TOOLS FOR REMOTELY ASSESSING RIPARIAN BUFFERS PROTECTING STREAMS FROM SEDIMENT POLLUTION

by

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(Under the Direction of E. W. TOLLNER)

ABSTRACT

The study evaluated tools for remotely assessing the impact of riparian buffers protecting streams from sediment pollution by integrating Google Earth Pro and USLE to predict site specific soil erosion and integrating GIS, remote sensing, and USLE to estimate erosion distribution within Nzoia basin (Kenya). Sediment deposition along the buffer was estimated using USFS SDR. Paired t – test comparison between GPS and Google Earth derived elevations showed difference between the elevations but within the GPS error margin. Ground truthing results from ten small watersheds yielded a mean absolute error of 0.76 tons ha^{-1} yr^{-1} with a coefficient of determination of 0.95. For sediment deposition, USFS method overestimated the amount of sediment deposited in riparian buffers. The integration of GIS, remote sensing, and USLE yielded a soil erosion distribution map for the Nzoia basin with most of the basin under slight erosion (0 – 5 tons ha^{-1} yr^{-1}) with some erosion hotspots. Therefore, Google Earth Pro, GIS, and remote sensing technologies can be integrated with erosion, sediment yield, and nutrient transport prediction models to asses the effectiveness of riparian buffers.

INDEX WORDS: Sediment yield, Erosion, Riparian buffer, Remote sensing, Stiff diagram, Google Earth Pro, GIS, USLE, and SDR

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BS Agricultural Engineering, Makerere University, Uganda, 2002

A Thesis Submitted to the Graduate Faculty of The University of Georgia in Partial Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE IN BIOLOGICAL ENGINEERING

ATHENS, GEORGIA

2007

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August 2007

DEDICATION

To my wife Christine Kyosimire, daughter Petra Mirembe, and the entire family for their encouragement and support throughout the years I spent away from home.

ACKNOWLEDGEMENTS

I would like to thank my major advisor Dr. E. W. Tollner for the continued support and mentorship plus the committee members, Dr. Steve McCutcheon, and Dr. Rose Mary Seymour for their feedback during and after the proposal development phase. Dr. Tollner motivated me by believing in my potential and comprehensively discussing the project details. Dr. Steve McCutcheon took time from a busy schedule to analyze all the critical details. Dr. Seymour inspired me to have a broader project outlook. Iam greatly indebted to Dr. Tommy Jordan for enabling me explore personal GIS and Remote Sensing capabilities. I am grateful to Aquaculture CRISP and USAID for funding the study. I am extremely grateful to the staff of Department of Biological and Agricultural Engineering and the graduate students for the continued moral support and for providing a conducive environment that fostered the learning process.

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1 INTRODUCTION

Background

The intensification of agriculture the world over has led to the deterioration of water quality draining from agricultural catchments. By 1988, the United States Department of Agriculture (USDA) endorsed vegetative filters strips as an approved cost-share practice under the conservation reserve program of the US Food Security Act of 1985. The United Kingdom adopted similar measures by 1992 to reduce the economic losses created by erosion of fertile soils which were transported into surface water bodies (Muscutt, 1993). The accelerated soil erosion due to water has prompted the global trend of promoting sustainable Agriculture and utilization of natural resources (Oldeman, 1994). Sustainable utilization of natural resources includes conservation and restoration of wetlands and riparian buffers to reduce nonpoint source (NPS) or diffuse pollutants. Nonpoint source pollution includes runoff from farms and ranches, urban areas, construction and industrial sites. The sources introduce harmful amounts of sediment, nutrients, bacteria, organic wastes, and chemicals, into surface waters. The damage to streams, lakes, and estuaries from NPS pollution in the US was estimated to be about $7 x 10^9 to $9 x 10^9 per year in the mid-1980s (Ribaudo, 1986). The damage is due to increased cost of water purification and hydropower generation, increased flood risk (Hansen et al., 1999) and reduction in fisheries. The fisheries productivity is affected because sediment clogs and scrapes fish gills, suffocates fish eggs and aquatic insect larvae thus causing fish to modify feeding and reproduction behaviors (Blankenship, 2005).

Riparian buffers are part of an integrated management system that includes nutrient management, sediment and erosion control practices to effectively keep excess nutrients and sediment from surface runoff and shallow groundwater. Thus, riparian vegetation buffers nutrient sensitive ecosystems from nutrient enriched sediment originating on agricultural land

(Likens and Bormann, 1995). Forested riparian buffers and grass filter strips reduce sediment yield from agricultural land by intercepting and spreading runoff, reducing the velocity, increasing the retention time, and allowing deposition.

The canopy, the roots, and the organic litter and debris are vital elements of buffers. The canopy intercepts and dissipates the energy of some precipitation, changing the raindrop size and velocity. The roots further bind the soil to stabilize slopes especially stream banks, increase macropores and infiltration, and take up water and nutrients from the soil. The depth and roughness surface of litter greatly increase infiltration, slows overland flow, traps sediments, and sequesters nutrients (Travis, 2003).

Throughout the African humid tropics are numerous surface water bodies and riparian forests that provide indigenous people with many of their social and economic needs plus wild life habitat (Leakey and Simons, 1998; Okafor and Lamb, 1994; Abbiw, 1990). But with the rapid population growth, the riparian forests are being destroyed with increasing demand for productive agricultural land. This especially explains the increased degradation of the surface water quality due to sedimentation. One of the affected water bodies includes Lake Victoria. The Lake Victoria Basin is a source of drinking and irrigation water, food, and energy, and a means of transport for people of Kenya, Uganda, and Tanzania. Development activities, nutrient discharge, and population growth (3% on the Kenyan side) have caused changes in the lake ecosystem. Massive blooms of algae and water hyacinth are blocking waterways and water supply intakes (LVEMP, 1995). Most of the degradation of the Lake Victoria Basin is caused by: (1) Loss of 89% of forest cover to poor agricultural practices; (2) Pollution from mines, urban areas, and industry; (3) Loss of lake fish species diversity due to introduction of the non-native Nile perch; (4) Poor fisheries management practices (Wangila and Shallow, 2001).

The study area

Lake Victoria Basin: Lake Victoria is the second largest source of fresh water in surface area, second to Lake Superior of North America. The lake is bordered by Kenya, Tanzania, and Uganda, though some inflowing rivers like the Kagera drain Burundi and Rwanda. From north to the south the lake is located between latitudes 0^0 30' N and 3^0 12' S while from west to east between longitudes 31^0 37' E and 34^0 53' E. The lake is located at an elevation of 1134 m above sea level and has a volume of about 2760 km^3 with an average depth of 40 m. It has a surface area of 68800 km^2 and a total catchment area of 193000 km^2 (LVEMP, 2001). The main rivers flowing into Lake Victoria from Tanzania are the Mara, Kagera, Mirongo, Grumeti, Mbalageti, Simiyu, and Mori (LVEMP, 2001). The main rivers from Kenya are the Nzoia, Sio, Yala, Nyando, Sondu-Miriu, Kuja, Migori, Riaria, and Mawa. From Uganda the main rivers are the Kagera, Bukora, and Katonga (LVEMP, 2003). River Kagera drains both Burundi and Rwanda. Rivers from Kenyan catchment contribute 37.6 % of the inflows into Lake Victoria. Within the Lake Victoria Basin, agricultural activity accounts for about 50 % of the land use. Forest, shrubs, grassland, swamps and water bodies are part of the catchment land cover. Agricultural activities contribute a higher proportion of surface runoff which is laden with large amounts of water pollutants including nutrients. Soil erosion on the order of 5 to 10 tons per hectare per year is associated with significant losses in soil nutrients that contribute significantly to negative farm nitrogen and phosphorous balances (Bosch et al., 1998). In 1983 about 60 % of the land in the Kenyan catchments was natural vegetation and 30 % was under agricultural. Productivity varies considerably, with the more arid uplands being least productive and increasingly subject to over-exploitation and degradation. The dominant land use in the Tanzanian part of the lake Basin is grassland for livestock rearing, which accounts for 50 % to over 70 % of land use, while the extent of cultivated land in these areas is between 30 % and 10 %. In the Ugandan Basin area, there is balance between cultivated land, pasture, and forest. In Kenya and Uganda, the extent of land taken for urban development, infrastructure and related uses is estimated to be over 20 % and increasing, however, urbanization is much lower in the Tanzanian Basin.

Figure 1.1: Location of the Nzoia River Basin

Sediment and nutrient laden runoff, urban and industrial point source pollution, and biomass burning have accelerated eutrophication of Lake Victoria, leading to decreased productivity of the fisheries. Bullock et al (1995) estimated that 50 % of the nitrogen input and 56 % of the phosphorus input into Lake Victoria is due to run-off from agricultural land. Studies carried out by Sangale et al (2001) and Okungu and Opango (2001) show that River Nzoai contributes the most sediment loading to Lake Victoria from the Kenyan catchment mainly because of the high mean discharge of 118 m^3/s.

Figure 1.2: Water hyacinth on Lake Victoria waterways

Nzoia River Basin: The Nzoia River Basin covers an area of 12842 km^2 and drains several districts on the way to Lake Victoria. The areas include Uasin, Gishu and Trans-Nzoia districts in the rift valley province; Mt. Elgon, Lugari, Teso, Bungoma, Kakamega, Butere-Mumias, and Busia districts in the western province; and Siaya district of the Nyanza province (NRBMI, 2006). River Nzoia is 355 km long with a mean discharge of 118 m^3/s and is the largest Basin within the Lake Victoria drainage. The River originates in the Cherengany Hills and on Mt. Elgon at 4320 m above sea level and is fed by several streams, namely the Kamukuywa, Moiben, Sosio, Kimilili, Kibisi, Kuywa, Malakisi, Tisi, Lwakhakha, Suam, Kisawai, and Kimothon among others. The River Nzoia drains small and large scale maize and wheat farms, coffee plantations, and receives discharges from a paper factory in Webuye, and Nzoia plus discharges from the Mumias Sugar Factories (NRBMI, 2006).

Runoff from rural and urban centers is drained by the River before reaching the Budalangi floodplains. The river periodically covers the Budalangi floodplains due to chanel blockage by heavy silt deposits transported from the deforested upper catchment areas. The river significantly contributes to pollution of Lake Victoria from areas with high agro-industrial activities. Further still, pollutants come from improperly treated wastewater from urban centers situated along the River which eventually drain into the Lake. The main Wetlands in the Nzoia Basin include Chepkoilel, Budalangi, Maji Mazuri, Ziwa-Sirikwa Dam, Saiwa Swamp, Siaga, Nyasanda, Kaplogoi Stream, Sosiot, Kaptule Wetland, Kapkis, Sergoit Dam / Lake Sergoit, Kerita swamp, Kholera stream, Saf Stream, Ukwala, Nambusi Wetland , Kisama, Tande, Kipsaina and Anyiko.

