

Identifying the Impacts of Land Use-Land Cover Changes and Soil Erosion Risk on Water Quality and Watershed Health - A Case Study of River Enderit in Nakuru County, Kenya

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Abstract: *The effects on water quality and the overall watershed health as a result of land use land cover changes that are normally associated with human activities and natural factors are scarcely documented. Landsat Satellite images collected between the years 1986 and 2013 covering various land cover and land use conditions were classified and evaluated. In addition, soil erosion activities within the watershed were analyzed through the Revised Universal Soil Loss Equation, RUSLE, in a GIS environment by comparing the erosion risk in 1989 and 2011 thus shedding more light on soil erosion trend and its effects on water quality and the overall watershed health. The results indicate that there has been loss of forest cover by 32% mainly due to conversion of forestland to cropland. RUSLE analysis indicates that as forest cover is cleared within the watershed so does the erosion risk increase. The water quality results indicated the deterioration of water quality from upstream to downstream. The combined effect of the deteriorating water quality, loss of forest cover and the increased erosion risk shows that River Enderit watershed health is at risk.*

Keywords: Geographical Information System (GIS); Remote Sensing, Revised Universal Soil Loss Equation (RUSLE), Water quality

1. Introduction

A watershed is a geographic area in which water, sediments and dissolved materials drain into a common outlet—a point into a larger stream, a lake, an underlying aquifer, an estuary or an ocean [1]. More so, watershed health is a state in which resource management activities sustain human needs and uses of the watershed while ensuring that ecological function is maintained. For this to exist there needs to be a balance between human uses on one hand and environmental issues on the other. [2]. In order to comprehensively understand the state of a watershed's health, watershed health indicators with desirable qualities such as measurability, relevance to stakeholders, cost effectiveness, quantifiable and responsive to change over time are used [1]. Different researchers use different indicators to measure watershed health, and there lacks a universal agreement on the sets of indicators to use [3]. It is obvious that no professional or volunteer program can monitor all of the possible indicators; instead, a researcher should select the indicators that yield the most valuable information with the least expenditure of time and money [1]. This research focusses mainly on three indicators namely soil erosion, water quality and deforestation which fall under the broad category of biophysical indicators of natural resource degradation in watersheds [3].

Land use and land cover changes, associated with human activities and natural factors comprise many ecosystem services in a watershed. For example, forestland converted to agricultural or urban land may have increased erosion, runoff, and flooding. Changes in land use and land cover interact with anthropogenic and natural drivers to affect the water quality of watersheds [4]. Accurate, reliable and comprehensive spatio-temporal information on watersheds and land use practices are key prerequisites for sustainable

land and watershed management. Remote sensing offers cost-effective solutions to these needs for both macro and micro level analysis leading to a comprehensive and secured urban environmental management. GIS is best utilized for integration of various data sets to obtain homogeneous composite watersheds and sub watersheds which helps in identifying the problem areas and suggests conservation measures [5]. The quality of receiving waters is affected by human activities by point sources, such as wastewater treatment facilities, and non-point sources, such as runoff from urban areas and farmland, understanding non-point source pollution requires an understanding of how particular land covers influence water quality within a watershed [4]. Land degradation and subsequent soil erosion and sedimentation play a significant role in impairing water resources within sub watersheds, watersheds and basins. Using conventional methods to assess soil erosion risk is expensive and time consuming. Geographic Information Systems (GIS), coupled with the use of an empirical model to assess risk, can identify and assess soil erosion potential and estimate the value of soil loss [6]. Several soil erosion and non-point source pollution models have been developed, modified, and combined with GIS software to take advantage of these new capabilities and provide regional soil erosion and non-point water quality assessments during the past decade. Among these models is the Revised Universal Soil Loss Equation, RUSLE [6]. River Enderit watershed is therefore no exception when it comes to watershed health analysis. This study shows how the three components mentioned above namely GIS and Remote sensing, the Revised Universal Soil Loss Equation and water quality results of streams and rivers within the watershed have been integrated to portray the overall watershed health of River Enderit.

2. Materials and Methods

2.1 Study Area

River Enderit watershed is located in Nakuru County in Kenya. Its geographical extent is between longitudes 35° 59' 25"E to 36° 11' 40"E and latitudes 0° 17' 38"S to 0° 44' 4"S, with a size of approximately 482square Kilometers. River

Enderit originates from the Eastern Mau forest which is part of the larger Mau forest complex, the largest water tower in Kenya and drains in Lake Nakuru, one of the lakes in the Great Rift Valley. It is worth noting that Lake Nakuru is surrounded by Lake Nakuru National Park which has a very high wildlife concentration and is internationally renowned for the large concentration of lesser flamingos that use it for feeding, displaying and occasionally for breeding [7].

