IOSR Journal of Applied Geology and Geophysics (IOSR-JAGG)
e-ISSN: 2321–0990, p-ISSN: 2321–0982.Volume 4, Issue 6 Ver. I (Nov. - Dec. 2016), PP 98-105
www.iosrjournals.org

Prediction of Soil Degradation Risk with aid of "3S" Techniques in the southern part of King County in Washington, USA

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Abstract: *This research integrated selected soil degradation indicators (physical, chemical, and biological degradation) with geo-information techniques (RS, GIS and GPS) to assess the severity of soil degradation risk in south King County, Washington, USA. Landsat TM images from July 1988 and a Landsat ETM+ image of July 2014, were used to produce land use/cover maps of the study area based on the maximum likelihood classification method. These maps were then used to generate the land use, land cover change, vegetation change, and land degradation maps for the study area. Results showed that, assuming a 10% risk, this impact has increased by 20.1, 17.7, and 4.7% for medium, high and very high soil degradation risk on the study areas respectively. The map of degradation risk is a valuable resource for planners to minimize soil degradation problems caused by future and ongoing development projects in the study area.*
Keywords: *Soil degradation, RUSLE, "3S" technology, King County, USA.*

I. Introduction

Soil degradation is one of the most important challenges facing mankind. The problem is as old as settled agriculture and worldwide concern has been increasing recently. Soil degradation is defined as "the decline in soil quality caused through its misuse by humans" [1]. UNEP, [2] refers to soil degradation as the diminution of current and/or potential capability of soils to produce quantities or qualities of goods or services as a result of one or more degradation processes. Danfeng [3] stated that most ancient civilizations flourished on fertile soil and that soil degradation was responsible for their decline.Soil degradation is a naturally occurring process on all land and it is a normal geologic process associated with hydrologic cycle. The agents of soil erosion are water and wind, each contributing a significant amount of soil loss each year [4].This research develops a soil degradation-predicting model based on the Universal Soil Loss Equation (USLE) and its subsequent Revised Universal Soil Loss Equation (RUSLE) in a geographic information system (GIS) environment. The Universal Soil Loss Equation (USLE) developed by Wichmeier [5] is the most frequently used empirical soil erosion model worldwide. More recently, Renard [6] has modified the USLE into Revised Universal Soil Loss Equation (RUSLE) by introducing improved means of computing the soil erosion factors. The geographic information system (GIS), according to Nuket [7] and (Desmet and Govers) [8] are an information technology which stores, analyses, and displays both spatial and non-spatial data. Among a lot of GIS systems, ArcGIS is a rather comprehensive package which allows using its storage, editing, data management, and plotting functions. The forms of the (soil degradation question) are:

$$D = F\ (S, C, T, H) \qquad (1)$$

Where: D = soil degradation, F = function, S = soil erodibility factor (Ton/hectare), C = Climatic factor (%), T = topographic factors and H = Human factor which include (Crop management and land use). The T and H values are dimensionless. These can then be converted into raster layers for input into a GIS to be analyzed to produce a soil degradation risk map [9-11]. In this study, three processes of soil degradation are usually recognized in the south part of King County. These are physical degradation, chemical degradation, and biological degradation. Physical degradation consists of a negative change in properties such as porosity, permeability, bulk density and structural stability. A decrease in infiltration capacity and plant-water deficiency are common effects. Chemical degradation comprises a variety of processes related to leaching of bases and essential nutrients and the build-up of toxic elements and excess of salts consists of processes of the accumulation of salt in the soil solution (salinization) and of the increase of exchangeable sodium on the cation exchange of soil colloids (sodication or alkalinization). Biological degradation is the increase in rate of mineralization of humus (decline in soil organic matter %/year) without replenishment of organic matter. These three processes interact in such manner that soil degradation will affect plant productivity in a number of ways simultaneously. According to Oldeman et al. (in: Hui [12]) human induced soil degradation processes can be grouped in two categories. The first concerns soil degradation by displacement of soil material, due to water. Water erosion comprises of loss of topsoil and terrain deformation. Common phenomena are the formation of rills, gullies and badlands. The second category considers physical and chemical soil deterioration. Physical deterioration includes compaction and crust forming, water-logging and subsidence of organic soils. Chemical deterioration comprises of loss of nutrients and/or organic matter, salinization, acidification and pollution. In this study, on site soil degradation affects soil productivity. Nutrients are lost in sediment and run-off. In general, the nutrients associated with organic matter (N and P) and the cation exchanges of soil colloids (K and Ca) are most vulnerable. Nutrients in sediment are approximately ten times the quantity of those dissolved in run-off. As soil degrades, the infiltration capacity declines. Surface sealing and crusting aggravate this process. The run-off water is lost to the soil and to plant growth. Because water erosion is selective of the finer, more fertile fraction of the soil, the eroded sediment usually has higher contents of nutrients and organic matter than the soil from which it is derived from. Eroded sediments may cause damage to off-site canals, water storage, irrigation schemes and hydro-electric power plants. Consequences such as sediment accumulation, eutrophication, water shortages in irrigation schemes and damage to machinery's like turbines are prone to occur. Soil erodibility is mainly determined by soil type, topographic factors, physical measures, rainfall and cover of vegetation. Topographic factors are slope, steepness, length and shape. Physical measures consist of procedures such as contour building or terracing. The amount and intensity of rain and seasonality of storms determine the erosivity of rainfall. By intercepting the kinetic energy of raindrops and by absorbing water into leaves and organic matter the vegetation cover is the only protection of the soil from the erosivity of rainfall. The term soil degradation is used to describe the total decrease of the productive potential of the land, including its major uses (rainfed arable, irrigated, rangeland, and forestry), its farming systems and its value as an economic resource. Land degradation is a constraint in the maintenance of sustainable agriculture. The origin of degradation can be natural, but also human induced. Changes in land and water management and resource exploitation might cross existing ecological thresholds, after which degradation will take place [13].

The purpose of the present study is to assess the degradation severity and to calculate, the soil degradation risk in the ecologically vulnerable area and to construct a GIS containing environmental parameters influencing the regional and global changes, with focus on soil degradation problems to produce a map of different classes of soil sensitivity to soil degradation. It has been achieved using remote sensing in developing a vegetation cover map and GIS in integration of different informative layers in the south King County.

II. 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). The mean annual precipitation is 800—1,200 mm and the annual average temperature is 50-80 F. 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, [14].

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 [15]. 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 [16]. 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.

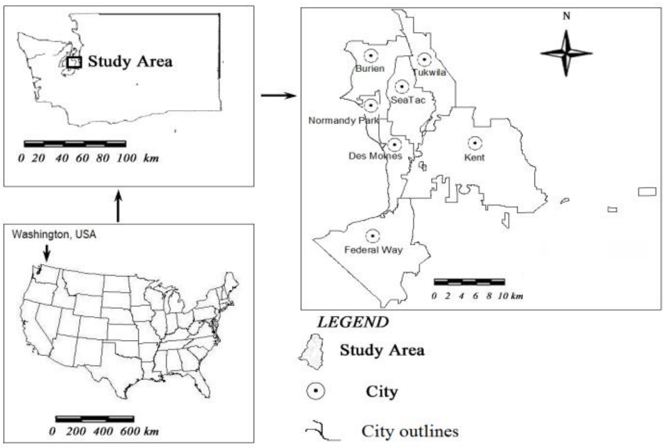

Fig. 1: General location of study area in the southern part of King County.

III. Methods

The soil degradation assessment method [17 and 18] is found to be a successful means identify, map and monitor the potential and present status of soil degradation. This methodology is base to be applicable at universal regional, detailed and very detailed levels. Climatic data, soil condition, topography, and human activity are the main inputs for assessment of soil degradation processes (Fig.2).