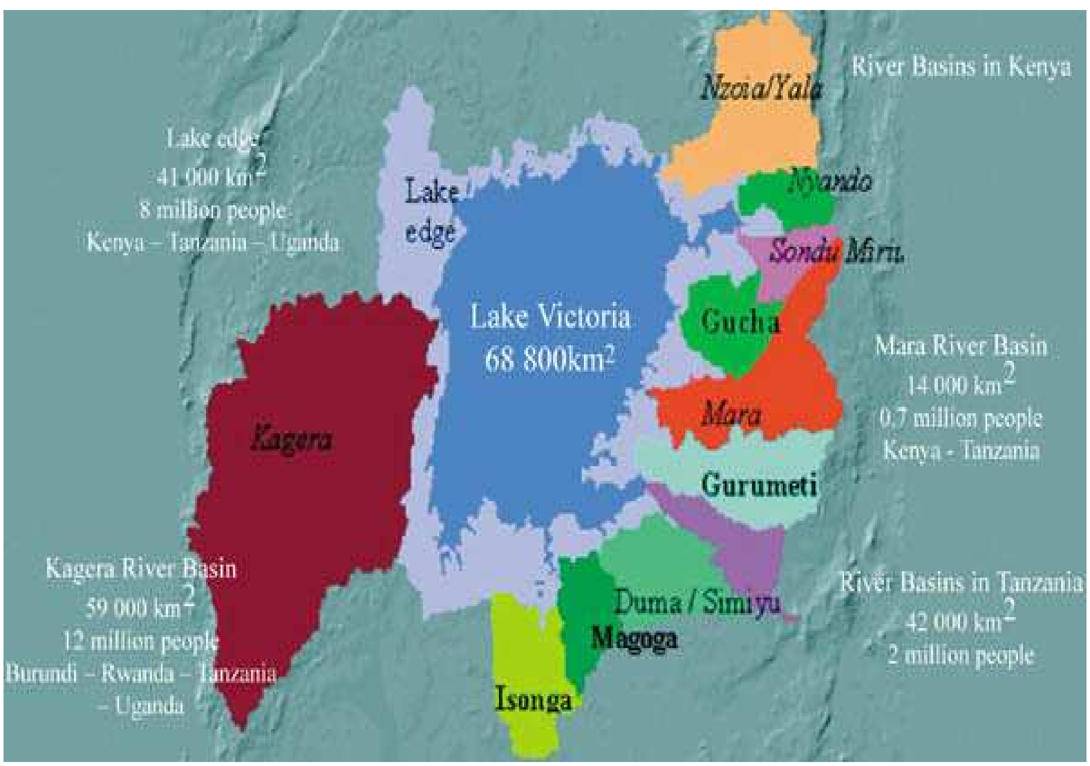

Figure 1.3: Lake Victoria Basin and sub-Basins

Figure 1.4: Nzoia River discharging into Lake Victoria at Busia

Study focus

Main objective: The main objective was to evaluate Google™ Earth Pro and GIS as remote sensing tools for defining topographic characteristics of micro-watersheds, integrating the derived topographic parameters with universal soil loss equation (USLE) and the sediment delivery ratio (SDR) to predict soil erosion from disturbed lands and sediment deposition in riparian buffers.

Specific objectives:

1. Carry out a reconnaissance survey to determine key sites that exhibit different land use patterns, farmer practices, and land cover for analysis of erosion potential in the Nzoia River Basin.
2. Assess the use of Google™ Earth Pro as a feasible tool for defining Basin characteristics at the selected sites.
3. Develop an approach for assessing erosion of agricultural land, and sediment trapping in riparian buffers on the Nzoia River and its tributaries.

2 LITERATURE REVIEW

Global extent of soil erosion

Soil erosion is a severe problem globally. Advancements in the fields of biotechnology and genetic engineering have not fully yielded expected crop productions, partly due to the erosion problem. Pimentel et al (1995) ascribe the slow growth rate in world food production to accelerated soil erosion. Oldeman (1994) estimated that the global land area affected by water erosion and wind erosion was 1094 x 10^6 and 548 x 10^6 hectares, respectively. On a continental scale, the severity of erosion by water in descending order has been more intense in Asia, Africa, South America, Europe, Oceania, North America and Central America (Oldeman, 1994). The main cause of soil degradation in Africa is overgrazing, in Europe is deforestation and agriculture, whereas in North America agriculture and construction activities are the causes. In addition Stewart et al (1990) attributes the difference in erosion on a continental scale to the difference in the climate. Soil erosion is more severe in hot and dry rather than in cool and moist climates.

In Africa, soil erosion has been worsened by population increase, drainage from roads, buildings, foot paths and cattle trails to rivers, subsistence agriculture, lack of effective conservation measures, high stocking rates and mechanization with inappropriate plowing techniques. All these factors contribute to heavy sediment loads. These trends have resulted into erosion hot spots in southeastern Nigeria (West Africa) and the highlands of eastern Africa (Lal, 1998). Other factors attributed to accelerated soil erosion in Africa include tropical deforestation (Lal, 1981), overstocking by livestock and over population by wildlife in eastern Africa specifically Kenya (Ongwenyi et al., 1993), lack of maintenance of traditional hillside terraces (Conelly, 1994), low soil fertility, and low available water holding capacity (Zaongo et al., 1994).

Onsite and offsite effects of soil erosion

Loss of soil quality is a global threat to the long-term sustainability of agricultural productivity. The main on-site impact of soil erosion is the reduction in soil quality due to loss of the nutrient-rich upper layers of the soil, resulting into reduced water-holding capacity and effective rooting depth. Increased use of chemical fertilizers may to an extent, and for a time, compensate for erosion-induced loss of soil quality where economic circumstances are favorable. But chemical fertilization is not usually feasible in developing countries.

The main off-site effect of soil erosion is the movement of sediment and agricultural pollutants into watercourses. This leads to silting-up of reservoirs, disruption of the ecosystems of lakes, and contamination of drinking water. Increased downstream flooding may also occur due to the reduced capacity of eroded soil to absorb water and silted drainage channels. Sedimentation of streams can have a pronounced effect on water quality and biota. Excessive sediment clogs and abrades fish gills, suffocates fish eggs and aquatic insect larvae, and causes fish to modify feeding and reproductive behaviors. Sediment also interferes with recreational activities by reducing water clarity. In addition to mineral soil particles, eroding sediments may transport plant and animal wastes, nutrients, pesticides, petroleum products, metals, and other compounds that can cause water quality problems (Clark, 1985; Neary, 1988).

Pimentel et al (1995) estimated that the total cost of soil eroded in the world is about US\$225 x 10^9 a year. The cost of all offsite environmental impact of soil erosion in the U.S. was estimated to be approximately US\$7 x 10^9 per year in the mid-1980s and US\$17 x 10^9 per year in the mid-1990s (Ribaudo, 1986). The offsite costs of erosion in Australia were approximately US\$20 x 10^6 to 30 x 10^6 per year, compared with onsite costs of approximately US\$260 x 10^6 per year by 1990 (Morgan, 1991). These costs illustrate the economic impact and severity of erosion.

Erosion estimation

Water Erosion Prediction Project (WEPP) erosion mode: The WEPP erosion model (Foster and Lane, 1987; Flanagan et al., 1995) computes interrill and rill soil loss along a slope and sediment yield at the end of a hill slope. Interrill erosion is a process of soil detachment by raindrop impact, transport by shallow sheet flow, and sediment delivery to rills (channels) on land surfaces. The sediment delivery rate to rills is conceptualized by the WEPP model as proportional to the product of rainfall intensity and interrill runoff rate. Rill erosion is a function of flow capability to detach sediment, the sediment transport capacity, and the existing sediment load in the flow.

The appropriate scales for application are tens of meters for hillslope profiles, and up to hundreds of meters for small watersheds. For scales greater than 100 meters, a watershed descretization into different slopes is necessary to prevent average erosion estimates from becoming unrealistically large. Overland flow processes are conceptualized as a mixture of broad sheet flow occurring in interrill areas and concentrated flow in rill. Broad sheet flow on uniform surface is the basis for overland flow routing and hydrograph development. Overland flow routing procedures include both an analytical solution to the kinematic wave equation and regression equation derived from the kinematic approximation for a range of slope steepness and lengths, friction factors (surface roughness coefficients), soil textural classes, and rainfall distributions. Because the solution to the kinematic wave equation is restricted to an upper boundary condition of zero depth, the routing process for strip cropping (cascading planes) uses the concept of the equivalent plane. Once the peak runoff rate and the duration of runoff have been determined from overland flow routing, or by solving the regression equations to approximate the peak runoff and duration, steady-state conditions are assumed at the peak runoff rate for erosion calculations. Runoff duration is calculated to maintain conservation of mass for total runoff volume.

The WEPP erosion equations are normalized to the discharge of water and flow shear stress at the end of a uniform slope and are then used to calculate sediment detachment, transport, and deposition at all points along a uniform landslope. Net detachment in a rill segment is considered to occur when the hydraulic shear stress of flow exceeds the critical shear stress of the soil and when the sediment load in the rill is less than sediment transport capacity. Net deposition in a rill segment occurs whenever the existing sediment load in the flow exceeds the sediment transport capacity. In watershed applications, detachment of soil in a channel is estimated to occur if the flow shear stress exceeds a critical value and the sediment load in the flow is below the sediment transport capacity. Deposition is predicted to occur if the channel sediment load exceeds the flow sediment transport capacity. Flow shear stress in channels is computed using regression equations that approximate the spatially-varied flow equations. Channel erosion to a non-erodible layer and subsequent channel widening can also be simulated. Deposition within and sediment discharge from impoundments is modeled using the conservation of mass and overflow rate. Soil erosion on a hill slope is represented as two components in the WEPP model: (1) Soil particles detached by raindrops and transported by thin sheet flow are known as interrill erosion and (2) Soil particle detached by shear stress and transported by concentrated flow known as rill erosion. The steady state sediment continuity equation for estimating net detachment on a land slope is (Foster and Nearing, 1995).

$$\frac{dG}{dx} = D_f + D_i \tag{1}$$

Where

G = sediment load (kg m^{-1} s^{-1}) at distance x from the origin of hill slope,

x = down slope distance (m),

D_f = rill detachment rate (kg m^{-2} s^{-1}), and

D_i = interrill sediment delivery rate to rill (kg m^{-2} s^{-1}).

The rill erosion function (D_f) is defined by Foster and Nearing (1995) as equation 2

$$D_f = K_{radj}\left(\tau_f - \tau_{cadj}\right)\left(1 - \frac{G}{T_c}\right) \quad (2)$$

Where

K_{radj} = adjusted soil erodibility parameter (s m^{-1}),

τ_f = flow shear stress (kg m^{-1} s^{-2}),

τ_{cadj} = adjusted critical shear stress on the rill surface (kg m^{-1} s^{-2}), and

T_c= sediment transport capacity for the rill flow (kg m^{-1} s^{-1}).

Sediment transport capacity for the rill flow (kg m^{-1} s^{-1}) is (Foster and Nearing, 1995; Huang and Bradford, 1993).

$$T_c = K_{tr} q_w s \quad (3)$$

Where

K_{tr} = a constant,

q_w = flow discharge per unit width (m^2 s^{-1}), and

s = slope as a percent.

Foster and Nearing (1995) defines the interrill sediment delivery rate (D_i) (equation 4) as

$$D_i = K_{iadj} I_e \sigma_{ir} SDR_{RR} F_{nozzle}\left(\frac{R_s}{w}\right) \quad (4)$$

Where

K_{iadj} = adjusted interrill erodibility (kg s m^{-4}),

I_e= effective rainfall intensity (mm h^{-1}),

σ_{ir} = interrill runoff rate (mm h^{-1}),

SDR_{RR} = interrill sediment delivery ratio,

F_{nozzle} = factor for sprinkler irrigation nozzle impact energy variation,

R_s = rill spacing (m),

w = width of rill (m).

The deposition equation (equation 5) is given as (Foster and Meyer 1975; Foster and Nearing, 1995):

$$\frac{dG}{dx} = \frac{\beta_r V_f}{q_w}\left(T_c - G\right) + D_i \qquad (5)$$

Where

V_f = the effective fall velocity of the sediment (m s^{-1}), and

β_r = the raindrop induced turbulence coefficient (0 to 1).

The parameters in equation 1 to equation 5 are normalized with corresponding parameter values for a uniform land slope condition. The equations are then solved to find soil erosion and deposition at a particular point of interest at distance x from the top of the hillslope during a desired time interval.

Erosion Productivity Impact Calculator (EPIC) model: The EPIC model documentation, components, and functions are detailed in Williams et al (1984), Williams (1990), and Sharpley and Williams (1990). The EPIC model is subdivided into nine separate components defined as weather, hydrology, erosion, nutrients, soil temperature, plant growth, plant environment control, tillage, and economic budgets. The model is a field-scale simulation that is designed to simulate drainage areas that can be characterized by weather, soil, landscape, crop rotation, and management system parameters. Operated on a continuous basis using a daily time step the EPIC model can perform long-term simulations for hundreds and even thousands of years. A wide range of crops and other vegetative systems can be simulated with the generic crop growth routine used in the EPIC model. An extensive array of tillage systems and other management practices can also be simulated with the model. Seven options simulate water erosion and five options simulate potential evapotranspiration (PET).