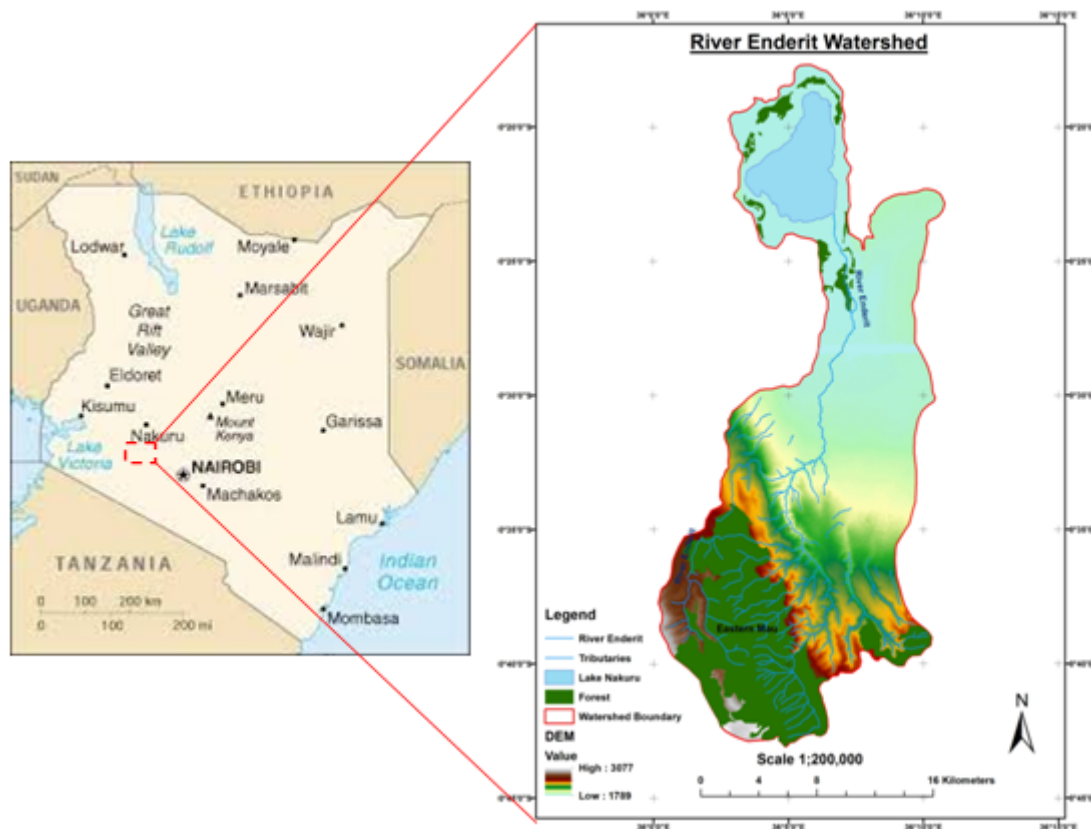


Figure 1: Study Area

2.2. Satellite Images

With the expansion of geo-spatial image and data availability, there is an increased interest in the civil applications of remote sensing products for land use planning, watershed analysis/delineation, assessing vegetation conditions, managing natural resources, and decision support tools for disaster response [5]. Three satellite images from three different epochs, 1986, 2000 and 2013 were used in this study. Their details are as outlined in table 1 below

Three bands were combined namely; band 4, band 3 and band 2 for Landsat 5 and 7 and band 5, band 4 and band 2 for Landsat 8 to make layerstacks. This was followed by clipping the layerstacks using the delineated watershed boundary shapefile to form subsets that were then used for classification. All the datasets were harmonized to UTM Arc 1960 Geographical coordinate system. The subsets were finally classified using supervised classification method guided by training data obtained during ground visits. The three images were classified into six classes namely; forest, cropland, bushland, grassland, water and settlement

Table 1: Specifications of satellite images used for classification

P169R60 Landsat Image Specifications				
Sensor	Resolution (m)	Spheroid and Datum	UTM Zone	Acquisition Month
Landsat 5 TM	30	WGS 84	37 North	January 1986
Landsat 7 ETM+	28.5	WGS 84	37 North	January 2000
Landsat 8 ETM+	28.5	WGS 84	37 North	May 2013

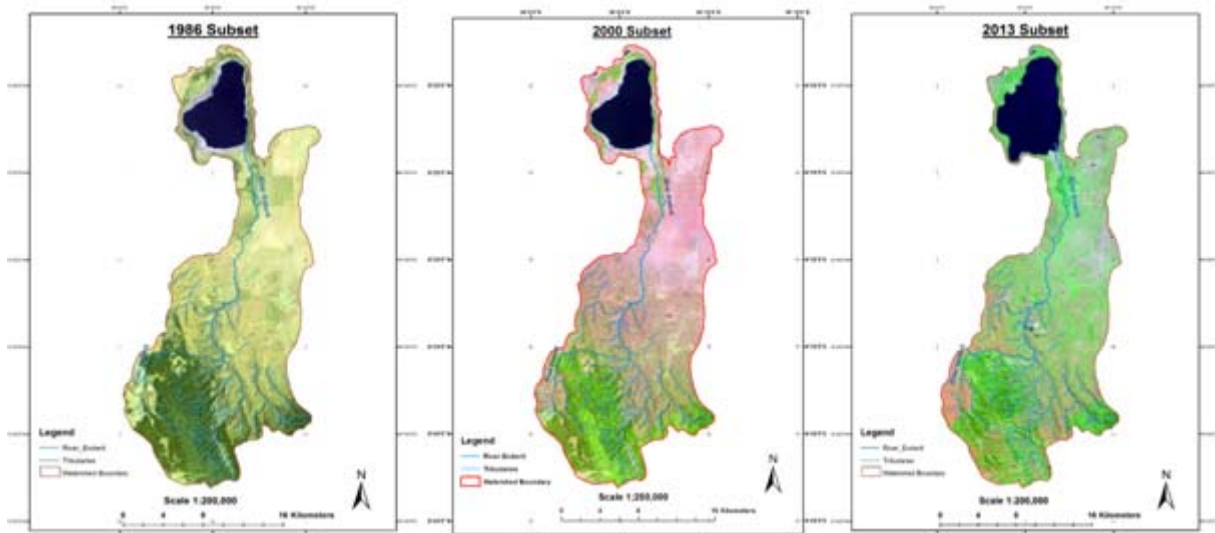


Figure 2: Satellite subsets before classification (from left, 1986, 2000 and 2013 subset)