Field investigation: An extensive field survey was performed throughout the seven polygons using Global Positioning System (GPS) Garmin receiver equipment. The GPS has developed into an efficient GIS data collection technology, that allows for users to compile their own data sets directly from the field as part of 'ground truthing'. The spatial data was digitized from the topographic maps of the study areas by using ArcGIS, and then the vegetation density attribute data were edited and added to the study databases. The polygons and their attributes were connected with uniform code. Values for average meteorological data were obtained for the investigated location according to information recorded during the period 1988- 2014 from the meteorological station.

Assigning environmental factors for each soil polygon: Numerical values were assigned to each soil polygon in the polygon attribute table of the soil coverage layer. The values were chosen according to the following parameters:

1. Soil Erodibility factor (S): Soil erodibility factor values were determined for each soil polygon in the GIS.
A-Soil physical degradation: For the assessment of physical degradation, the silt/clay ratio is considered as an important factor contributing to soil sealing and crusting. Rating values are based on that ratio.
B- Soil chemical degradation: To define the exact rating value of soil chemical degradation according to the FAO/UNEP and UNESCO methodology, soil texture and depth to ground water have been utilized.
C- Soil biological degradation: For the assessment of biological degradation (decline in soil organic matter), soil factor can be estimated by the follow formula [17 and 18].

$$S.F = 1200 / (A+200)\,(C+200) \qquad (2)$$

Where: S.F= Soil Factor; A = Clay (%); and C = $CaCo_3$ (%)