The EPIC water erosion model is an equation of the form expressed in equation 6.

$$A = XKCP(LS)(ROKF) \qquad (6)$$

Where

A = sediment yield (tons ha^{-1}),

K = soil erodibility factor (tons ha hr ha^{-1} MJ^{-1} mm^{-1}),

C = crop management factor,

P = erosion control practice factor,

LS = the slope length and steepness factor, $ROKF$ is the coarse fragment factor,

X = erosivity index option (MJ mm ha^{-1} hr^{-1}).

The *LS, C, P*, and *ROKF* are dimensionless parameter.

The crop management factor C is estimated from the equation 7 as

$$C = \exp\left[\left(Ln(0.8) - Ln(C_{nmj})\right)\exp\left(-1.15CV\right) + Ln(C_{nmj})\right] \qquad (7)$$

Where

Cmnj = minimum value of the crop management factor for crop *j*, and

CV = soil cover (above ground biomass plus residue; Williams, 1994).

Universal Soil Loss Equation (USLE): Soil erosion was recognized as a problem by farmers as like Jefferson (1813) who highlighted the detrimental effects on crop productivity. Later on the work of scientists like Duley and Miller (1923) sensitized the public regarding the erosion problem. Still, soil erosion was not recognized as a national problem until publication of "*Menace to the National Welfare*" (Bennet and Chapline, 1928). In 1929, the US congress appropriated US$ 160,000 for research into the causes of soil erosion, and prevention.

Soil erosion research stations were located at Statesville (North Carolina), Zanesville (Ohio), La Crosse (Wisconsin), Clarida (Iowa), Bethany (Missouri), Hays (Kansas), Guthrie (Oklahoma), Tyler (Texas),Temple (Texas), and Pullman (Washington). Plot design was based on earlier work by M.F. Miller and associates at the University of Missouri (Meyer and Moldenhauer, 1985). The most prevalent design was a plot of 6 feet wide and 72.6 feet long (1% of an acre). Slopes were limited to topography of the sites.

Many public officials supported research into soil erosion. Franklin D. Roosevelt as a New York state senator in 1910 worked diligently for farmers and conservation, emphasizing promotion of agriculture and conservation. In less than six months after being elected as US president, Roosevelt established the "*New Deal*" in 1933 which was designed to stimulate economic recovery. This program included the National Industrial Recovery Act, and the creation of the soil conservation service with H.H. Bennet as the first Director being part of the Department of the Interior. Congressional testimony by Bennet on May 12, 1934 combined with the effects of the great dust storm led to the enactment of the 1935 Soil Conservation Act. This Act committed U.S. government to soil conservation. Thus, most of the work related to erosion prediction was conducted by United States Department of Agriculture (USDA) scientists employed by the Soil Conservation Service (SCS).

In 1934, Duley and Ackerman published measurements of the effect of slope and flow length on soil erosion but did not develop a mathematical relationship. In 1940, Austin Zingg located at the Bethany station and later an authority on wind erosion, evaluated data from field experiments under natural rainfall and from rainfall simulations (equation 8). He developed the following empirical relationship;

$$X = CS^m L^n \tag{8}$$

Where

X = total soil loss from a hill slope of unit width,

C = a constant of variation,

S = land slope expressed as a percentage (%),

L = horizontal length of land slope, and

m and n = exponents derived from the simulated rainfall experiments.

The following year Smith (1941) expanded the empirical equation 8 from to equation 9.

$$A = CS^{1.4} L^{0.6} P \tag{9}$$

Where

A = total soil loss

P = the ratio of soil loss with a mechanical conservation practice to soil loss without the practice.

Smith maintained the exponents m, and n derived by Zingg on the slope and length factors. The data used by Smith (1941) was collected on Shelby series, the same soil investigated by Zingg. These equations were based on Midwestern data and applicable only to the Midwest. Browning et al (1947) added soil erodibility and management factors to the Smith (1941) equation and prepared more extensive tables for different soils**,** crop rotations, and slope lengths. Smith and Whitt (1947) also presented a method for estimating soil losses from claypan soils. Soil loss ratios at different slopes were estimated for contour farming, strip-cropping, and terracing. Recommended limits for slope length were derived to guide contour farming. Then Smith and Whitt (1948) presented an erosion estimating equation (equation 10), to widen the application to the principal soils of Missouri.

$$A = CSLKP \tag{10}$$

Where

A = average annual soil loss

C = the average annual soil loss from claypan soils for specific crop rotation, Slope length, slope steepness, and row direction,

S = dimensionless slope steepness factor,

L = dimensionless slope length factor,

K = dimensionless soil erodibility, and

P = dimensionless support practice.

The SCS offices in Wisconsin teamed up with area experts to develop a system for regional application. The regional collaboration resulted in the "*slope-practice method*" of estimating soil loss for use in the Corn Belt. To adapt the Corn Belt equation for use in other regions, a workshop for erosion specialists throughout the US was held in Ohio in 1946. The workshop reviewed soil-loss data from all over the US, reappraised the parameter previously used, and added a rainfall factor. This resulted into the "*Musgrave equation"* which included factors for rainfall, flow characteristics of surface runoff as affected by slope steepness and slope length, soil characteristics, and vegetal cover effects (Musgrave, 1947). The equation factor were tabulated for many major condition in the northeastern US. Also, Doren and Bartelli (1956) proposed an erosion equation for Illinois soils and cropping conditions that estimated annual soil loss as a function of nine factors.

In the early 1950s, the SCS recognized and pushed for one equation for all of the U.S. Dwight Smith and others led a resolute effort towards a nationwide soil-loss prediction equation. This resulted in the establishment of the National Runoff and Soil Loss Data Center at Purdue in 1954, headed by Walt Wischmeier. Wischmeier focused on assembling the available data with guidance from Dwight Smith. In 1956, two meetings that made great strides towards the development of the universal soil loss equation (USLE) were held at Purdue. Leading soil conservation specialists from Agricultural Research Service (ARS), SCS, and several universities were invited to attend. At the first meeting, the core issues that were addressed included decisions about the type of relationship to be used in the USLE, which factors to include, how to quantify the factors, and what soil-loss tolerance limits to use. The second meeting held in July decided what factor values to use for conditions where insufficient or no data existed. Also, the need for a nationwide rainfall erosion index was emphasized as a priority. Subsequently, Wischmeier made an extensive analysis of rainfall and erosion data from fallow erosion plots and US Weather Bureau rainfall records to derive an erosion index for the R factor in the soil-loss prediction equation. In 1958, Jerry Mannering was hired to replace Don McCune and Tam Olson was hired to work with Wischmeier on K-factor values from 1960 to 1962.

Using the data assembled at the Purdue data center along with conclusions from deliberations at the 1956 conferences and subsequent analyses, Wischmeier, and Smith developed USLE (Wischmeier and Smith 1965, 1978). In 1961, ARS Special Report 22-66 was distributed as the first published information on the complete USLE. Then in 1965, Agricultural Handbook 282 (Wischmeier and Smith, 1965) for USLE users was published. Agricultural Handbook 282 was based on more than 10,000 plot-years of data from 47 locations in 24 states. The USLE empirical formula expressed by equation 11 is

$$A = RKSLCP \tag{11}$$

Where

A = average Annual Soil loss in tons acre^{-1} or Mg hectare^{-1},

R = rainfall –Runoff erosive index factor in MJ mm ha^{-1} hr^{-1} yr^{-1},

K = soil erodibility factor (ton ha hr ha^{-1} MJ^{-1} mm^{-1}),

S = slope steepness factor (dimensionless),

L = slope Length factor (dimensionless),

C = crop-Management factor (dimensionless), and

P = conservation Practice factor (dimensionless).

USLE quantifies soil erosion as the product of six factors representing rainfall – runoff erosivity, soil erodibility, slope length, slope steepness, cover crop management practices, and support conservation practices. Further revisions to the USLE factors have led to the development of Agriculture Handbook No. 703 which takes into account additional data that was not used earlier.

USLE Rainfall factor [R] calculation: The long term average annual rainfall factor can be calculated using the following two procedures:

1. Using the average annual Isoerodent maps developed by Wischmeier and Smith (1965, 1978).
2. Utilizing the 2 year, 6 hour storm concept developed by Hotes et al (1973) which accounts for the storm type.

   a. Storm type I: $$R = \frac{EI_{30}}{100} = 16.55 P_{(2,6)}^{2.2} \qquad (12)$$

   b. Storm type II: $$R = \frac{EI_{30}}{100} = 27 P_{(2,6)}^{2.2} \qquad (13)$$

   Where

   E = rainfall energy

   I = maximum 30 – minute rainfall intensity

   $P_{(2,6)}$ = the 2 - year, 6 - hr precipitation in inches.

Storm type I and type II are the least and most intense short duration rainfalls respectively.

Hotes et al (1973) developed another relationship for determining the storm runoff erosivity index $R_{st,}$ from the precipitation P (inches) and the storm duration D (hours)

a. Storm type I: $R_{st} = \dfrac{15P^{2.2}}{D^{0.6065}}$ (14)

b. Storm type II: $R_{st} = \dfrac{19.25P^{2.2}}{D^{0.4672}}$ (15)

For SI units, multiply the result by 17.02 and divide the precipitation (inches) by 25.4 yielding an equation like

$$R_{st}(MJmmha^{-1}hr^{-1}yr^{-1}) = 17.02\left(\frac{19.25\left[\frac{P}{25.4}\right]^{2.2}}{D^{0.4672}}\right) \quad (16)$$

Cooley (1980) further developed the relationships in equations (12) to (15) for all SCS storm types *I, Ia, II*, and *IIa* as

$$R_{st} = \frac{a_1 P^{f(D)}}{D^{b_1}} \quad (17)$$

Where

$f(D) = 2.119D^{0.0086}$

The values of P are in inches, D is in hours, and the values of a_1 and b_1, are provided in Table 2.1.

Table 2.1: Cooley's coefficient values for different storm types

SCS Storm Type	a_1	b_1
I	15.03	0.5780
Ia	12.98	0.7488
II	17.90	0.4134
IIa	21.51	0.2811

In 1994, Renard and Freimund derived a regression equation of R using 155 stations in the US. The equations are

$$R = \begin{cases} 0.0483P^{1.610}, & P \le 850mm \\ 587.8 - 1.249P + 0.004105P^2, & P > 850mm \end{cases} \quad (19)$$

Where

R (MJ mm ha^{-1} hr^{-1} yr^{-1}), and

P = annual precipitation in mm

The Renard and Freimund (1994) equation approximates R for most East African areas due to the similarity in the rainfall energy of US and East African storms.

Renard et al (1997) proposed another approach for determining single a storm value of R_{st} as

$$R_{st} = \frac{\sum EI_{30}}{100} = 0.29 I_{30\max} \sum_{i=1}^{N} P_i \left(1 - e^{-0.05 I_i}\right) \quad (18)$$

Where

EI_{30} = maximum 30 minute erosion index,

$I_{30\max}$ = the 30 minute period during a storm yielding the highest intensity,

N = number of storm segments

P_i = precipitation (mm) occurring during the ith storm segment

I_i = intensity (mm hr^{-1}) during the ith storm segment

Soil erodibility factor, K. The soil erodibility factor can be computed as a simple parameter, K_{simple} (Renard et al., 1997) or as a complex parameter, $K_{complex}$. The simple K_{simple} factor is calculated independently, while the complex $K_{complex}$ factor is computed as a composite *KLS* factor.

