soil Loss Equation; USDA, 1997) has broad application to different situations, including forest, rangeland, and disturbed areas [10]. The RUSLE is written as

$$A = LS \times R \times K \times C \times P \qquad (1)$$

where A is the soil loss in t/ha over a period selected for R, usually a yearly basis; R is the rainfall–runoff erosivity factor in MJmm/ha h; K is the soil erodibility factor (t h/MJ mm); L is the slope length factor; S is the slope steepness factor; C is the cover and management factor; and P is the conservation support-practices factor. The L, S, C, and P values are dimensionless. These can then be converted into raster layers for input into a GIS to be analyzed to produce a soil erosion risk map [11].

The use of geo-information techniques (*RS, GIS and GPS*) makes soil erosion estimation and its spatial distribution feasible with reasonable costs and better accuracy in larger areas [12-14]. For example, a combination of remote sensing, GIS, and RUSLE provides the potential to estimate soil erosion loss on a cell-by-cell basis [15]. Liu et al. [16] assessed soil erosion risk based on a simplified version of RUSLE using DEM (Digital Elevation Model) data and land-units maps. William *et al.* [17] used GIS techniques to interpolate RUSLE parameters for sample plots to determine the soil erosion risk at Camp Wiliams, Utah. Shi *et al.* [18] reviewed the applications of GIS in estimating soil erosion, discussed the difficulty and limitations of previous research and identified that GIS provided tremendous potential for improving soil erosion estimation. Symeonakis, and Drake [19] used a sample ground dataset, Thematic Mapper (TM) images, and DEM data to predict soil erosion loss through geo-statistical analysis. They showed that such methods provided significantly better results than using traditional methods. In general, remote-sensing data were primarily used to develop the cover-management factor image through land-cover classifications Jia *et al.* [20], while GIS tools were used for derivation of the topographic factor from DEM data, data interpolation of sample plots, and calculation of soil erosion loss [21].

The objectives of this study were monitoring, and mapping the soil erosion by application of geo-information technology and RUSLE model, and to assess the soil erosion risk in the year of 1988 and 2014 in the southern part of King County in Washington, USA.

II. MATERIAL AND METHODS

A. Materials

Study Area: The study area, located in the southern part of King County in Washington State, lies within longitude 122^o 42′ to -121^o 99′ W and latitude 47^o 26′ to 47^o 51′ N, and has a total area of 249.434 km^2 (Fig. 1). Present population density averages at 1300/Km^2. The mean annual precipitation is 800—1,200 mm and the annual average temperature is 16-19°C. The land surface is mainly yellow red soil derived from granite and loam soil. These soils are classified into Euic and mesic Hemic Haplosaprists, based on the soil Taxonomy of the U.S.D.A, [22]. Since 1988, vegetation change has been reversed in some area, but in others, vegetation change has continued to aggregate.