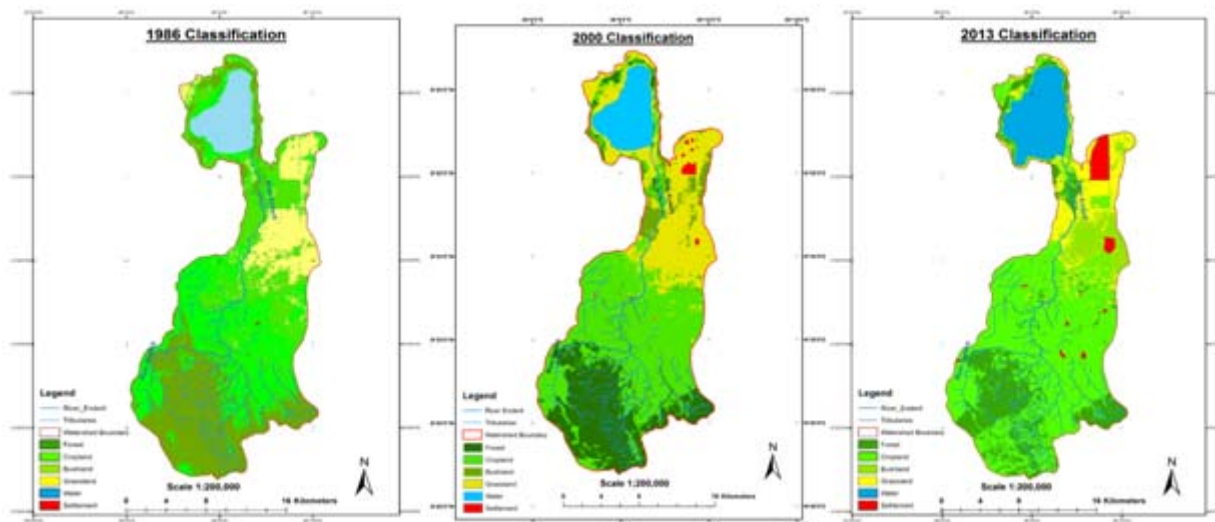


Figure 3: Supervised classification results (from left, 1986, 2000 and 2013 classification)

2.3. Water Quality Data

Rivers are the most important sources of fresh water for man. The social, economic and political developments have largely been related to the availability and distribution of fresh waters contained in riverine systems. Water quality problems have intensified over time in response to increased growth and concentration of populations and industrial centres. The major sources of terrestrial water pollution can be classified as municipal, industrial, and agricultural. Municipal water pollutants consist of wastewater from homes and commercial establishments. Agricultural land including commercial livestock and poultry farming is the source of many organic and inorganic pollutants in surface and ground waters [8]. These contaminants include both sediment from eroded croplands and compounds of phosphorus and nitrogen that partly originate from animal wastes and commercial fertilizers [8]

For River Enderit water quality to be analyzed, samples were collected from various River locations throughout the watershed. The samples were collected at a depth of about 20cm into 500mm plastic bottles on 4th August 2013. The geographical location of the sampling points was determined

using geographical positioning System (GPS). The water samples were then tested and analyzed. The sampling locations are as shown in figure 4 below.

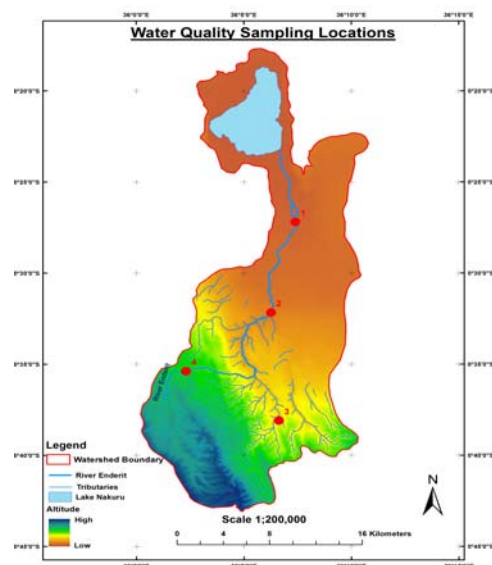


Figure 4: Water quality sampling points

2.4. Soil Erosion Risk Analysis

2.4.1 Empirical Model

The Universal Soil Loss Equation (USLE), developed by Wischmeier and Smith in 1978, is the most frequently used empirical soil erosion model worldwide and was later modified into a revised Universal Soil Loss Equation model by including improved means of computing soil erosion factors [6]. These improved means for computing soil erosion factors generally fit into two categories: incorporation of new/better data and consideration of selected erosion processes. The inclusion of these factors into RUSLE has “the potential for broader prediction improvements” [6].

The RUSLE model can predict erosion potential on a cell-by-cell basis, which is effective when attempting to identify the spatial pattern of soil loss present within a large region. GIS can then be used to isolate and query these locations to identify the role of individual variables in contributing to the observed erosion potential value [6].