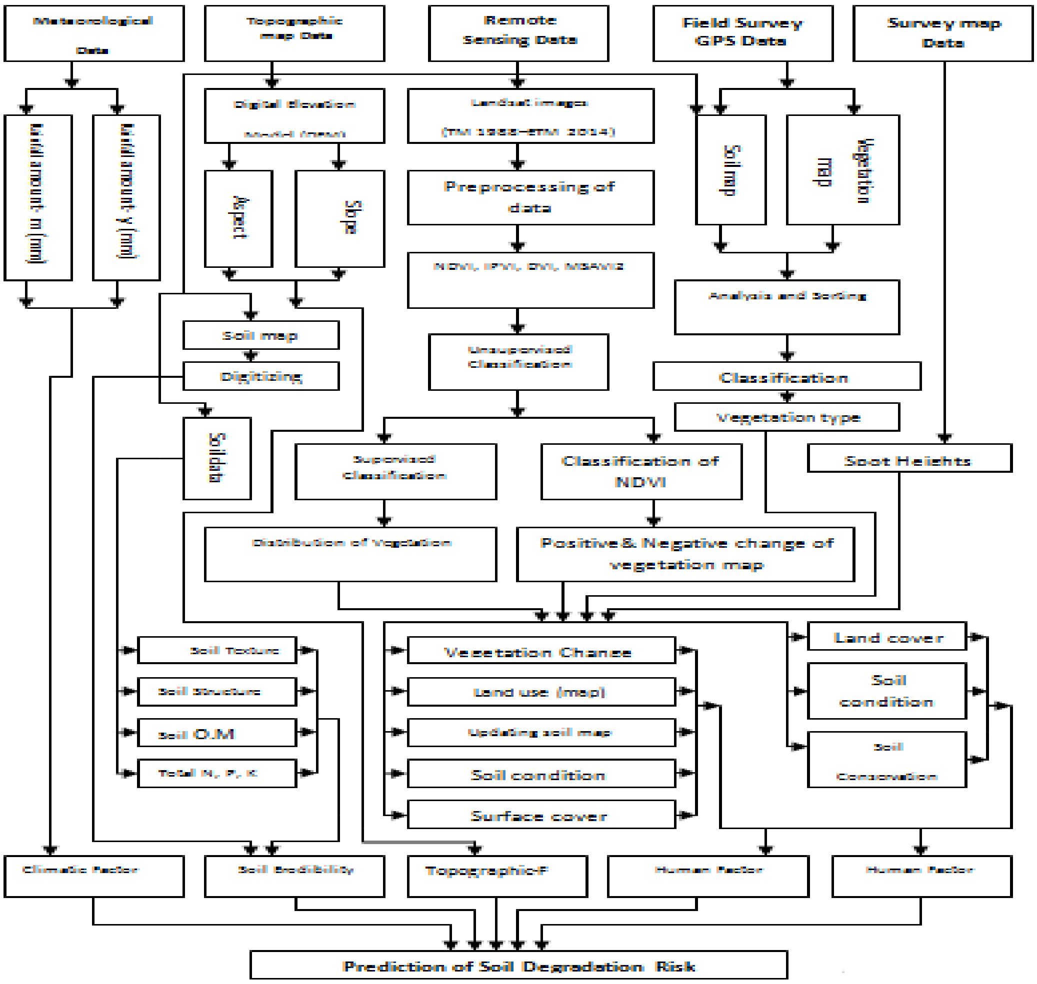

Fig. 2: General flow chats of soil degradation question model using 3S techniques for the determination of the soil degradation assessment.

2. Climatic factor (C): Climatic factor, contributing to each soil degradation process, was calculated for each soil polygon, in the GIS, according to its relative location.
A-Soil physical degradation: For the assessment of physical degradation, the aggressively index for water erosion is used [17 and 18].
B- Soil chemical degradation: For the assessment of soil chemical degradation, the intensity of proportional to the precipitation over evaporation (P/PET). Thus, the climatic factor was taken as PET in meters [17 and 18].
C- Soil biological degradation: For the assessment of biological degradation (decline in soil organic matter), climatic factor can be estimated by the follow formula [17 and 18].

$$C.F=1/2\ e^{0.1065T}\ (P/PET) \quad (3)$$

Where: C.F= Climatic Factor; P=annual rainfall; ETP=evapotranspiration (mm), and (T) =annual temperature.
3. Human factor (H): 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 [5], [6], and [19]. Table (1) lists the C-factor values for 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 technologic manual of soil and water conservation in the location study. Table 2 listed the *P* values.

Table 1: Determining of Human factor which include (Crop management and land use) for different class.

Crop management		**land use**		
Land use class	**C-factor**	**Land use type**	**Slop (%)**	**P-factor**
Forest (cover >40%)*	0.002	Agricultural land	0-5	0.11
Forest (cover>10-40%)	0.006		5–10	0.12
Shrub*	0.014		10-20	0.14
Rice**	0.10		20-30	0.22
Orchard**	0.11		30-50	0.31
Upland**	0.377		50-100	0.43
Grazing land**	0.11	Other land	all	1.00

*Adapted from Wischmeier and Smith [5], Renard [6]; ** Calculation from Morgan [19].

4. Topographic factors (T): The slope factors (LS) refer to topographic and/or relief factor. In the computation of the LS factors, the topographic factors, L and S factor are usually considered together. The slope length factor L, computes the effect of slope length on erosion and the slope steepness factor S and computes the effect of slope steepness on erosion.Substituting the values for cell outlet and cell inlet into the Foster and Wischmeier [20] equation solves the slope length L component:

$$L_{i,j} = \frac{A_{i,j-out}^{m+1} + A_{i,j-in}^{m+1}}{(A_{i,j-out} - A_{i.j-in})(22.13)^m} \quad (4)$$

where $L_{(i,\ j)}$ is the slope length factor for the cell with coordinates (i, j) , $A_{(i,j\text{-}out)}$ is the contributing area at the outlet of the grid cell with coordinates (i, j), $A_{(i,j\text{-}in)}$ is the contributing area at the inlet of the grid cell with coordinates (i, j) , and m is the slope length exponent of the RUSLE S-factor [21].

To describe the influence of slope steepness, Liu [22] researched steep slopes data from China. Based on synthesizing the results presented by Liu [22] and Nearing [23] produced a single continuous function for S:

$$s = -1.5 + \frac{17}{\left(1+e^{2.3-6.1\sin\theta}\right)} \quad (5)$$

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 (Desmet and Govers, [21]) was used to compute LS factor.