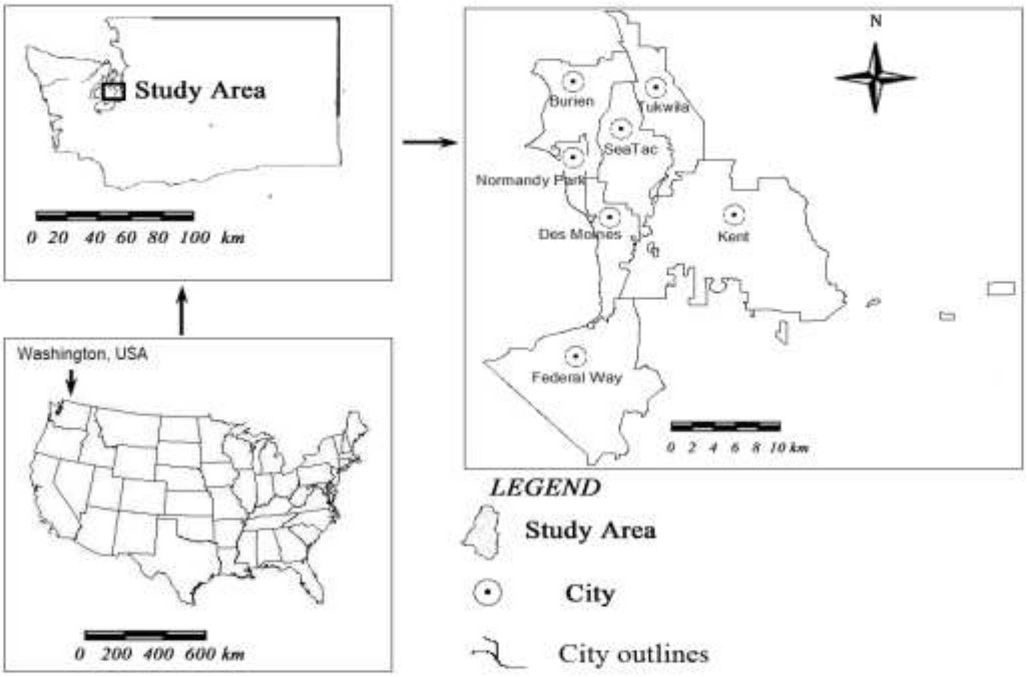


Fig. 1: General location of study area in the southern part of King County.

Spatial Database Using GIS and Remote Sensing: This study, used monthly rainfall data of 26 years period (1988-2014) of the southern part of King County in Washington State. Digital soil map of the study area was extracted from the soil map of location study collected in hardcopy from Highline College. The GIS-based land use/land cover map of the catchment was developed from satellite imagery (Landsat TM and ETM) of July, 1988 and 2014 collected from the USGS Global Visualization Viewer (http://glovis.usgs.gov) with the datum WGS84 and projection UTM N10. A topographic map 1: 10, 000, including the location study, was input to the GIS by digitization [11]. This factor elevation map was converted to raster with a spatial resolution of 30×30 m^2. The digital elevation map (DEM) was used as the base for other topographic-related analyses [23]. The polygons and their attributes were connected with uniform code. These vector maps were also converted into raster, which had the same reference system and resolution as the DEM. The data sources were integrated in the GIS with grid-cell format. Each defined cell (pixel) had an exact location in space, determined by the grid orientation and cell size and a list of assigned attributes.

B. Methods

The overall methodology involved use of RUSLE in a GIS environment, with factors obtained from meteorological stations, reconnaissance soil surveys, topographic maps, and results of other relevant studies. Individual GIS files were built for each factor in the RUSLE and combined by cell-grid modelling procedures in ArcGIS software (Eastman, [23]) to predict soil loss in a spatial domain and then assess the effects of environmental change (Fig. 2).