The simple soil erodibility factor is expressed as, $\boldsymbol{K_{simple}}$

$$K_{simple} = 2.8x10^{-7}\left[(\%Silt + \%VFS)(100 - \%Clay)\right]^{1.14}(12 - a) + 4.3x10^{-3}(b - 2) + 3.3x10^{-3}(c - 3) \quad (20)$$

Where

% Silt = percent silt

% VFS = percent very fine sand

% Clay = percent clay

a = percent organic matter

b = structure code (1 = very fine granular, 2 = fine granular, 3 = medium to coarse granular, and 4 = massive, blocky or Platy), and

c = Permeability Class (1 = rapid, 2 = moderate to fast, 3 = moderate, 4 = Slow to moderate, 5 = slow, and 6 = very slow)

The complex soil erodibility parameter is more suited for non-uniform hillsides. To estimate $K_{complex}$, the procedure involves five steps for each slope segment: (1) calculation of slope length parameter, (2) calculation of slope steepness parameter, (3) calculation of slope length adjustment parameter, (4) calculation of soil erodibility parameter, and (5) summing up the product of the above four segment parameter.

The soil erodibility factor can also be estimated by global erodibility equation recommended by Torri et al (1997). The equation is based on soil texture, organic matter percent, and the geometric mean of the particle size.

$$K = 0.0293\left(0.65 - D_g + 0.24 D_g^2\right)\exp\left\{-0.0021\frac{OM}{f_{clay}} - 0.00037\left(\frac{OM}{f_{clay}}\right)^2 - 4.02 f_{clay} + 1.72 f_{clay}^2\right\} \quad (21)$$

$$D_g = -3.5 f_{clay} - 2.0 f_{silt} - 0.5 f_{sand}$$

Where

K = soil erodibility (ton ha hr ha^{-1} MJ^{-1} mm^{-1})

D_g = geometric mean of the particle size

OM = percent organic matter

f_{clay} = clay fraction

f_{silt} = silt fraction

f_{sand} = sand fraction

Table 2.2 lists average *K* values based on soil textural class and the percent organic matter.

Table 2.2: *K* values based on percent organic matter

Textural Class	Average	Less than 2 %	More than 2 %
Clay	0.22	0.24	0.21
Clay Loam	0.30	0.33	0.28
Coarse Sandy Loam	0.07	--	0.07
Fine Sand	0.08	0.09	0.06
Fine Sandy Loam	0.18	0.22	0.17
Heavy Clay	0.17	0.19	0.15
Loam	0.30	0.34	0.26
Loamy Fine Sand	0.11	0.15	0.09
Loamy Sand	0.04	0.05	0.04
Loamy Very Fine Sand	0.39	0.44	0.25
Sand	0.02	0.03	0.01
Sandy Clay Loam	0.20	--	0.20
Sandy Loam	0.13	0.14	0.12
Silt Loam	0.38	0.41	0.37
Silty Clay	0.26	0.27	0.26
Silty Clay Loam	0.32	0.35	0.30
Very Fine Sand	0.43	0.46	0.37
Very Fine Sandy Loam	0.35	0.41	0.33

Adapted from Ontario Ministry of agriculture, food, and rural affairs fact sheet (Stone, 2000)

The slope length factor, L_i

$$L_i = \left[\frac{l}{22}\right]^{Mer}$$

$$M_{er} = \frac{RillFactor(\sin\theta)}{\sin\theta + 0.269(\sin\theta)^{0.8} + 0.05} \qquad (22)$$

$$\theta = \tan^{-1}\left[\frac{s}{100}\right]$$

Where

l = length along the slope face (m), if slope length is in feet change the value of 22 to 72.2.

M_{er} = factor relating angle to slope length erosion severity.

RillFactor = rill erosion susceptibility parameter [0.5 = not susceptible, 1 = average susceptibility, 2 – very susceptible].

The slope Steepness factor, S_i

$$S_i = 3(\sin\theta)^{0.8} - 0.56 \qquad \text{If } l < 4 \text{ m}$$
$$S_i = 10.8\sin\theta + 0.03 \qquad \text{If } l > 4 \text{ m and } s < 9\ \% \qquad (23)$$
$$S_i = 16.8\sin\theta - 0.5 \qquad \text{If } l > 4 \text{ m and } s > 9\ \%$$

For irregular slopes, the use of a slope length adjustment factor (SAF) is applied.

$$SAF_i = \frac{i^{Mer+1} - (i-1)^{Mer+1}}{n^{Mer}} \qquad (24)$$

Where

i = the slope length segment number, and

n = total number of segments

The i^{th} segment soil erodibility factor K_i is calculated using the same procedure as simple *K*. Then, the complex soil erodibility factor KLS is given as:

$$KLS = \sum_{i=1}^{n} K_i L_i S_i (SAF)_i \qquad (25)$$

According to Renard and Foster (1995), the cropping management factor *C* is a combination of five sub-factors in an agricultural setting. These factors include: (1) prior land use, (2) canopy cover, (3) surface cover, (4) surface roughness, and (5) soil moisture. Since these sub-factors vary throughout the year or growing season, Haan et al (1994), and Renard et al (1997), and Tollner (2002) present a method of aggregating the *C* factor based on the percentage canopy cover and the rainfall distribution throughout the year.

The practice factor *P* is a dimensionless factor that has a maximum value of 1 for no conservation services. The practice factor has three components: (1) contouring practice sub-factor (P_c), (2) strip-cropping practice sub-factor (P_s), and (3) the terracing practice sub-factor (P_t). The contouring sub-factor P_c can be estimated using a slope dependant Table 2.3. Where the slope exceeds the Table 2.3 slopes and maximum slope lengths, $P_c = 1$. The strip cropping sub-factor P_s is 1 for contouring only, and 0.75 for a 4 year rotation with 2 year row crop and 2 year meadow or small grain; P_s is 0.5 with 1 year row crop with 3 year meadow or small grain. The P_s factor is 1 for shorter rotations and where the given strip width for a specific slope is exceeded. The terrace sub-factor P_t is 1 for no terraces, 0.2 for terraces with graded sod outlets, and 0.1 for tile terraces. For construction, mining, and clear cut forest harvest areas, $P_t = 1$.

$$P = P_c P_s P_t \tag{26}$$

Table 2.3 shows calculation of the practice sub factors based on the slope length, slope gradient, and the support practice. Table 2.4 depicts average *C* and *P* factors based on land cover and land use while Table 2.5 shows average *C* factor based on crops grown.

Other erosion estimation tools include the Hydrological Simulation Program-Fortran (Bicknell et al., 1997), the Soil and Water Assessment Tool (Neitsch et al., 1999), Soil and Water Integrated Model (Krysanova et al., 2000), and the Surface water modeling system (Ems-I, 2002).

Table 2.3: Contour sub-factors at different slopes

Land slope (%)	**P_c**	**Maximum slope length (m)**	**Maximum strip crop width (m)**
1 to 2	0.6	≤ 120	≤ 40
3 to 5	0.5	≤ 90	≤ 30
6 to 8	0.5	≤ 60	≤ 30
9 to 12	0.6	≤ 36	≤ 24
13 to 16	0.7	≤ 24	≤ 24
17 to 20	0.8	≤ 18	≤ 18
21 to 25	0.9	≤ 15	≤ 15

Adopted from Schwab et al. (1993) and Wischmeier and Smith (1978)

Table 2.4: ***C* and *P* factors for different land use and land cover type**

Land classes	**Crop management factor, C**	**Management practice Factor, P**
Barren and sparsely vegetated	0.4	1
Cropland / grassland mosaic	0.3	0.12
Cropland / woodland mosaic	0.3	0.12
Grassland	0.04	0.12
Savanna	0.039	0.12
Shrubland	0.036	0.12
Dryland cropland and pasture	0.013	0.1
Irrigated cropland and pasture	0.013	0.1
Urban and built-up land	0.01	1
Deciduous broadleaf forest	0.006	0.8
Evergreen broadleaf forest	0.006	0.8
Herbaceous wetland	0	1
Wooden wetland	0	1

Table 2.5: Average *C* factor for common crop groups

Crop group	**Average C factor**
Sunflower	0.65
Grain maize	0.60
Potatoes	0.60
Vegetables	0.50
Forage maize	0.45
Sugar beet	0.44
Legumes	0.30
Several year forage crops	0.15
Cereals	0.13
One year forage crops	0.1

Adopted from Suri et al (2002).

Sediment yield

Sediment delivery ratio (SDR) – area relationship: The relationships between *SDR* and drainage area has been established in the form of standard curves. Watersheds with large drainage area and the fields with a long distance to the streams have a low sediment delivery ratio. Large watersheds have more chances to trap sediment, thus the chance of soil particles reaching a water channel system is lower. At regional scales, the most widely used method to estimate *SDR* is through a generalized *SDR* – area power function proposed by Maner (1958) and Roehl (1962)

$$SDR = \alpha A^{\beta} \tag{27}$$

Where

SDR = sediment delivery ratio (dimensionless),

A = the catchment area (km^2)

α and β = empirical parameters

Field measurements by Walling (1983) and Richards (1993) suggest that β falls in the range of -0.01 to –0.025. This largely negative range generally implies an inverse relationship between *SDR* and area; thus *SDR* typically decreases with increasing catchment area. Field data from studies carried out in different catchments of the world show that the relationship between *SDR* and drainage area varies considerably for each catchment. Vanoni (1975) using data from 300 watersheds throughout the world calibrated the generalized form as

$$SDR = 0.42 A^{-0.125} \tag{28}$$

Where

A = drainage area (mi^2).

The USDA SCS (1979) developed a *SDR* equation based on the data from Blackland Prairie, Texas. The power function derived is expressed as

$$SDR = 0.51A^{-0.11} \quad (29)$$

Where

A = drainage area (mi^2)

<u>The Modified Universal Soil Loss Equation (MUSLE):</u> Sediment delivery ratios to determine sediment yield vary greatly due to the variation in rainfall distribution over time from year to year. As a result of the uncertainty of the delivery ratio, the MUSLE was proposed by Williams and Berndt (1972) by replacing the rainfall factor with a runoff factor.

$$Y = 11.8(Qq_p)^{0.56} K(LS)CP \quad (30)$$

Where

Y = sediment yield from an individual storm in metric tons,

Q = storm runoff volume in m^3

q_p = peak runoff rate in m^3 s^{-1}

K, *LS*, *C* and *P* = USLE factors

The difference between USLE and MUSLE is the replacement of the rainfall factor with the runoff factor. The runoff volume Q, and the peak runoff rate q_p have to be determined. Also, Dency and Bolten (1976) suggested general watershed sediment yield equations relating deposits in 800 reservoirs to drainage area size and mean annual runoff. The equations are

$S = 1280\ Q^{0.46}\ (1.43 - 0.26 \log A)$ (for areas where runoff is less than 2 inches) (31)

$S = 1958\ e^{-0.055}\ Q\ (1.43 - 0.26 \log A)$ (for areas where runoff is less than 2 inches)

Where

S = sediment yield (tons mi^{-1} year^{-1})

Q = runoff (inches)

A = watershed area (square miles)

Particle size effects on SDR: The *SDR* is also affected by the texture of the eroded soils. The texture of the eroded materials is related to the erosion source. Naturally coarse materials are created by stream bank and gully erosion, while the fine materials are due to sheet and rill erosion. Less energy is needed to transport fine particles than coarse materials. Accordingly, sands are probably deposited during the transport process while eroded silt and clay particles are more easily transported downstream. Thus, sediment containing high clay content will have a high delivery ratio. Walling (1983) suggested that sediment delivery ratio may be calculated from the proportions of clay in the sediment and in the soil.

$$SDR(\%) = \frac{C_{soil}}{C_{sed}} \tag{32}$$

Where

C_{soil} = the content of clay in the soil (%)

C_{sed} = the content of clay in sediment (%)

US Forest Service (USFS) SDR and the Stiff Diagram: Initially developed by the USFS (1980) for use in silvicultural applications however, this SDR relationship is useful in evaluating a wide variety of buffer types. The following seven parameters are involved: (1) percent ground cover, (2) texture of eroded material (% silt & smaller), (3) surface runoff (cfs/ft), (4) slope gradient, (5) surface roughness, (6) delivery distance (feet) and (7) slope shape. The values for each parameter are connected by a line on the Stiff diagram resulting in a polygon. The ratio of the area of the resulting polygon to the area by the bounding rectangle is used to estimate the sediment delivery ratio. The factors on the stiff diagram influence the capability of runoff to transport sediment. The slope is that of the zone (e.g., a riparian zone) between the sediment source area and the receiving water way (river). The slope shape factor of 0 represents a convex slope, 2 represent a uniform slope and that of 4 represents a concave slope. Surface roughness (within the riparian zone) is assigned where a factor of 0 and 4 represent smooth and rough surfaces respectively.