IV. Results and Discusion

All the factor maps of S, C, T, and H were run within the ArcGIS and the quantitative output of predicted soil physical, chemical, and biological degradation rates for the south King County area resulting from current farming practices were computed and grouped into six ordinal classes and displayed three ordinal classes on the map. The values of the variable are chosen in such a way that the solving of the equation gives a numerical indication of the degradation rate. This indication is expressed as increase of soil bulk density in g/cm^3/year for physical degradation, increase of E.C in ds/m for chemical degradation (salinization), and increase of decline SOM in %/year for biological degradation. The formula describes the processes only approximately, and the values assigned to each factor are approximate in the present state of knowledge. These values are merely giving an approximate indication of the magnitude of degradation [17 and 18].

1. Soil physical degradation:

Figure (3) presents the values of risk and present status of soil physical degradation and the input parameters for their computation. It is obvious that the heavy textured soils in the location study (loam to silty loam), could be subjected to many interrelated processes (fig. 3), including sealing, crusting, impermeability and compaction, due to its high contents of silt and clay, also cultivation and irrigation practices provoke these interrelated processes and cause higher values of present status. The whole study area is characterized by a high soil physical degradation of present status while the risk is also high. However, in order to reveal the effect of different conditions, re-categorization was elaborated. All types are subjected to a higher risk of soil physical degradation compared with the present status. The soil is silty loam flats characterized by their silty texture and poor drainage conditions. Thus, impermeability surface sealing and runoff may occur. These conditions are favorable for both gully erosion and mass movement. Accordingly, values of soil erodibility and soil texture factors are high. The miscellaneous rock land has the characteristics which favor gully formation due to their surface sealing impermeability. Also, rugged topographic steep slopes and dissected landscape concentrate runoff.

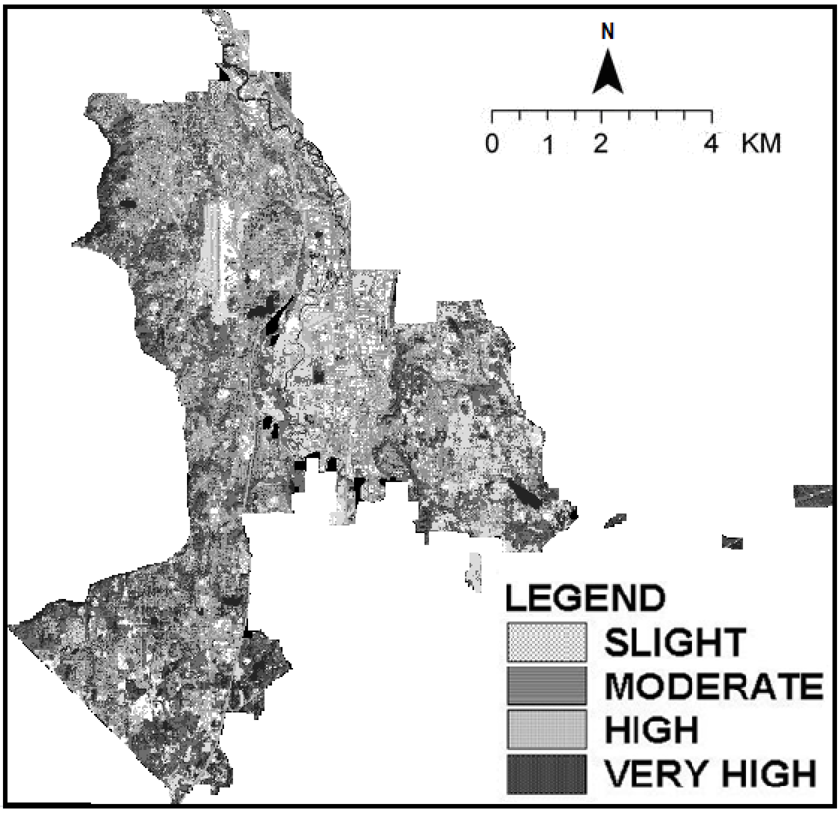

Fig. 3: Physical degradation in the location study in 2014.