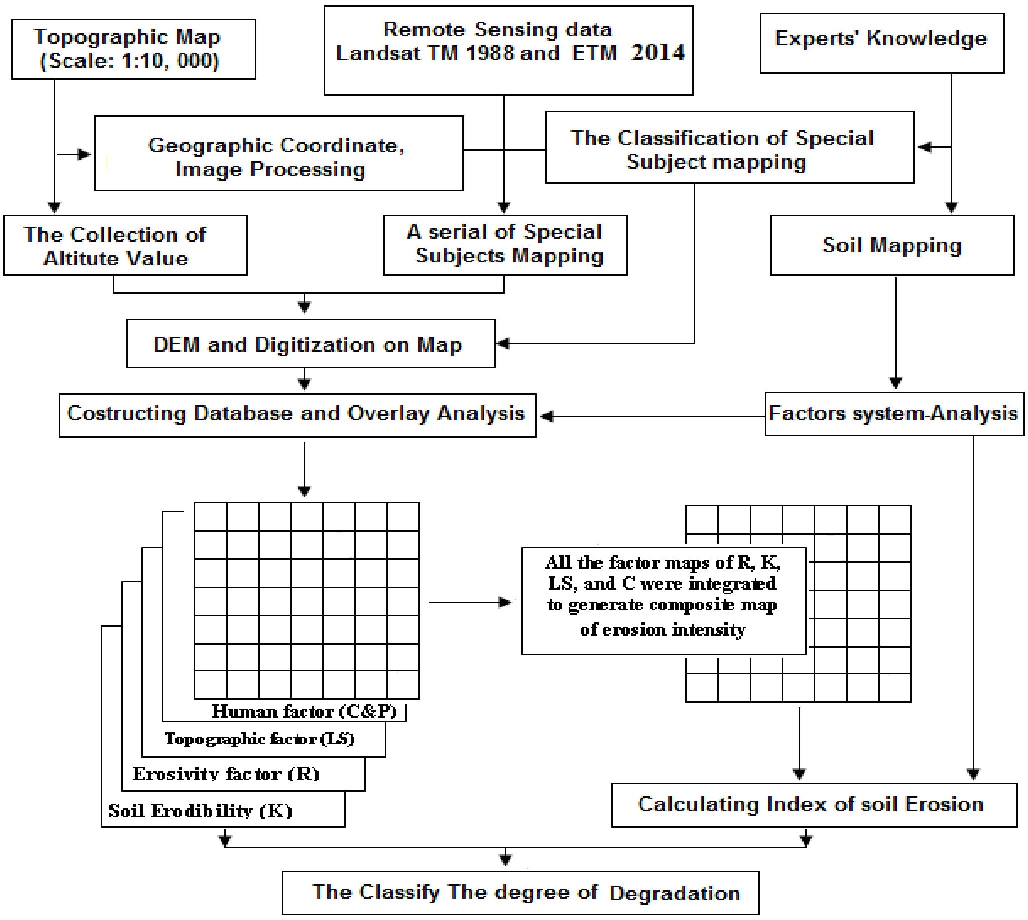


Fig. 2: The Chart of soil loss assessment using Geo-information Technology.

Determining RUSLE factor values Derivation of the factors required by the RUSLE is well documented in the literature [4 and 10]. However, recent advancements in GIS technology has enabled more accurate estimation of some RUSLE factors, specifically those related to slope length and steepness [5 and 10]. Values assigned to the RUSLE factors are discussed below.

The K-factor, termed as 'soil erodibility factor', is the integrated effect of processes that regulate rainfall acceptance and resistance of soil to particle detachment and transportation. The K-factor is an empirical measure of soil erodibility and is a function of intrinsic soil properties. The main soil properties affecting the K-factor are soil texture, amount of fine sand in addition to the usual sand, silt and clay percentages used to describe soil texture, organic matter, soil structure, and permeability of soil profile. The K-factor can be computed by empirical method [4], nomograph [10] or K-value triangle based on soil texture [10]. The empirical method requires several parameters for each soil type, which were not easily available for all soil types in the study area. Hence, in this study, it is attempted to compile texture, depth, permeability, and then K-values were selected from USDA [6] by careful examining the soil texture. The values were adjusted according to local experiences and available literature (Table 1).

Table 1: K value based on the soil texture and organic matter content.

Soil Types	K value			
	Soil Texture class	Average	<2%	>2%
Cambic Arenosols	Sand	0.02	0.03	0.01
Eutric Cambisols	Sandyloam,clay,clayloam	0.13	0.14	0.12
Eutric Leptosols	Clayloam	0.30	0.33	0.28
Rendacize Leptosols	Sandyloam,Loam,clayloam	0.30	0.33	0.28
Vertic Cambisols	Clay	0.22	0.24	0.21
Rock surface (Regosols)	Coarse Sandy	0.07	-	0.07

The rainfall erosivity factor (R-factor) is defined as the product of total storm energy and maximum 30-min intensity divided by 100 for numerical convenience, known as the EI30 index [10]. The EI30 index method is developed by evaluating correlations between soil erosion and a number of rainfall parameters [10]. The annual R-factor is computed as sum of EI30 values for individual storms during a year. In absence of rainfall intensity records, as is the case with present study, monthly rainfall data can be used to calculate R-factor annually using the following relationship developed by [10]. With this in mind, it was felt that rainfall characteristics of the entire watershed (249.434 km^2) were adequately represented by data collected from the single weather station in the airport Sea-Tac station and Kent station. Rainfall–runoff erosivity was determined by calculating the erosivity value for each storm using the method described by [10]. The storm erosivity of each storm was then accumulated to produce a yearly erosivity value (R factor). Monthly distribution of rainfall and the corresponding proportion of rainfall runoff erosivity are given in Table 2.

$$R = \sum_{i=1}^{12} 1.735 \times 10^{\left(1.5 \times \log \frac{Pi^2}{P} - 0.8188\right)} \qquad (2)$$

Where, R = rainfall erositivity factor in MJmm/ha h, Pi = monthly rainfall in mm, and P = annual rainfall in mm. As the location under study is having single station, one R-factor value was considered for the whole location in a year.