RUSLE computes average annual erosion from cover slopes as

$$A = R * K * L * S * C * P \quad (1)$$

Where:

A = computed average annual soil loss in tons/acre/year

R = rainfall-runoff erosivity factor

K = soil erodibility factor

L = slope length factor

S = slope steepness factor

C = cover management factor

P = conservation practice factor [9].

In examining the RUSLE variables the equation can be broken down into two parts:

- 1: Environmental variables and
- 2: Management variables.

The environmental variables include the R, L, S and K factors. These variables remain relatively constant over time. The management variables include the C and P factors and may change over the course of a year or less [6].

2.4.1.1 L and S Factors

The LS empirical equation used for this research is:

$$LS = (\text{Flow Accumulation grid} * \text{cell Size} / 22.13)^{0.4} * (\text{Sin}(\text{Slope grid} * 0.01745) / 0.0896)^{1.4} * 1.4 \quad (2)$$

The resulting LS Factor raster cell grid size was set at 30m

2.4.1.2 C Factor

The C Factor is calculated using the formula below:

$$C = \exp[-\alpha * NDVI / (\beta - NDVI)] \quad (3)$$

Where α , β : Parameters that determine the shape of the NDVI-C curve An α -value of 2 and a β -value of 1 seem to give reasonable results [10]

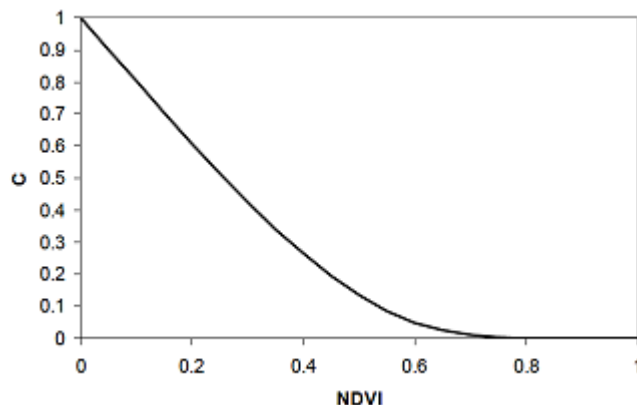


Figure 5: Relationship between NDVI and RUSLE-C using exponential scaling formula [10]

2.4.1.3 R factor

Rainfall erosivity is a measure of the intensity of rainfall events and so is determined by climatic data. The rainfall erosivity factor (R) is calculated as:

$$R = 38.5 + 0.35 (P) \quad [11] \quad (4)$$

2.4.1.4 K Factor

Erodibility is a measure of the susceptibility of the soil to erosion. It is based on the nature (structure, texture, etc) of the topsoil. (Hartcher and post, 2005). The soil Erodibility factor (K) can be calculated as:

$$K = 0.0034 + 0.0405 \exp \left[\left(-0.5 \left[\frac{\log Dg + 1.638}{0.7101} \right]^2 \right) \right] \quad (5)$$

Where:

K: Soil erodibility factor (t ha h ha⁻¹ MJ⁻¹ mm⁻¹)

Dg: Geometric mean particle diameter (mm) [10]

The formulas above were applied in a GIS environment using the spatial analyst map algebra and math tools in Arc GIS 10.1

2.4.2 River Enderit Watershed RUSLE Components

2.4.2.1 L and S Factors

The effect of topography on erosion in RUSLE is accounted for by the LS factor. Erosion increases as slope length increases, and is considered by the slope length factor (L) [9]. Contour Data at a contour interval of 20m obtained from the Regional Centre of Mapping Resources for Development (RMCRD) was used to generate the watershed Digital Elevation Model (DEM) with a 30 meter grid size and thus providing the elevation data needed to generate the LS factors. The slope grid and the flow accumulation grids were then used to generate the 30m grid LS Factor as shown in figure 6 below.

2.4.2.2 C Factor

The hill slope factor accounts for the fact that soil erosion increases with increasing slope [11]. The C-factor represents a comparison of soil loss with that expected from freshly tilled soil and has a range between 0 and 1 where higher values mean more erosion [11]. The 1989 and 2011 Landsat Image subsets of the watershed were used to generate the Normalized Difference Vegetation Index (NDVI) that was consequently used to generate the C factor (cover management) for the two epochs. The two images were

chosen because they were captured around the dry season (January for 1989 and March for 2011) and thus the NDVI and C Factor values generated would represent the region without effects of weather variations, which would have happened if NDVI values were generated from the wet 2013 image. The lack of a 2013 landsat image between the months of January and March and lack of a 2012 image within this period lacking distortions due to stripping also led to the use of the 2011 image. The resulting C factor raster grid cell value was set to 30m. The C factors are shown in figure 7 below

2.4.2.3 P Factor

This accounts for the effects of contours, strip cropping or terracing. If data on these are not available, this factor was not used (i.e. set to 1), although it may be accounted for, to some degree, in the choice of C factors [11]. Since the P factor data for River Enderit watershed was not available, this factor was set to 1 and therefore not used.