SDR based on other catchment characteristics: From the late 1950s to the early 1980s, empirical equations were developed relating the SDR to specific catchment characteristics. Listed below are some of the equations.

Maner (1958): $\log(SDR) = 2.962 + 0.869R - 0.854\log L$ (33)

Roehl (1962): $\log(SDR) = 4.5 - 0.23\log_{10} A - 0.510co\log(R/L) - 2.786\log BR$ (34)

Williams and Berndt (1972): $SDR = 0.627 s_d^{0.403}$ (35)

Williams and Berndt (1977): $SDR = 1.366x10^{-11} A^{-0.1} (R/L)^{0.363} CN^{5.444}$ (36)

Mou and Meng (1980): $SDR = 1.29 + 1.37Ln(RC) - 0.025Ln(A)$ (37)

Where

R = Basin relief defined as the difference in elevation between the average elevation of the watershed divide and the watershed outlet

L = maximum Basin length measured roughly parallel to mainstream drainage

R/L = Basin relief to length ratio

BR = bifurcation ratio

s_d = slope of main channel (%)

CN = the long-term average SCS curve number

A = drainage area (km^2)

RC = gully density

GIS, remote sensing and estimation of soil erosion

Geographical information system (GIS), digital elevation model (DEM) and remote sensing (RS) provide a new capability for analyzing and monitoring the dynamics of land – use change. Geographical information systems organize spatial information to efficiently capture, store, update, manipulate, analyze and display all forms of geographically referenced data. Remote sensing is used to collect information about the earth's features, such as its geology, vegetation, soil, atmosphere, water, ice surfaces and land-use by a sensor on a satellite, aircraft or ship. Digital elevation models (DEM) are defined as "any digital representation of the continuous variation of relief over space" (Burrough, 1986). Digital elevation models can be created from stereo-pairs derived from RS data or aerial photographs, or can be generated from digital terrain elevation data. Digital elevation model derived products can be readily combined with RS data for data analysis. For example, Guneriussen et al (1996) used a DEM to calibrate and geocode satellite data for monitoring snow and very useful for discriminating land use and ground cover classes during the digital processing of RS data.

Since the launch of ERTS-1 (Landsat 1) in 1972, remote sensing has been used to monitor natural resources and better manage the Earth. Applications have included monitoring of deforestation, agro-ecologic zoning, ozone depletion, flood early warning systems (FEWS), monitoring of large atmospheric-oceanic anomalies such as El Niño, climate and weather forecasting, ocean mapping and monitoring, wetland degradation, vegetation mapping, soil mapping, natural disaster and hazard assessment and mapping. A number of satellite systems monitor the global environment. The most commonly used satellite for natural resource management is the North Oceanic and Atmospheric Administration (NOAA) advanced very high resolution radiometer (AVHRR), which has a twice daily overpass and can freely relay information to ground receiving stations. The AVHRR data has a nominal pixel size of 1.1 km and records two spectral bands in the visible and near infrared has been used to map global land cover.

Geographical information system and RS applications for predicting soil erosion utilize the USLE. Each factor of the USLE is computed by use of RS data organized in layers of spatial data on which mathematical manipulations are enabled by GIS. Remote sensing and GIS have been used to study other fields like the mangrove forests (Ramachandran et al., 1998), seagrass beds (Ferguson and Korfmacher, 1997) and coral reefs (Holden and Ledrew, 1999). The quality and accuracy of the GIS outputs relies primarily on the quality of spatial resolution.

Erosion and sediment control management practices

The US Environmental Protection Agency (EPA) and USDA-SCS (1988) recommend different practices as viable measures for controlling erosion and sediment transport. The recommended practices detailed in the USDA-SCS (1988) include

- Conservation cover using crop residue and other materials
- Conservation cropping sequence
- Contour farming
- Delayed seed bed preparation
- Diversion of storm runoff
- Field borders of vegetation and filter strips
- Grassed waterways
- Terracing
- Maintaining and creating riparian buffers

Riparian buffers

One of the best management practices (BMP) that effectively controls nonpoint source pollution is the utilization of naturally occurring or constructed riparian buffers along streams, lakes, and other surface waters. The riparian buffer is a landscape located immediately adjacent to streams, lakes, or other surface waters. The riparian areas differ from the adjoining uplands because of high levels of soil moisture, frequent flooding, and the unique assemblage of plant and animal communities found there. Through the interaction of unique soils, hydrology, and vegetation, riparian buffers influence water quality as contaminants are taken up into plant tissues, adsorbed onto soil particles, or modified by soil organisms.

Studies indicate that both forest and grass riparian buffers can effectively trap sediment. For example Dillaha et al (1989) found that orchard grass filter strips 30 feet wide removed 84 percent of the sediment and dissolved solids from surface runoff, while grass strips 15 feet wide reduced sediment loads by 70 percent. In North Carolina, Cooper et al (1987) estimated that 84 percent to 90 percent of the sediment from cultivated agricultural fields was trapped in an adjoining deciduous hardwood riparian area. Sand was deposited along the edge of the riparian forest, while silt and clay were deposited further in the forest. Along the Little River in Georgia, Lowrance et al (1986) found that a riparian forest had accumulated 3.1×10^5 to 4.7×10^5 pounds per acre of sediment annually over the last 100 years.

Many factors influence the effectiveness of a buffer to remove sediments from land runoff, including the sediment size and loads, slope, type and density of riparian vegetation, presence or absence of a surface litter layer, soil structure, subsurface drainage patterns, and frequency and force of storm events (Osborne and Kovacic, 1993). Riparian buffers need to be properly maintained and regularly monitored to maintain effectiveness because some research has shown decrease in effectiveness over time due to excessive fast deposition. Probably the most important consideration is the maintenance of shallow sheet flow into and across the buffer. Where concentrated flow paths begin to form or deep sediments begin to accumulate, the buffer can no longer trap contaminants.

Nutrients such as nitrogen (*N*) and phosphorous (*P*) are essential elements for aquatic ecosystems, but in excess amounts lead to changes in the aquatic environment like eutrophication and reduced water quality (Dupont, 1992). Grass and forest buffers are effective at removing *N* and *P* from runoff, however forests are more efficient at removing dissolved nutrients from groundwater (Osborn and Kovacic, 1993). Several studies have found that buffers that include both grass and forest zones have increased nutrient removal capacities (Dillaha et al., 1989; Lowrance et al., 2000 and 2005; Novak et al., 2002).

USLE, SDR and the best management practices (BMPs)

To establish the effectiveness of BMPs in controlling erosion and sedimentation, the amount of soil eroded and how much ends down stream must be determined. Ideally, the sediment load entering and leaving the BMPs should be measured to accurately determine the BMP effectiveness. But the field measurements are difficult to set up, expensive and time consuming. Alternatively, the USLE has been adopted the world over as an effective approach to estimate the amount of soil eroded from a plot, catchment, and construction sites. However, the USLE does not determine the amount of sediment deposition. Thus, the SDR is used to determine how much of the eroded soils are deposited in the riparian zones. Therefore, the USLE and the USFS-SDR were used as tools to estimate riparian buffer effectiveness in this investigation.

3 USE OF GOOGLE ^{TM} EARTH PRO TO REMOTELY ASSESS THE IMPACT OF RIPARIAN BUFFERS PROTECTING STREAMS FROM SEDIMENT POLLUTION [1]

[1] Ssegane H and E. W. Tollner. To be submitted to *Transactions of the ASABE*

USE OF GOOGLE ™ EARTH PRO TO REMOTELY ASSESS THE IMPACT OF RIPARIAN BUFFERS PROTECTING STREAMS FROM SEDIMENT POLLUTION

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Abstract

Google ™ Earth Pro was used to define site characteristics. Extensive analysis of components of universal soil loss equation (USLE) and the USFS SDR method was carried out to determine erosion potential and sediment yield respectively. A paired t-test comparison between GPS and Google Earth derived elevations showed difference between the elevations but the error margin was within the GPS unit's error margin of 5 meters. The ground truth results obtained from measured data of ten small watersheds yielded mean absolute error of 0.76 tons ha^{-1} yr^{-1} with R^2 of 0.95. However, the USFS method over estimated the amount of sediment trapped within the riparian buffers. The Moore and Sergoit bridge sites located near Eldoret, Kenya were analyzed. The predicted average soil loss and sediment yield at Moore's bridge site was 192 and 1.8 tons ha^{-1} yr^{-1} respectively while at Sergoit site was 5.3 and 0.05 tons ha^{-1} yr^{-1} respectively. The study established an approach that integrates Google ™ Earth Pro derived elevations and Surfer ® 7.0 3D modeling software to estimate the slope length for estimation of USLE slope length and slope steepness factors. Thus the study stretched the applications of Google ™ Earth Pro from a location search and 3D Earth observatory tool to a remote sensing tool useful in extracting micro-watershed topographic parameters. Also,

KEYWORDS: Sediment yield, Erosion, Riparian buffer, Remote sensing, Stiff diagram, Google ™ Earth Pro, GIS, USLE, and Sediment delivery ratio

Introduction

The global intensification of agriculture has led to the deterioration of the water quality draining from agricultural catchments to receiving surface waters. Nonpoint source (NPS) pollution from agricultural land runoff, urban areas, and construction sites introduces destructive amounts of sediment, nutrients, bacteria, organic wastes, chemicals, and metals into surface waters. The financial cost due to damage on streams, lakes, and estuaries from NPS pollution in the US was estimated to be about $7 to $9 billion per year in the mid-1980s (Ribaudo, 1986). The monetary implications are due to increased cost of water purification, hydropower generation, increased flood risk (Hansen et al., 1999) and reduction in the fisheries. The fisheries productivity is affected given that sediment causes injuries to the fish, suffocates fish eggs and aquatic insect larvae, and results in modified fish feeding and reproduction behaviors. In addition to mineral soil particles, eroded sediment transports other substances such as plant and animal wastes, nutrients, pesticides, petroleum products, and metals that cause water quality problems (Clark 1985, Neary, 1988).

The accelerated soil erosion due to water has prompted the global trend of promoting sustainable agriculture and utilization of natural resources (Oldeman, 1994). Target areas for promoting sustainable utilization of natural resources include conservation and restoration of wetlands and riparian buffers as control measures in the reduction of NPS pollutants. Riparian buffers are part of an integrated nutrient management system that includes sediment and erosion control practices to effectively remove excess nutrients and sediment from surface runoff and shallow groundwater. The riparian buffers act as safeguards such that water quality in nutrient sensitive ecosystems is not contaminated by nutrient enriched sediment from agricultural land and construction sites (Likens and Bormann, 1995).

Throughout the African humid tropics are numerous surface water bodies and riparian forests that have provided native people and wildlife with social and economic needs (Leakey and Simons, 1998; Okafor and Lamb, 1994). However, the rapid population growth has led to encroachment and destruction of riparian buffers (forests) because of the increased demand of productive agricultural land. This principally explains the increased degradation of the water quality due to sedimentation. Lake Victoria, the second largest source of fresh surface water is among the affected water bodies. Lake Victoria is shared by three East African countries of Kenya, Uganda, and Tanzania. Massive blooms of algae and water hyacinth are blocking waterways and water supply intakes due to nutrient discharge (LVEMP, 1995, 2001). River Nzoia that drains several western districts of Kenya is a significant pollution contributor to Lake Victoria because of the high discharge of about 118 cubic meters per second. The total suspended solids contributed by Nzoia River are in the magnitude of 2.5 million tons per year (Okungu and Opango, 2001). The river periodically causes flooding of the Budalangi floodplains due to the heavy silt deposits transported from the deforested upper catchment areas.