Table 2: Monthly distribution of cumulative rainfall and rainfall runoff erosivity.

Month	Cumulative rainfall (mm)		Erosivity factor (%)	
	1988	2014	1988	2014
Jan	103.3	93.9	10.2	5.1
Feb	18.0	155.2	0.0	19.2
Mar	95.2	239.8	5.3	27.4
Apr	81.3	106.8	3.9	10.8
May	76.5	80.0	2.2	3.8
Jun	39.6	18.5	1.3	0.0
Jul	12.7	19.5	0.0	0.0
Aug	7.1	45.9	0.0	1.5
Sep	44.5	56.6	1.4	1.7
Oct	56.9	171.4	1.7	23.8
Nov	214.1	122.9	25.3	14.9
Dec	88.4	121.6	4.1	14.3

The *LS* factor was limited of slopes ≤ 18% because data used to develop RUSLE involved slopes up to 18 percent only [24]. However, the study area has 30% of its slope gradient in excess of 20 % (USDA-ARS) [24]. USDA-ARS [6] employed data from different sites in USA with slopes up to 25-45 % and reported that the relationship between slope length and soil loss was well approximated by the USLE equation, but not as well when using the RUSLE equation. Thus, the algorithm of USLE for computing the *L* factor was adopted in this study, i.e. *L* factor was described as follow:

$$\mathrm{LS} = (L / 22.13)^m \qquad (3)$$

Where: *m* is an exponent that depends on slope steepness, being 0.5 for slopes exceeding 5 percent, 0.4 for 4 percent slopes and 0.3 for slopes less than 3 percent.

To describe the influence of slope steepness, Nearing [5] produced a single continuous function for *S*:

$$s = -1.5 + \frac{17}{\left(1 + e^{2.3 - 6.1 \sin \theta}\right)} \qquad (4)$$

where θ is the slope angle (degrees).
In order to utilize DEM calculating LS factor, a program USLE2D.EXE, which is designed to calculate the LS-factor in the RUSLE from a grid-based DEM and provided the user with a number of options in selecting the hydrological flow routing algorithm and the LS algorithm [16] was used to compute LS factor.

The classified land cover map was converted to the C factor layer in RUSLE through reclassification of each land cover type into its corresponding C factor value, which estimated from RUSLE guide tables [4, 8, and 10]. Table (3) lists the C-factor values for each of the land use categories. These values were used to re-classify the land cover map to obtain the C-factor map for the study area. While the *P* factor map was prepared from Land use/over maps. The *P* factor values were chosen based on technical manual of soil and water conservation in location study. Table 4 lists the *P* values.

Table 3: Cropping and land-cover (C) factor values used in different studies.

Land-use and land-cover type	C factor value
Forest	0.02
Grassland	0.01
Cultivated land (cereals/pulses)	0.17
Bare land	0.60
Shrub	0.014

Table 4: Conservation practices factor (*P*).

Land use type	Slope (%)	P-factor
Agricultural land	0-5	0.11
	5–10	0.12
	10-20	0.14
	20-30	0.22
	30-50	0.31
	50-100	0.43
Other land	all	1.00