2.4.2.4 R Factor

Rainfall/precipitation data was obtained from the Kenya National Water Master Plan (JICA) which was used to generate the R factor (rainfall-runoff erosivity) for the Enderit River watershed. The resulting R factor raster grid cell value was set to 30m. The R factor as shown in figure 8 below

2.4.2.5 K Factor

The soil map shapefile with various soil properties provided by the International Livestock Research Institute, ILRI provided the soil attributes data needed to generate the K factor (soil erodibility). The resulting K factor raster grid cell value was set to 30m. The K factor is shown in figure 8 below

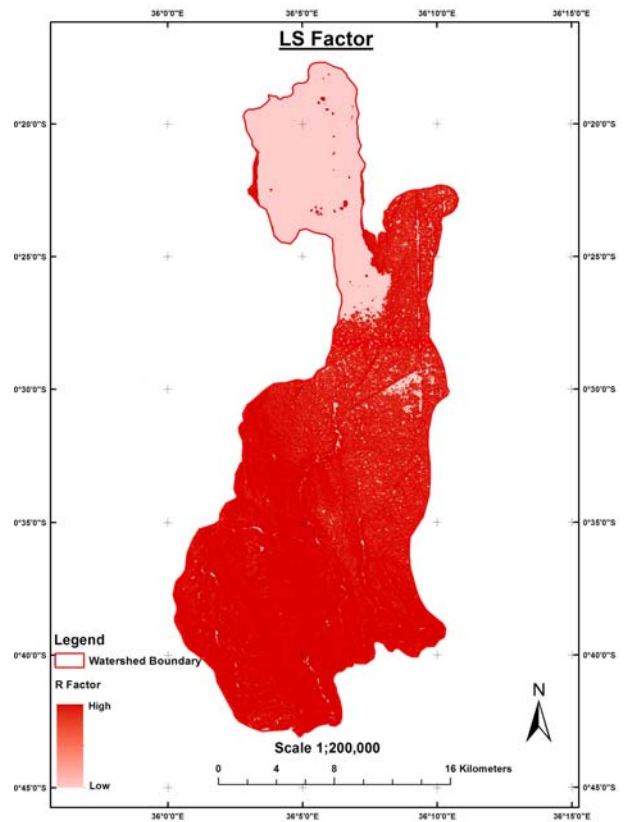
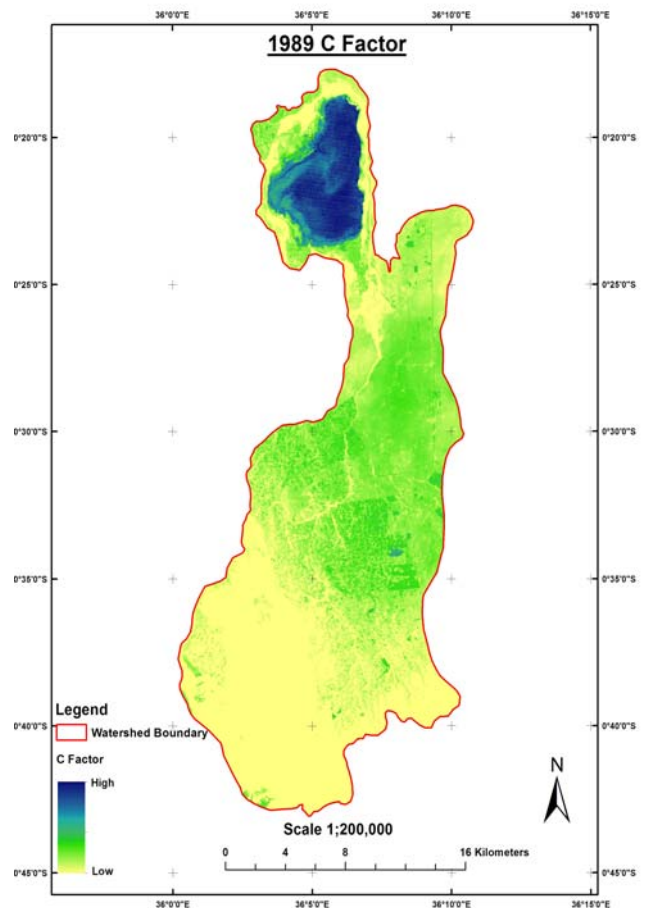
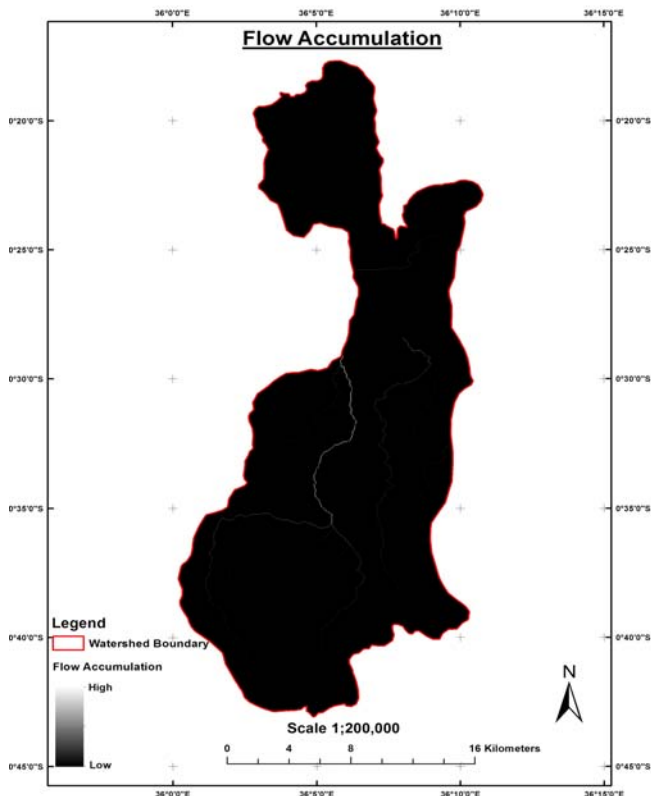