There are environmental laws prohibiting agricultural activities within 30 m radius of the rivers. However, the pressure for agricultural land compels small scale farmers specifically on subsistence scale to encroach on the riparian buffers. The traditional and cultural practice of growing crops alongside rivers and lakes render the enforcement of environmental laws difficult. Also, the financial and human resource constraints limit the government's efforts to effectively implement the environmental laws. Therefore, it's not possible to conserve all areas under the threat of erosion. Consequently, for practical purposes, vulnerable areas under severe conditions are prioritized. The prioritization process requires reasonable assessment of the erosion problem to identify target areas for conservation and implementation of environmental laws. Therefore, the study was set to assess the effectiveness of using Google ™ Earth Pro ro as a remote sensing tool for extracting watershed variables with the core thesis focusing on integration of extracted watershed variables into erosion prediction and sediment yield models. The envisaged benefit of studying such tools is the possibilities they provide for studying watersheds in developing countries where detailed remote sensing data and technology is not readily available.

Background

Basin reconnaissance survey: The study involved a reconnaissance survey to determine sites that exhibit high erosion risk characteristics within the upper Nzoia Basin. The Nzoia Basin has three physiographic regions; (1) the highlands (include Mt. Elgon), (2) Upper plateau (include Eldoret valley), (3) the lowlands (include Busia). The reconnaissance survey targeted the Sergoit and Moiben sub-watersheds (upper Nzoia). Both sub-watersheds are located above the Eldoret valley. Two sites along the rivers were selected for detailed analysis based on agricultural intensity, heavy cattle grazing incidences, and water turbidity. Moore's bridge site was selected because even with farmer's encroachment of the forest, evidence of a forested riparian buffer existed while Sergoit bridge site was selected because with the prevailing agricultural activities, the riparian buffer was not as forested as at Moore's bridge. The site geographical position system (GPS) coordinates, and elevations were recorded.

Google ™ Earth Pro and Basin characteristics. Google ™ Earth Pro is a program that maps the earth by pasting images obtained from satellite imagery, aerial photography, and other geographic information system (GIS) over a three dimensional (3D) globe. Google ™ Earth Pro has extra features compared to Google Earth that enable the capture of high resolution images for subsequent use as base maps. It also has additional tools for path length and polygon area measurement. The degree of resolution for most land is at least 15 meters but some places have a high resolution of 60 – 70 cm. Google ™ Earth Pro is currently used to track air freights, used by structural and environmental engineers to visualize 3D buildings at suggested construction sites and in monitoring of forests and other land use forms. This study set out to assess its effectiveness in defining watershed variables. Using the GPS generated coordinates of the selected sites, Google ™ Earth Pro was used to locate the same sites and extract: (1) slope length, (2) gradient, (3) identify area under cultivation, (3) riparian buffer width, and (4) elevations for desired site features. Then, Surfer, 3D modeling software was used generate contours and flow direction vital for length, gradient, and slope shape determination. A paired student t – test was carried out to assess the comparison between Google ™ Earth Pro and Global positioning system (GPS) derived elevations for Moiben watershed recorded between 10:00 a.m. to 4:00 p.m. on July 27, 2006. For Watkinsville the GPS elevations were recorded between 12:30 p.m. to 1:00 p.m. on October 11, 2006.

Estimation of soil erosion using the universal soil loss equation (USLE): According to Tiwari et al (2000) and Oliviera et al (2004) the Universal soil loss equation (USLE) model performed better than the Water erosion prediction (WEPP) model. However, the USLE model tends to over estimate erosion on plots with low erosion and under estimate erosion on plots with high erosion rates. The less parameterization required and simplicity coupled with the world wide acceptance of the USLE, explain the choice of USLE as the soil erosion prediction model for this study. The USLE predicts soil loss as a product of six factors; rainfall factor; soil erodibility; slope length; slope steepness; crop management; and support practice.

The rainfall factor quantifies the interrelated erosive forces of rainfall and runoff that are direct results of the rainstorms. For this study the equation used to predict rainfall erosivity was developed by Renard and Freimund (1994) by regressing annual precipitation and the USLE rainfall factor values for 155 stations in the United States. The soil erodibility factor estimates the long term soil response to rainfall and runoff erosive forces. For this study due to absence of the soil permeability and soil structure data, the global erodibility equation recommended by Torri et al (1997) was used. In absence of relevant data, tabulated *K* values were used based on the soil texture. The crop management (*C*) factor was calculated using the approach proposed by Haan et al (1994). Tabulated *C* values were used in absence of detailed rainfall distribution data. Tabulated *P* values recommended by Renard et al (1997) were used. The slope length factor relates the effect of the slope length on soil loss since there is greater accumulation of runoff on longer lengths and more runoff volume leads to high runoff velocities, thus more soil loss. The slope length factor was calculated using method described by Renard et al (1997). Also, Renard et al (1997) recommend different relationships for determining slope steepness factor depending on the slope length and slope steepness (gradient).

Measured erosion data from nine small watersheds in the US and Lake Victoria micro-watershed of Bukora (Uganda) was used for ground-truthing. The US watersheds used are located at Watkinsville (GA), Coshocton (OH), Chickasha (OK), Tifton (GA), and Riesel (TX).

Determination of sediment yield: Numerous methodologies have been developed to predict sediment transported through riparian buffers (sediment yield). The most prevalent methodology utilizes the concept of sediment delivery ratio (SDR). The models use the universal soil loss equation (Wischmeier and Smith, 1978) or the revised version (Renard at al., 1997) to model erosion on watersheds in conjunction with sediment delivery ratios to determine the sediment delivered from the watershed to water bodies. The sediment delivery ratio (SDR) is thus defined as the ratio of the sediment yield from a watershed to the total erosion generated on the watershed (Barfield et al., 1985).

The sediment delivery ratio models account for most of the on-site factors that influence sediment transport. On-site factors such as water available for overland flow (run-off); texture of eroded material; ground cover; slope shape; slope gradient; slope length; and surface roughness have been recommended by the US Forest Service (1980). The generalized models relating watershed parameters to the SDR include sediment delivery and watershed area relationship (Vanoni, 1975 and USDA SCS, 1979); Modified universal soil Loss equation (Williams and Berndt, 1972) known as MUSLE; particle size and SDR (Walling, 1983); and others (Maner, 1958; Roehl, 1962; Williams, 1977; Mou and Meng, 1980).

US Forestry Services (1980) sediment yield model: The US forest service developed a model to predict sediment delivery ratio from a disturbed land to a stream channel. The methodology allows for determination of sediment delivery ratios for a given design storm in addition to annual estimates. The model is based on an index approach that accounts for seven watershed parameters and a site specific factor that affect sediment transport. The parameters include: (1) surface run-off, (2) texture of eroded material, (3) ground cover, (4) slope shape, (5) slope gradient, (6) delivery distance, and (7) surface roughness. Each of these factors is determined and the stiff diagram is used to account for the relationship between the factors and the SDR in terms of percent area. The runoff factor represents the key sediment transporting agent of surface flow. Incase the surface runoff is greater than 0.1 cfs, the maximum scale factor of 0.1 is used (Figure 3.1). The texture of the eroded material is expressed as a percent of the soil texture that is greater than 0.5 mm. Sum of percent silt and percent clay of the eroded material is used. In case of detailed soil textural data, the sum of percent very fine sand, percent silt and half percent clay is used since part of clay acts as aggregate cement. The ground cover factor represents the percent of ground cover in actual contact with the soil. A bare soil is indicated by zero percent while a completely covered surface is indicated by 100 percent. The slope gradient factor is the slope of the riparian zone between the sediment producing area and the receiving water way. A slope shape of 0 represents a convex slope, 2 represent a uniform slope and 4 represents a concave slope. Surface roughness within the riparian zone is a subjective factor where an indicator of 0 represents a smooth surface, and 4 represent a rough surface. The delivery distance is the logarithm of the distance in feet from the boundary of the disturbed land to the receiving waters.

Once each parametric indicator is estimated and entered into stiff diagram (Figure 3.1), a line is drawn to connect the points yielding an irregular polygon. The area inside the polygon is determined and expressed as a percent of the total area of stiff diagram1. The sediment delivery ratio is calculated by entering the percent area obtained from stiff diagram into a logistic – probit graph shown in Figure 3.1.

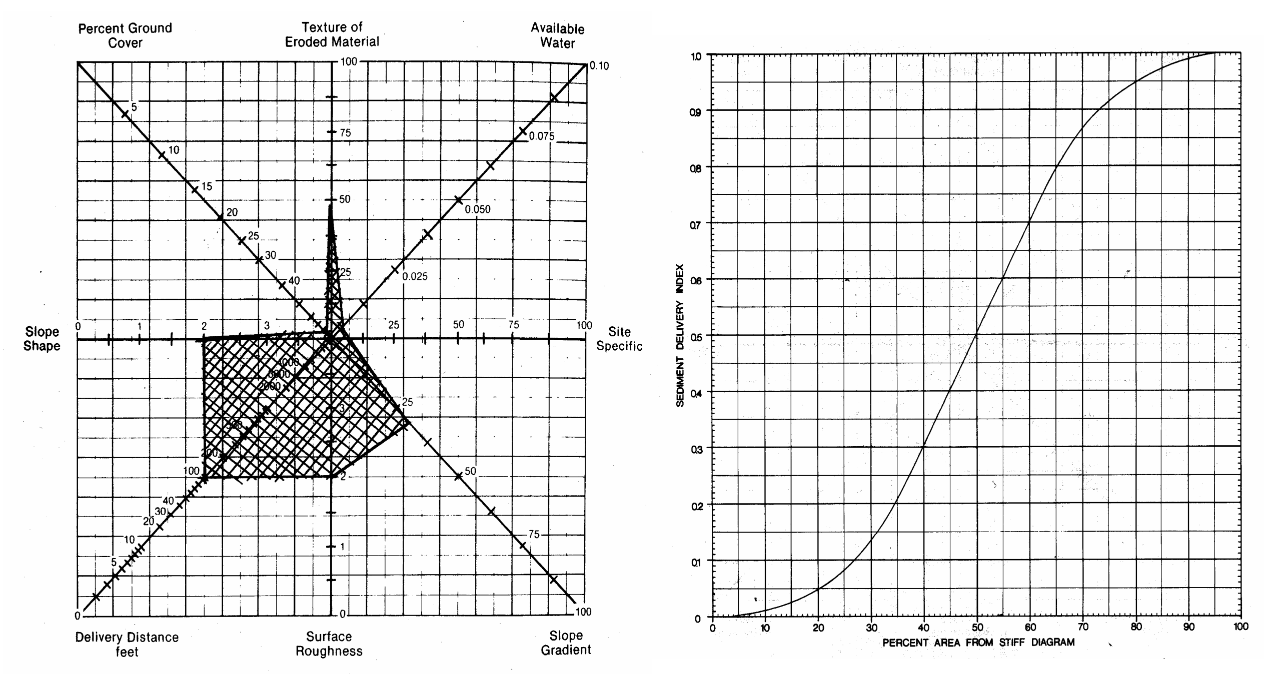

Figure 3.1: Stiff diagram and logistic probit function for determining the SDR

Methods and materials

The coordinates of Watkinsville P1 watershed were obtained by the use of a Gamin handheld GPS unit. Coordinates of other watersheds were obtained from literature and the WEPP validation data (Liu et al., 1997). Using Google ™ Earth Pro and site coordinates, the watersheds were located. The watershed delineations were confirmed by reference to the size and shape of the micro-watersheds from literature. This was necessary because some of the coordinates listed in WEPP validation data were slightly off the watershed site. Using Google ™ Earth Pro, a grid was overlaid over the site image (Google ™ Earth Pro allows for this operation) and grid size determined by zooming in and out. Coordinates and elevation values at each grid point were recorded.

Surfer 7.0 a three dimensional (3D) modeling software was used to generate a vector diagram depicting runoff flow direction, site contour map, and a three dimensional representation of the watershed. The 3D representation was used to determine the shape of the slope. The generated vector map was overlaid over the Google ™ Earth Pro image to define the probable runoff flow direction over the watershed. The flow length was defined as the longest flow path depicted by the vector direction. The map overlay was used concurrently with the Google ™ Earth Pro measure tool to estimate the slope length and the slope gradient. Figures 3.2, Figure 3.3, and Figure 3.4 demonstrate the process to determine the slope length, and slope gradient for the disturbed land and slope gradient, slope shape, and delivery distance for the buffer zone. In figure 3.3, vectors with longer arrows indicate a steeper slope thus runoff from such areas can influence the direction of runoff from less steeper slopes assuming the runoff volume is the same.