III. RESULTS AND DISCUSSION

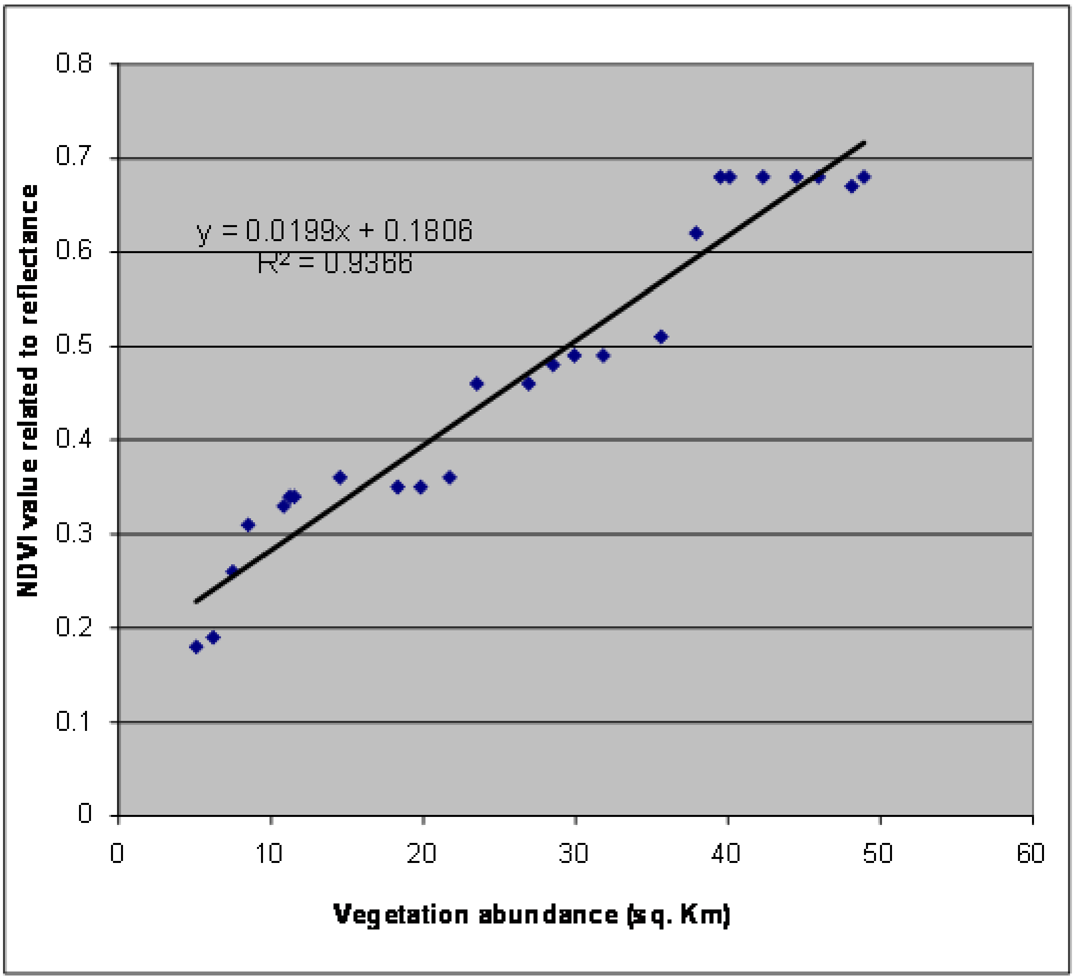
A. Evaluation of vegetation change

By and large, the term ‘land degradation’ comprises vegetation degradation and soil erosion which are considered to be key components of terrestrial ecosystems. The use of supervised classification and vegetation index (NDVI) (This was the most common form of vegetation index (Purevdorj, et al. [25]), and was basically the difference between the red and near infrared band combination divided by their sum combination or NDVI= (NIR-R)/ (NIR+R)) in evaluating vegetation change was helpful for grade indices of degraded land in this research. Table 5 shows that vegetation cover in the entire study area was 193.31 km^2 in the year 1988, and it decreased to 185.33 km^2 in the year 2014; it forms 77.5 and 74.3% of the land area respectively. The statistical analysis showed this index (NDVI) has a significant correlation with vegetation abundance positive change (0.93) (Fig.3). A comparison between values obtained in 1988 and 2014 (Table 5) suggested that large-scale vegetation cover change occurred in this area during the 26 years covered by this study. However, the vegetation area had low increased as a result of depletion of agrochemical pollution and soil erosion. This result revealed potentially high-risk land degradation areas for further investigation. Results also suggested that enhancements to this method could help monitor the condition and extent of soil erosion cover areas on the margins of vegetation areas. In the Table 5, the general estimation for vegetation cover change in the study area was detailed. The entire area was presumed to be subject to vegetation degradation, mainly by anthropogenic activities. Thus, 26.1% of the land area had severe to high vegetation change, while 72.7% had moderate to low vegetation change revealing the gravity of vegetation cover change problem in this study location.