Figure 6: Flow Accumulation (Left) and LS Factor (Right)



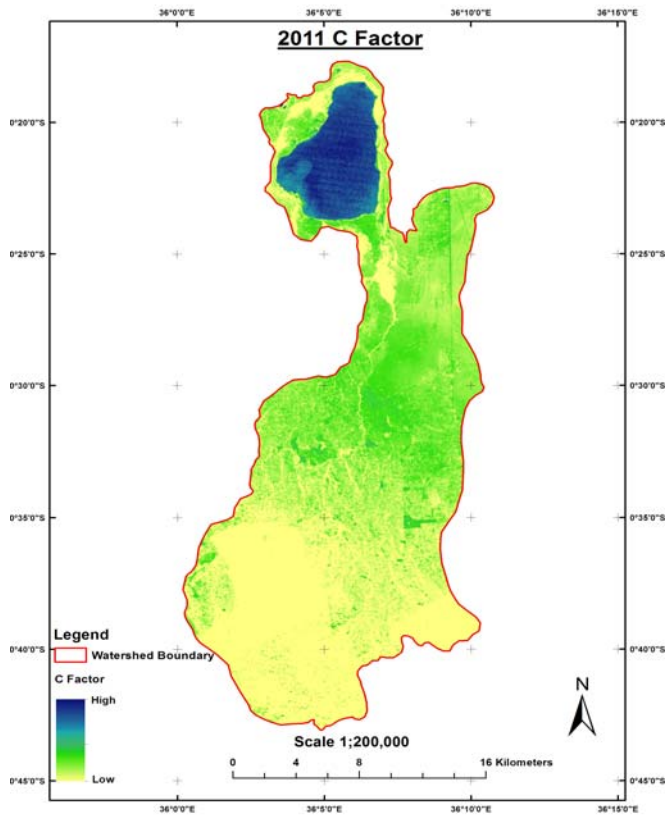


Figure 7: 1989 C Factor (Left) and 2011 C Factor (Right)

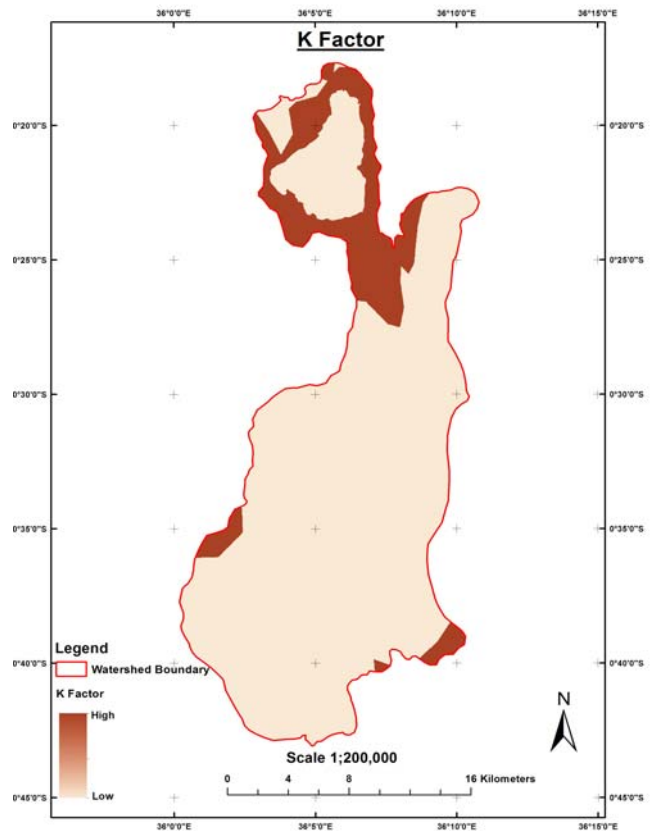
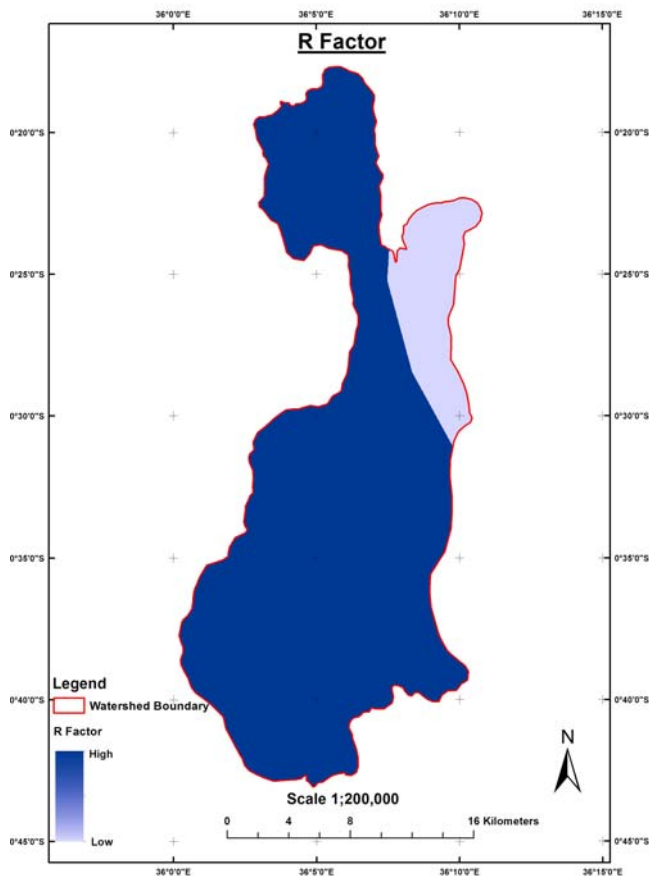