2. Soil chemical degradation:

Figure (4) shows the value of risk and present status of soil chemical degradation and the input parameters for their calculation. The present status and risk in the cultivated area of location study is slight (Fig. 4). The soil in the transitional zone (soil type Loam and Silty Loam) are subjected to moderate to high value, this is attributed to the existence of clay subsoil layer. According to information analysis, precipitation in location area is being reduced in recent decade. Temperatures in other parts of the mentioned affected regions are being increased, and consequently, the evaporation potential is being accelerated and formation of soil salinization is being deteriorated by the above mentioned tends. Agriculture expansion would be highly risks in these areas and their surroundings. The coarse soil texture in these areas reduces the risk of salinization.

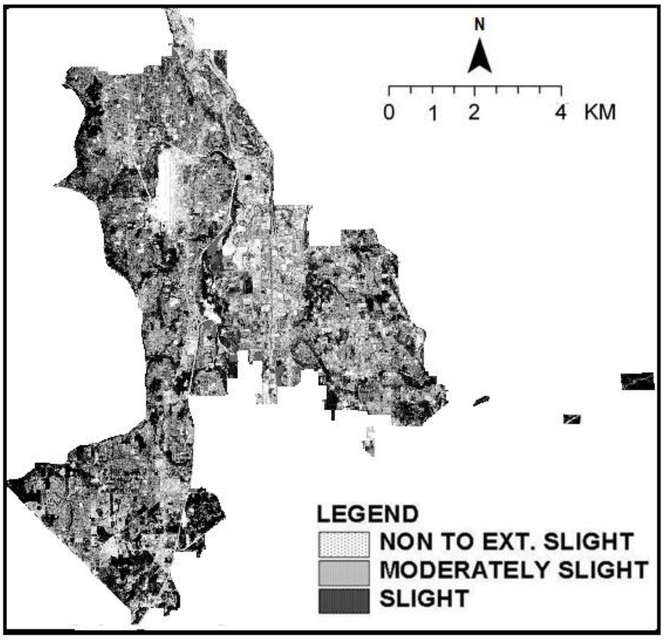

Fig. 4: Chemical degradation in the location study in 2014.

3. Soil biological degradation:

Figure (5) shows the value of risk and present status of biological degradation (decline in soil organic matter %/year) and the input parameters for their calculation. The environment of the study area (in summer season) is characterized by high temperature, high evapotranspiration and low precipitation. The present status and risk in the cultivated area of location study is distinctive, this decline results from increased decomposition of existing soil organic matter because of tillage and changes in moisture, aeration, temperature conditions and reduced replenishment of soil organic matter by crop residues. However, soil quality is largely governed by organic matter content, which is dynamic and responds effectively to changes in soil management. A decline in organic matter content will affect soil structure and stability, water retention properties, buffering capacity, biological activity and the retention and exchange of nutrients. It may also in the medium and long term, make the soil more vulnerable to erosion, compaction, acidification, salinization, and nutrient deficiency.