Figure 3.2: Google [TM] Earth Pro Image at Sergoit bridge site with site photos

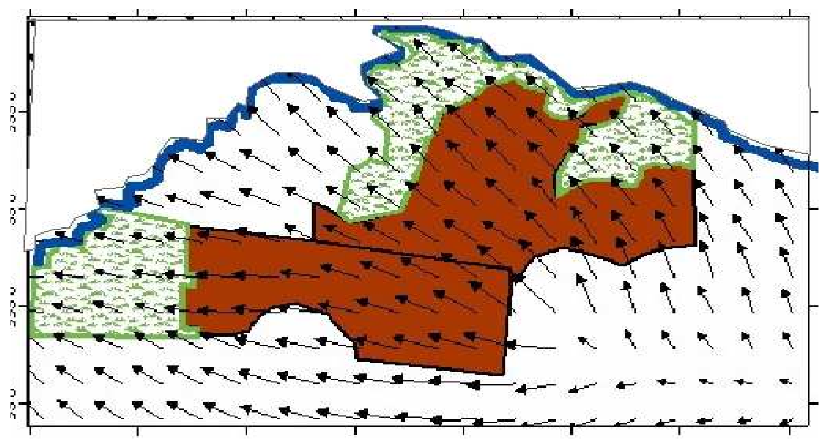

Figure 3.3: Sergoit site vector diagram showing the run-off flow direction developed using Surfer software

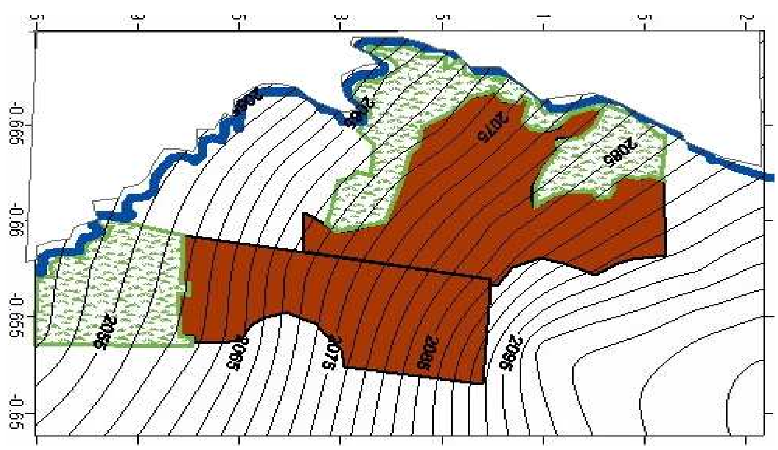

Figure 3.4: Sergoit site contour map generated by Surfer software

The above approach was used to determine the length and slope values used in calculation of the USLE length and slope factors. The annual rainfall data collected at the respective watershed was used to estimate the rainfall erosivity factor. The Natural Resources Conservation Services (NRCS) web soil survey was used to determine the soil erodibility factor for US watersheds. For other watersheds, soil data from earlier studies was used. Land use and land cover description during the measured data time period was used to estimate the cover management and support practice factors.

Validation of the USFS (1980): Research work by Sheridan et al (1998) at Gibbs farm site located near the University of Georgia coastal plain experimental station at Tifton was used to validate the USFS (1980). The study by Sheridan et al (1998) established the effectiveness of different riparian forest management practices recommended by the US Department of Agriculture (USDA) forest service. Using Google ™ Earth Pro the current site image was demarcated into the original three buffer zones (Figure 3.5). The respective topographic parameters were measured. Focus was put on three riparian zones; (1) grass filter, (2) mature forest, and (3) selectively thinned forest. The runoff parameter was calculated as the peak runoff rate using the runoff volume collected at the end of each riparian buffer and the respective time of concentration.

$$q_p = \frac{runoff\_Volume}{T_c + T_r} \tag{2}$$

Where

q_p = peak runoff rate (Cfs)

T_c = time of concentration (min) determined by the Kirpich method (Tollner,2002)

T_r = the recession time (min) given as 3.33Tc.

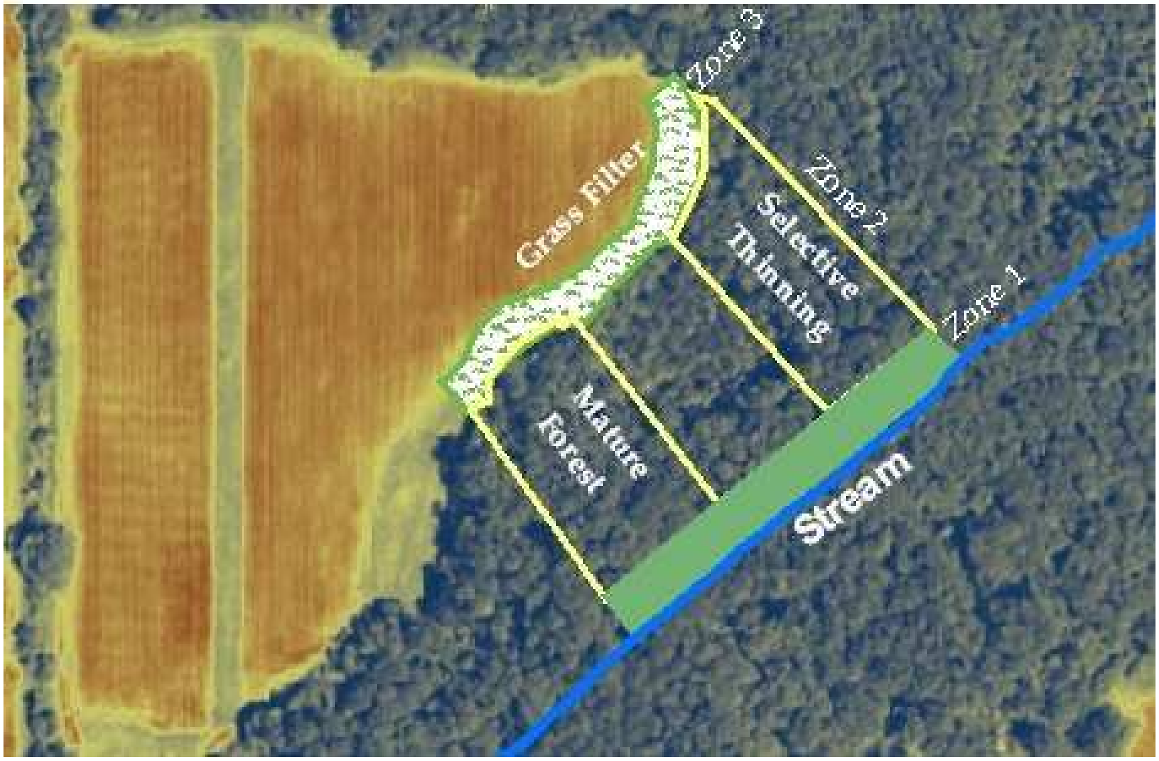

Figure 3.5: Google ™ Earth Pro Gibbs farm site image

Results and discussion

Paired t – test: The paired t-test comparison between GPS elevation and Google ™ Earth Pro derived elevations (Table 3.1) showed no significant statistical difference between the elevations for Moiben watershed (Table 3.2). However the paired t – test results showed significant statistical difference between elevations at Watkinsville with 2.6 m as the mean of the differences (Table 3.2). Though the error margin is within the GPS unit's error margin of 5 meters, the results are counterintuitive. The Watkinsville GPS and Google ™ Earth Pro elevations were expected to have no significant difference compared to the Moiben elevations. This observation can in part be attributed to the satellite coverage and difference of GPS units used. Therefore the Google ™ Earth Pro derived elevations at the sites had the same level of accuracy depicted by the GPS unit. Table 3.6 compares the referenced watershed area and slope to Google ™ Earth Pro derived values. The area values are exact to the first decimal point showing a high level of accuracy for area measurement using Google ™ Earth Pro. Most of the slope values are within the referenced range with some values slightly off. The elevation paired t test results and comparison of watershed area and slope values provided a level of confidence to use the Google ™ Earth Pro derived topographic parameters.

Table 3.1: GPS and Google ™ Earth Pro elevations for two watersheds

Moiben watershed elevation values		**Watkinsville P1 watershed Elevations**	
GPS derived values (m)	**Google ™ Earth Pro derived values (m)**	**GPS derived values (m)**	**Google ™ Earth Pro derived values (m)**
2065	2064	237	234
2057	2067	233	231
1989	1994	232	231
1981	1989	234	231
1866	1864	235	231
1865	1865	237	233
1899	1899	238	234
1919	1927	237	235
1943	1942	240	236
1994	1983	236	236
2012	2005	235	234
2003	2001		
2289	2270		
2150	2175		

Table 3.2: Paired t – test results for elevations

Group parameter	Moiben watershed elevation values		Watkinsville P1 watershed Elevations	
	GPS derived values (m)	Google ™ Earth Pro derived values (m)	GPS derived values (m)	Google ™ Earth Pro derived values (m)
Mean	2002	2003	236	233
Standard deviation	114.45	113.7	2.3	2.0
Standard error of measurement	30.6	30.34	0.7	0.6
Data points	14	14	11	11
Two-tailed *P* value	0.7437		0.0002	
Mean of group differences	-0.9		2.6	
95% confidence interval of the difference	-6.9 – 5.1		1.6 – 3.5	
t – value	0.334		5.86	
Standard error of difference	2.8		0.43	
Comment	Difference is not statistically significant		Difference is statistically significant	

*Ground truthing results: Erosion prediction***.** The ground truth results obtained from measured data for ten small watersheds (Table 3.5) compared to the predicted values yielded mean absolute errors (MAE) of 0.76 tons ha^{-1} yr^{-1} with a coefficient of determination R^2 of 0.95 (refer to Figure 3.6). The proximity of the coefficient of determination to one was attributed to the readily available data at the respective sites and high resolution images that allowed for accurate site assessment using the USLE model. One can argue that the accuracy of two high erosion values at Watkinsville P1 watershed under conventional tillage and at Bukora micro-watershed offset the low accuracy of the other eight watersheds resulting into a high R^2 value for the entire dataset. This was addressed by correlating predicted and measured soil erosion for watersheds with erosion magnitudes less than 10 tons per hectare per year. The mean absolute error of 0.91 tons ha^{-1} yr^{-1} and coefficient of determination of 0.53 fitted datasets of watersheds with erosion values below 10 tons ha^{-1} yr^{-1}. In regard to the field of application of the tools described in this study, the MAE and R^2 values are acceptable because the predicted and measured data had the same order of magnitude. It's important to note that the overall application of the USLE model, Google ™ Earth Pro, and USFS – SDR model is the determination of erosion severity at different sites. Therefore, the point of interest is the order of magnitude for the predicted and the measured data. From Table 3.5, the predicted and measured soil erosion magnitudes have the same soil erosion class as classified by Šúri et al (2002), refer to Table 3.7.

It's worth noting that the resolution of the satellite images is poor in some areas such that watershed delineation is impossible. For example, data from three watersheds of WC-1, WC-2, and WC-3 of Holly springs, Mississippi could not be used for ground truthing due to the low and poor satellite image resolution.

Ground truthing results: Sediment yield. Table 3.1 shows the stiff diagram parameters used to estimate sediment yield through the grass filter, mature forest, and the selectively thinned forest at the Gibbs farm site. Table 3.4 compares the measured and estimated sediment delivery ratios for the three buffers respectively. From Table 3.4 results, the USFS (1980) method over estimates the amount of sediment trapped within the riparian buffers. This observation can be attributed to the fact that the approach does not account for channelization and assumes no erosion within the buffer zone. The effectiveness of the riparian buffers will be reduced depending on the level of channelization. As expected, the method estimates more sediment trapping within the mature forest compared to the selectively thinned forest. The approach underestimated the performance of grass filters compared to forested buffers. This underperformance of the model on grass filters was expected since it was originally developed for use with forested riparian buffer systems.