Table 5: Calculated (LULC) classes totals monitored from satellite image for the study area during the period from 1988 to 2014.

(LULC) classes	Area (Km^2)				Amount of change (Km^2)	Percentage Growth
	1988	(%)	2014	(%)		
Water Bodies	16.463	6.6	16.213	6.5	-0.249 [a]	-1.512 [b]
Forested	38.912	15.6	39.411	15.8	0.498	1.281
Forested Urban	43.402	17.4	40.158	16.1	-3.243	-7.472
Grass shrub Crops	62.608	25.1	61.859	24.8	-0.748	-1.195
Grass shrub Urban	48.390	19.4	43.900	17.6	-4.489	-9.277
Paved and Bare Land	29.433	11.8	32.676	13.1	3.243	11.018
Urban Area	10.226	4.1	15.215	6.1	4.989	48.792

Fig. 3: Correlation between vegetation area and NDVI in the study location.



A. Evaluation of Spatial Soil Loss Rate

Distributed maps of the factors influencing the process of soil erosion used in RUSLE model, namely rainfall erosivity, soil erodibility, slope length, steepness, crop and management, and support practice factors were created within the GIS software. The quantitative output of predicted spatial soil loss rates for the southern part of King County in Washington State resulting from current farming practices were computed and grouped into six ordinal classes and displayed on the map in Fig. 4. Morgan [8] argued that the amount of (10 $t.ha^{-1}$ yr^{-1}) was an appropriate boundary measure for soil loss over which agriculturists should be concerned. According to Morgan [8] Table 6 shows the annual soil loss by water erosion in southern part of King County for the year 2014. This was acceptable as the soil loss tolerance value for the middle and lower reaches of location study, and was identified as the separation of the low and moderate categories [11 and 26]. The results indicated that 42.1% of the total study area in southern part of King County in Washington State (Fig. 4 and Table 6) had slight annual soil erosion in the year 2014, while 19.7% had high annual soil erosion for the same years. Statistical analysis of the results in the southern part of King County area showed that there were statistical correlations among the RUSLE's factors and the annual soil loss values of the years 1988 and 2014. The strongest correlation was between the RUSLE_LS factor and the annual soil loss for the two years. They were (r^2=0.79) and (r^2=0. 81) for the years 1988 and 2014, respectively, which illustrates that RUSLE-LS factor is the most effective on the value of soil loss by water erosion in the southern part of King County in Washington State (Fig. 5 and 6). Change in agricultural pattern from traditional agriculture to orchard cultivation along with the conservation activity taken up in the southern part of King County showed a positive impact on soil erosion, leading towards sustainable farming system. However, the rate of soil erosion (12.39 Km^2) after 26 years of implementation of the project is still high and more erosion control practices are required in study location on priority basis to make the farming system sustainable in the a true sense. Given that very severe and extremely severe potential soil loss locations represent areas was soil conservation practices are necessary, these results were viewed favorably. From observation data, the RUSLE model's ability to map soil erosion risk within the study area is viewed as very good, when considering the purpose of this model as a conservation tool.

Fig. 4: Soil erosion risk map of study area in 2014.