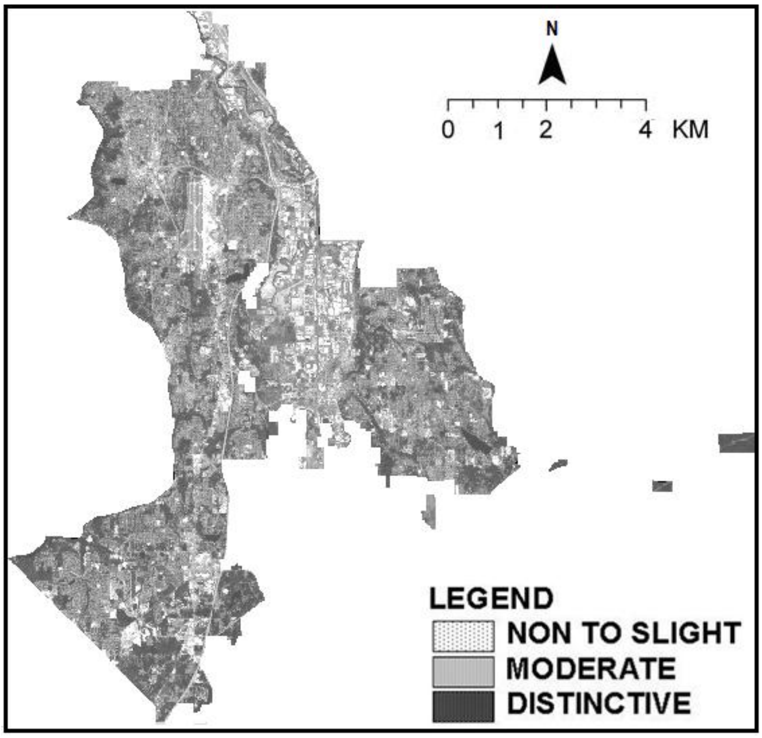

Fig. 5: Biological degradation in the location study in 2014.

4. Soil Degradation Assessment:

In Table (2), we have the general estimation for soil degradation in the study area, located in the south King County, Washington in USA. It is supposed that all the area is subject of soil degradation as we mentioned previously, mainly by physical degradation processes followed by chemical degradation processes and biological degradation processes. The average annual soil degradation rate in the study increased from 45.89 Km^2 in 1988 to 60.85 Km^2 in 2014. The results indicated that 35.9% and 30.2% of the total study area in the south King County (Table 3) had very slight annual soil degradation in the years 1988 and 2014, respectively, while 16.2% and 19.7% had high annual soil degradation for the same years. Without doubt these results show the gravity of soil degradation problem in the study area. This reduction in soil degradation rate was due to the conservation measures and plantation program taken up in the area. Change in agricultural pattern from traditional agriculture to orchard cultivation along with the conservation activity taken up in the location study showed a positive impact on soil erosion, leading towards sustainable farming system. However, the rate of soil degradation (60.85 Km^2) after 26 years of implementation of the project is still high and more erosion control practices are required in study area on priority basis to make the farming system sustainable in a true sense. Given that moderate and high potential soil degradation 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 degradation risk within the study area is viewed as very good, when considering the purpose of this model as a conservation tool. 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.

Table2: Categories of annual soil degradation in location study and their respective areas for the years 1988 and 2014.

	Legend	**1988**		**2014**	
		Area (km^2)	**%**	*Area (km^2)*	**%**
1	Very Slight	89.54	35.9	75.33	30.2
2	Slight	67.85	27.2	63.11	25.3
3	Medium	46.15	18.5	50.14	20.1
4	High	40.41	16.2	49.13	19.7
5	Very high	5.48	2.2	11.72	4.7
6	Extremely high	-	-	-	-

V. Conclusion

It is clear from the results of this study that the study area has been suffering seriously from soil degradation by water erosion resulting from climate variations but mainly from human activities and modified RUSEL is a powerful model for the qualitative as well as quantitative assessment of soil degradation intensity for the conservation management. Multi-temporal and multi-spectral remote sensing data have provided valuable and very important factor like C for this study. Since the crop cover is a powerful weapon to reduce the direct impact of rainfall on soil particles, it can be recommended that all barren lands in local areas be converted to agricultural land or forest plantations through proper land reclamation measures. GIS has given a very useful environment to undertake the task of data compilation and analysis within a short period at very high resolution. GPS data can be used for updating the age-old survey of local area topographic map, which is the prime source of data for the Digital Elevation Model and Geo-coding of images.

Acknowledgements

This research was supported by the Highline College. The authors are grateful to the anonymous reviewers for their critical review and comments on drafts of this manuscript.

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