Figure 8: The Rainfall- runoff erosivity Factor (Left) and the Soil erodibility Factor, K-Factor (Right)



3. Results and Discussion

3.1 Land Use Land Cover

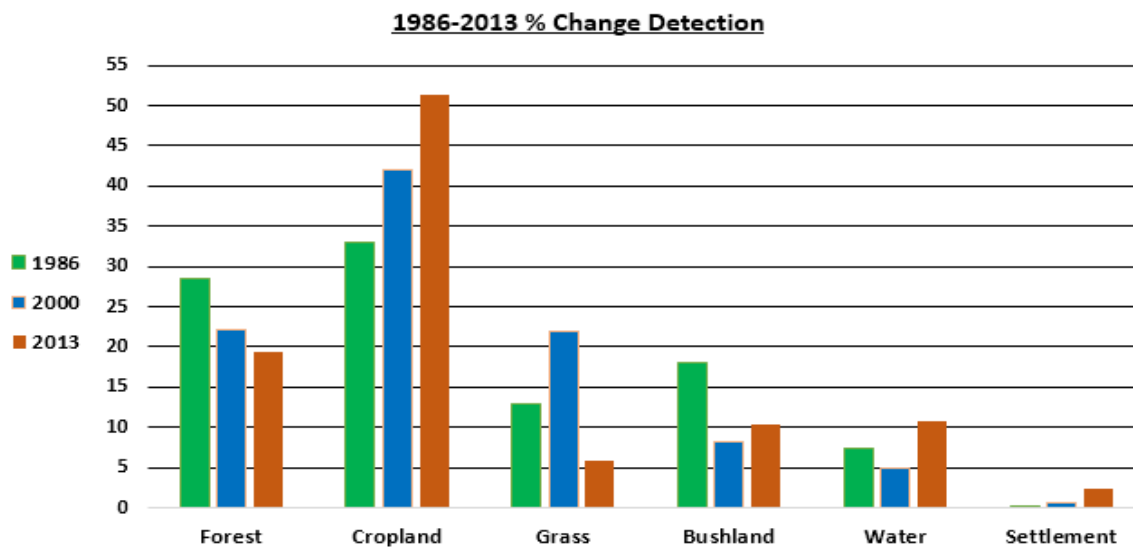


Figure 9: Land Use Land Cover Change

From the Land use land cover classification and change detection results, forest cover within the watershed has reduced by 32%. This is as a result of the continuous forest depletion from 1986 to 2013 of the Eastern Mau forest, which is part of River Enderit Watershed. Depletion of the forest has been due to a number of factors the main ones including clearing of the forest for purposes of creating more land for agricultural purposes such as tea and maize farming and in order to accommodate the growing population looking for more land to settle.

It is also worth noting that from 1986 to 2013 the area under cropland has increased by 62% whereas settlements have increased by 250%. The large increase in the area under settlement is due to conversion of grassland area near Nakuru town to residential holdings. The increase in settlements especially in the upper regions of the watershed accounts for the decreased forest cover and the increase in areas under cropland. One class with a notable increase is the water class. This was due to the effect long rains occurring at the time of 2013 image capture causing the lake size to swell as a result of increased water volumes by Feeder Rivers. Lake Nakuru size therefore increased by approximately 40% in this period.

3.2 Water Quality

Table 2: Water quality Laboratory analysis Results (Source, WARMA 2013)

Parameters	Sample 1	Sample 2	Sample 3	Sample 4	WHO Standards
PH	7.22	7.7	7.42	7.7	6.5-8.5
Colour	750	350	500	225	Max 15
Turbidity	155.2	81.9	91.1	54.6	Max 5
Conductivity	193.6	292	217	334	Max 2500
Iron	3.93	2.43	2.89	2.2	Max 0.3
Manganese	0.12	0.14	0.16	0.14	Max 0.1
Calcium	7.2	10.4	8	12	Max 100
Magnesium	2.43	4.38	1.95	4.87	Max 100
Sodium	19.8	36.2	31	42	Max 200

Potassium	20	18	10	20	Max 50
Total Hardness	28	44	28	50	Max 500
Total Alkalinity	48	72	64	76	Max 500
Chloride	21	2.9	19	33	Max 250
Fluoride	1.1	1.44	1.33	1.47	Max 1.5
Nitrate	6.62	7.49	4.5	8.86	Max 50
Nitrite	<0.01	<0.01	<0.01	<0.01	Max 0.1
Sulphate	2.5	9.29	6.94	13	Max 450
Free Carbon Dioxide	2.5	9.29	6.94	13	
Total Dissolved Solids	120	181	134.5	207.1	Max 1500
Water Quality	207.15	124.564	146.598	99.552	

From table 2 above, among the four samples tested, sample 1 has the highest turbidity and water colour probably due to the accumulation of sediments from feeder streams as the river flows downstream. Sample 4 exhibits the highest nitrate values. High nitrate values are normally associated with high use of fertilizers as a result of farming activities and according to the classification results, the region around sample 4 has been cleared of forestland to create land for farming, this could explain the high nitrate values. In addition sample 4 was found to exhibit high levels of total dissolved solids. This could be because of two factors; the clearing of forest cover to accommodate more land for farming thus increasing erosion risk and the high erodibility of the soil around this region.