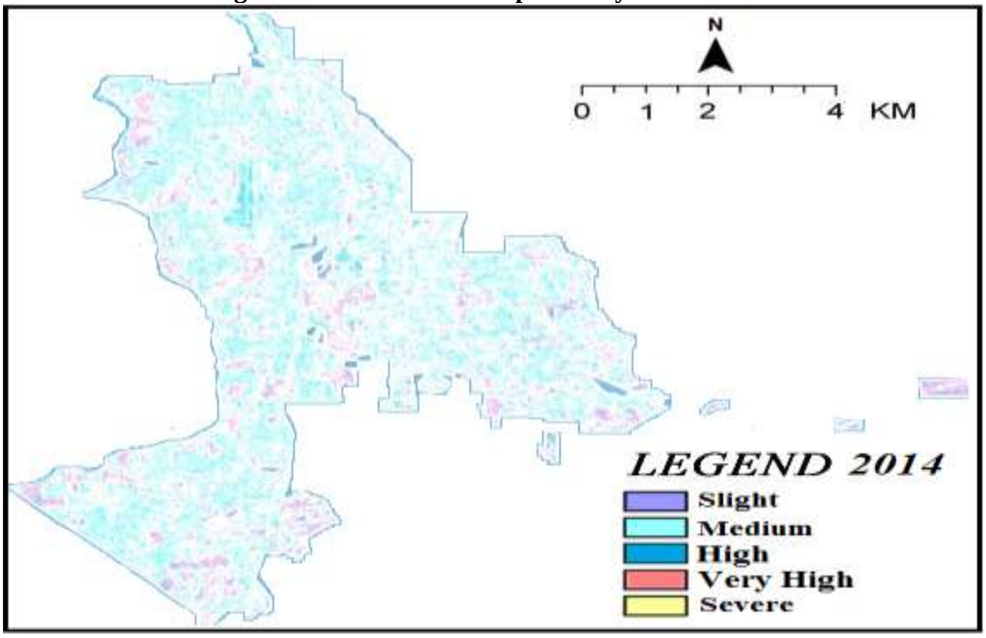


Fig. 6: Relationship between the soil loss and LS factor of the study area in 1988.

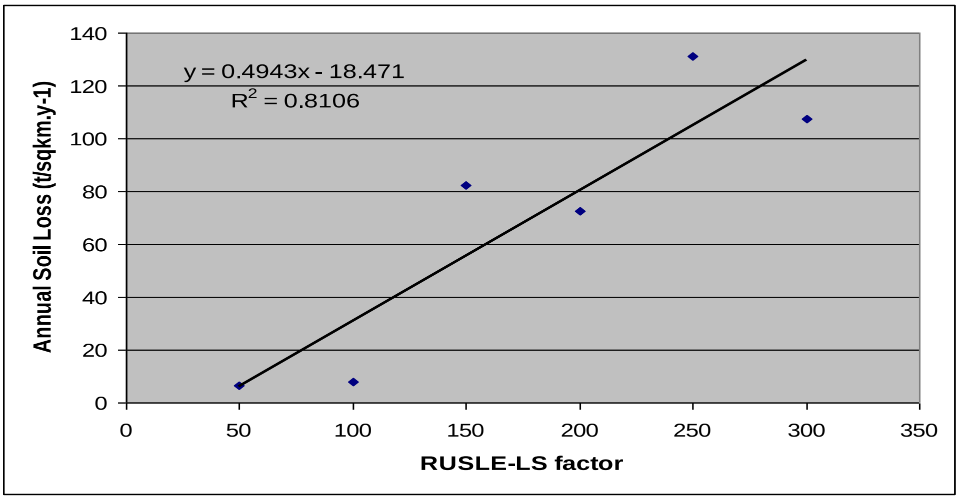
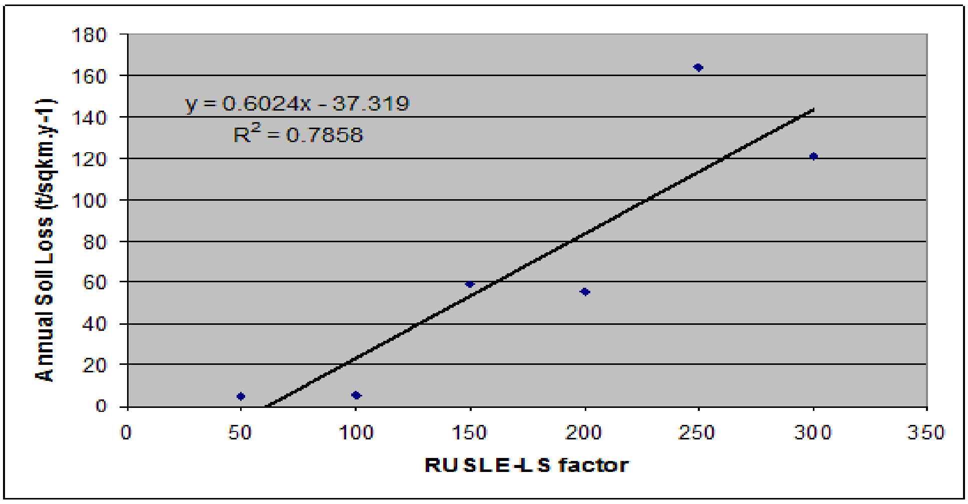


Fig. 7: Relationship between the soil loss and LS factor of the study area in 2014.



B. Land Degradation by Erosion Assessment

According to statistics of land degradation thematic map from the two previous prominent land degradation by erosion processes and vegetation change were driven together for the assessment of the land degradation by erosion areas, on basis of the calculated excessive land use changes. Table 6 shows the general estimation for degradation in the southern part of King County in Washington State. It is supposed that all the area is subject to land degradation by erosion as we mentioned previously, mainly by anthropogenic activities and climatic variation. So we conclude that 42.1% of the land area in the southern part of King County had slight land degradation, 30.6% had moderate land degradation, and 19.7% had high land degradation by erosion. These results show the gravity of degradation as a problem in the southern part of King County. The low sensitivity for land degradation by erosion is due to the good vegetation cover and soil quality. The results of this study indicated that land degradation by water erosion results from natural and anthropogenic factors. Overlay of environment degradation by water erosion processes layers interpreted from multi-temporal remotely sensed materials in a GIS, in conjunction with field investigation. Land degradation by water erosion processes in the study area was assessed through consideration of both natural (vegetative index, soil index, climatic index) and anthropogenic (Land use change) factors in the study. It was found that most of the study locations were highly land degradation. The overall sensitivity of environmental change has worsened during the study period with degraded areas accounting for 21.8% of the total area in 2014. The risk has risen considerably, on an average, by 10% for all study location between 1988 and 2014. In particular, the risk has increased considerably for those areas not previously considered highly vulnerable to degradation. Consequently, the disparity of land degradation hazard among the study locations has shrunk as all of them are at a higher risk in 2014 than ever before. The accentuation of land degradation is attributed to conflicts among human interest, increasing population pressure, limited land resource, and fragile ecosystems. Inappropriate human activities such as excessive exploitation of natural resource and mismanagement of land, to a certain extent, have contributed to the environmental destruction.

Table 6: The categories of land degradation by water erosion and the proportion of each category.

Soil Erosion rate (t ha^{-1} $year^{-1}$)	Area (km^2)	Percent Area	Soil Erosion / Priority Class
0-5	105.012	42.1	Slight soil erosion areas
5-10	76.327	30.6	Moderately soil erosion areas
10-20	49.138	19.7	High soil erosion areas
20-40	15.963	06.4	Very High soil erosion areas
40-80	2.994	01.2	Sever soil erosion areas
>80	-	-	Very Sever soil erosion areas
Total	249.434	100	

IV. CONCLUSIONS

This study has looked into the possibility of applying data collected by the land use variation survey to study the anticipated relationship between land uses/ cover changes and degradation by water erosion and developed a simple methodology to determine soil loss quantitatively and spatially using RUSLE in a GIS environment, and then various soil conservation planning scenarios can be evaluated through database manipulation in the southwest part of the southern part of King County in Washington State. This procedure is a tool that can be used at different levels of agricultural land planning. Land managers in the southern part of King County area with available software and data, can operate the tool locally. The major factors influencing soil erosion in the study area were the land use/cover RUSLE_*C* factor (r^2=0.73), and in the second order was the conservation support-practices factor RUSLE_*P* factor (r^2= 0.62). In general, it is clear from the results of this study that the RUSLE–GIS model provides a robust soil conservation-planning tool readily transferable and accessible to other land managers. Remote sensing, GIS, and GPS can serve as valuable tools in assessing and monitoring the environment degradation and soil erosion qualitatively and quantitatively as well, which will help in developing appropriate and timely conservation strategies. It is clear from the results of this study that RUSLE is a powerful model for the qualitative as well as quantitative assessment of soil erosion intensity for the conservation management and demonstrates the effectiveness of the geo-information technology in generating essential quantitative information on soil erosion risk map. Land degradation by soil water erosion appears to be worsening; recently study area experienced the most drastic undesirable changes in land use. These undesirable land use/cover changes might have been furthered by inadequate policy measures which encouraged land degradation. The outcome of this type of studies represents a valuable resource for decision makers to guard against land acquisition in high erosion risk areas or to issue conditional permission with conservation measures to future development projects in the study areas in the southern part of King County in Washington State.

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