3.3 Erosion Risk

By comparing the RUSLE map of 1989 and that of 2011 in figure 10 below, we find that on the southern and south western sections of the watershed, erosion risk has increased due to the clearing of trees in this section and hence the reduction of forest cover. Reduction of forest cover thus resulted in increased C Factor values in this region due to reduced NDVI values and therefore increasing the soil erosion amounts in the final 2011 RUSLE computation. The area around Lake Nakuru also shows increased soil erosion

risk from 1989 to 2011. This is as a result of clearing of vegetation cover around the lake and due to the high erodibility of the soil in that region.

As more land in the middle section of the watershed is continuously cultivated, there are varying areas with erosion risk due to farming activities; however, there are two sections as shown in with the red colour that erosion risk remains predominantly high. One section is at the center of the watershed near River Enderit and the other is at the south eastern parts of the watershed. This two sections have other RUSLE factors remaining relatively constant apart from the LS factor and thus the lack of substantive vegetation cover in the two areas over the two epochs led to high C factor values and therefore the high erosion risk.

Finally, there are two areas with the least amount of erosion risk which include the lake region that is generally flat and thus having very low LS factor value therefore cancelling out other RUSLE parameters and the upper region with forest cover which results to very low C factor values and also cancelling other RUSLE parameters.

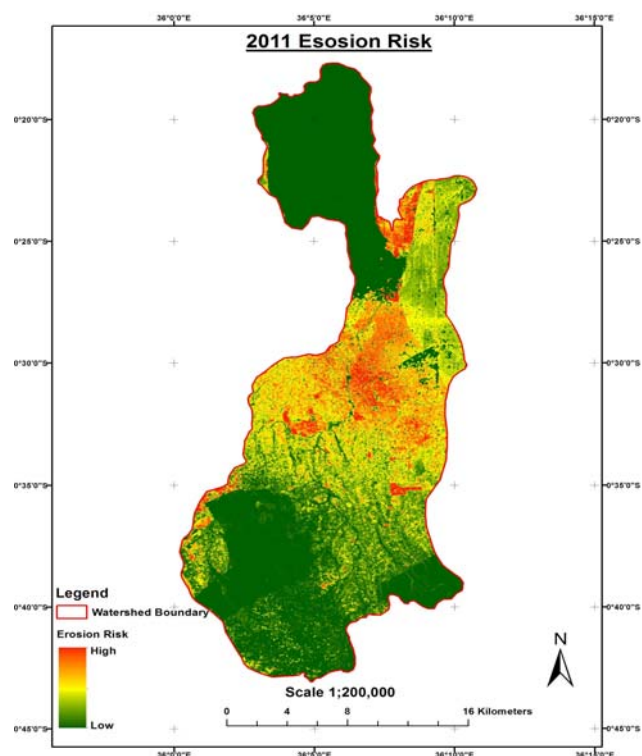
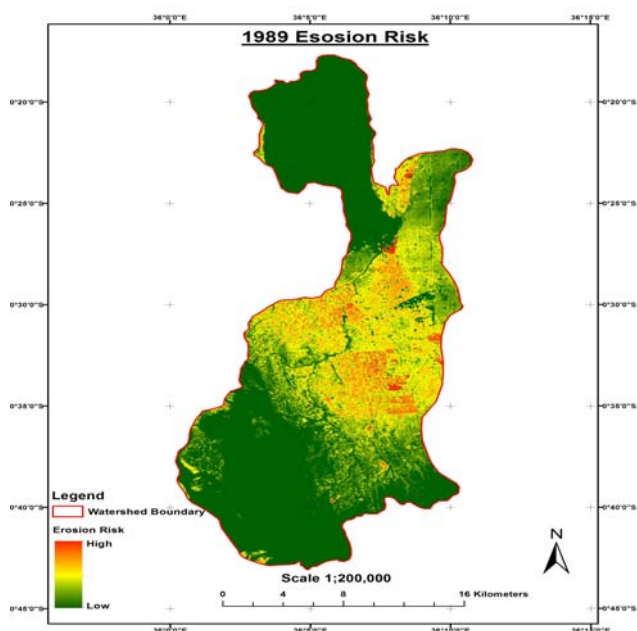


Figure 10: River Enderit Watershed Erosion Risk

4. Conclusion

This research shows that the health of River Enderit watershed is at risk as supported by; the satellite image change detection results that mainly show the reduction in forest cover due to clearing of trees to create more land for cultivation, the RUSLE results that show the increased erosion risk within the watershed and the water quality results that supports the change detection and RUSLE results. The research therefore re-enforces the need for the Kenyan Government to come up with good policies and stringent implementation measures for protection of watersheds such as that of River Enderit and others at risk of deterioration due to destructive human activities. This requires a concerted effort involving the Government and local communities living within the watersheds

5. Recommendations

Finally, the research has room for improvement when the following factors are considered;

- 1) The water samples collected should be more, well distributed within the watershed and statistically adequate in order to generate a good map that shows the relationship between the sampling locations and watershed water quality.
- 2) The water quality laboratory results should include tests for fertilizers and pesticides in order to adequately map their effects on the watershed water quality.

6. Acknowledgement

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