Table 3.3: Parameters for estimating Sediment Yield at the Gibbs farm site

Parameter	Grass Filter	Mature Forest	Selective thinning
Percent ground cover (%)	100	90	60
Texture of eroded material (%)	33	34	34
Runoff (Cfs)[2]	0.55	3.04	2.97
Slope shape	2	2	2
Delivery Distance(feet)	26	180	180
Surface Roughness	2	2	2
Slope gradient (%)	2.6	3.8	3.8

Table 3.4: Sediment delivery ratio (SDR) at Gibbs farm site

	Measured SDR	Predicted SDR
Grass filter	0.134	0.025
Mature forest	0.284	0.018
Selectively thinned forest	0.508	0.021

[2] If Runoff (Cfs) exceeds the maximum value of 0.1, use 0.1 Cfs

Table 3.5: Estimated and measured Erosion

Watershed	Latitude (Degrees)	Longitude (Degrees)	Area (ha)	Record years (number of years)	Average annual rainfall (mm)	Measured soil loss[3] (tons / ha-yr)	Predicted soil loss[3] (tons / ha-yr)
Chickasha-Oklahoma, C-5 watershed	35.0333333	-97.9091667	5.14	1971 – 1974 (4)	776.5	1.2 (L)	1.1 (L)
Coshocton-Ohio, 109 watershed	40.3697222	-81.7941667	0.68	1979 - 1989 (11)	976.7	0.3 (VL)	0.6 (VL)
Tifton-Georgia, TZ watershed	31.4750000	-83.5319444	0.34	1969 – 1986 (4)	1205.4	1.1 (L)	1.8 (L)
Riesel-Texas, W-12 watershed	31.4655556	-96.8852778	4.01	1974 – 1974 (4)	1026.5	2.6 (L)	3.5 (L)
Riesel-Texas, W-13 watershed	31.4658333	-96.8855556	4.57	1975 – 1974 (4)	1026.5	1.8 (L)	1.6 (L)
Watkinsville P1 conventional tillage	33.8876140	-83.4203650	2.71	1972 - 1974 (2.5)	1093.6	23.3 (H)	24.7 (H)
Watkinsville P1 conservation tillage	33.8876140	-83.4203650	2.71	1976 - 2000 (24)	1210.0	1.0 (L)	2.2 (L)
Watkinsville P2, Georgia	33.88472222	-83.42722222	1.29	1973 – 1975 (3)	1434.0	6.1(L)	6.5 (L)
Watkinsville P3, Georgia	33.86888889	-83.45277778	1.26	1972 - 1982 (11)	1247.0	1.1 (L)	4.0 (L)
Watkinsville P4, Georgia	33.87000000	-83.45277778	1.40	1973 - 1981 (10)	1325.0	0.8 (L)	2.5 (L)
Bukora watershed (Uganda), perennials mixed with annuals	-0.850000	31.483300	…	1997 - 2002 (5)	1250.0	27.4 (H)	23.5 (H)

[3] Class of soil erosion. VL – Very Low, L – Low, H – High. Refer to Table 3.7 for detailed classification.

Table 3.6: Google ™ Earth Pro derived area and slope data

Watershed	Watershed area (ha)	Google ™ Earth Pro derived Area (ha)	Slope (%)	Google ™ Earth Pro derived slope (%)
Chickasha-Oklahoma, C-5 watershed	5.14	5.16	0.5 - 1	2.90
Coshocton-Ohio, 109 watershed	0.68	0.68	9 - 15.6	5.66
Tifton-Georgia, TZ watershed	0.34	0.34	3.6	2.86
Riesel-Texas, W-12 watershed	4.01	4.01	1 - 2.7	1.54
Riesel-Texas, W-13 watershed	4.57	4.57	1.3	0.70
Watkinsville P1 conventional tillage	2.70	2.70	2.0 - 7.0	2.90
Watkinsville P1 24 yr conservation tillage	2.70	2.70	2.0 - 7.1	2.90
Watkinsville P2, Georgia	1.29	1.30	1.6 - 4.5	1.86
Watkinsville P3, Georgia	1.26	1.26	3	1.85
Watkinsville P4, Georgia	1.40	1.41	3	1.80

Table 3.7: Soil erosion ranges and the corresponding soil erosion class

Annual soil erosion	Level of erosion severity
0 – 0.7	None or Very low
0.8 – 7.5	Low
22.6 – 75	High
75.1 – 300	Very high
300.1 – 900	Extreme
> 900	Catastrophic

Source: Šúri et al (2002)

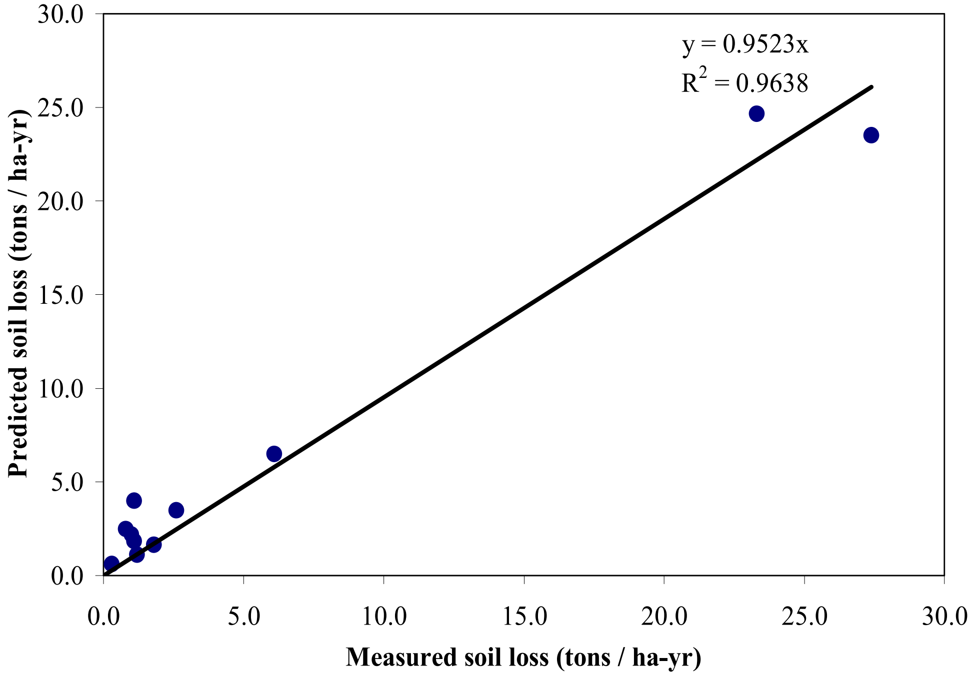

Figure 3.6: Graph of measured against Predicted soil loss for entire data

Selected site results within the Nzoia Basin: The Sergoit and Moore bridge sites were analyzed for erosion in Nzoia Basin. The sites are characterized by shrubs, rangeland, forests, and cultivated land. The main crops grown are corn, wheat, and sunflower with corn covering about 80% of the cultivated land. The predicted average soil loss at Moore's bridge site is 192 tons ha^{-1} yr^{-1} with a stream sediment yield of 1.8 tons ha^{-1} yr^{-1} (Table 3.8) while at Sergoit site is 5.3 tons ha^{-1} yr^{-1} with a stream sediment yield of 0.05 tons ha^{-1} yr^{-1} (Table 3.9). The erosion level at Moore's bridge site is severe though the sediment yield is low. The low sediment yield is attributed to the riparian buffer. Further encroachment into the buffer zone will yield high stream sediment yield. The high soil loss at Moore site is attributed to greater rainfall erosivity and high slope of 5% compared to 1.6% at Sergoit.

There are miles of streams placed on the USEPA 303d impaired streams list in Georgia US in part due to sediment impairments since sediment is the leading pollutant in terms of pollutant mass. The methodology can be integrated with Total maximum daily load (TMDL) tools to carry out TMDL related assessment in Georgia, US, and other countries.

Table 3.8: Moore bridge site analysis results

Plot	Erosion (tons / ha yr)	Sediment delivery index (SDR)	Sediment yield (tons / ha yr)
1	97	0.015	1.455
2	320	0.007	2.240
3	171	0.010	1.710
Average	196	0.011	1.802

Table 3.9: Sergoit bridge site analysis results

Plot	Erosion (tons / ha yr)	Sediment delivery index (SDR)	Sediment yield (tons / ha yr)
1	7.8	0.008	0.0624
2	2.7	0.010	0.0270
Average	5.3	0.009	0.0447

To improve the performance of the USFS (1980) stiff diagram model, there is a need to integrate the concept of channelization into the model. This can be achieved by envisaging the mechanisms and processes that influence the transformation of flow from sheet overland flow into channelized flow based on the ground cover, elevation, and soil type. The generated index to account for channelization can then be added to the SDR value. The combination of Google ™ Earth Pro, sediment prediction, and riparian buffer evaluation may enable the needed fine grained approach to setting workable setbacks that account for parameters affecting erosion and sedimentation compared to the coarse grained approach of dictating "a legislated single value setback". Assigning a single riparian buffer width overlooks the differences in sediment transport mechanics caused by difference in watershed characteristics. This combination of tools may be very useful for assessing areas for receiving agricultural wastes such as poultry liter as part of a comprehensive nutrient management planning. Thus, this work has much promise for Georgia and the US agriculture as well as for the developing countries.

Conclusions

Google™ Earth Pro was proven to be scientifically useful to define watershed and site characteristics in the U.S. and Kenya. Elevation differences within the Global Position System were within the margin of error ($\pm$5 meters). Google™ derived slopes were determined to within the referenced data range and Google™ derived areas were accurately estimated to the first decimal. An extensive analysis of the components of the Universal Soil Loss Equation and the US Forest Service sediment delivery ratio method was made. The ground truth results obtained from measured data for ten small watersheds (Table 3.5) compared to the predicted values yielded mean absolute errors (MAE) of 0.76 tons ha^{-1} yr^{-1} with a coefficient of determination R^2 of 0.95 (refer to Figure 3.6). The soil loss at Moore site of 192 tons ha^{-1} yr^{-1} is severe while at Sergoit site is low (5.3 tons ha^{-1} yr^{-1}). However, the sediment yield at both sites is low in the magnitudes of 1.8 and 0.05 tons ha^{-1} yr^{-1}. This depicts the effectiveness of the riparian buffers. Therefore, the buffers should be protected from future encroachment. However, the USFS (1980) method over estimated the amount of sediment trapped within the riparian buffers. This confirms earlier work by Kinnell (2004) which suggest that sediment delivery ratios are not the best methods to estimate sediment delivery because they do not vary independently of erosion. The sediment delivery ratios remain constant irrespective of upslope erosion. To improve the performance of the USFS (1980) stiff diagram model, there is a need to integrate the concept of channelization into the model. This can be achieved by envisaging the mechanisms and processes that influence the transformation of flow from sheet overland flow into channelized flow based on the ground cover, elevation, and soil type. Using Google ™ Earth Pro, the USLE model coupled with the US Forest Service sediment delivery ratio method, it was determined that topography could be mapped and predictions of erosion and sediment yield made possible. Thus the study stretched the applications of Google ™ Earth Pro from a location search and 3D Earth observatory tool to a remote sensing tool useful in extracting micro-watershed topographic parameters. Also, the study established an approach that integrates Google ™ Earth Pro derived elevations and Surfer ® 7.0 3D modeling software to estimate the slope length used in estimation of USLE slope length and slope steepness factors.

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4 INTEGRATION OF GIS, REMOTE SENSING AND USLE TO ESTIMATE SOIL EROSION SUSCEPTIBILITY IN NZOIA BASIN (KENYA) [4].

[4] Ssegane H, T. Jordan and E. W. Tollner. To be submitted to *Transactions of the ASABE*

Integration of GIS, Remote Sensing and USLE to estimate Soil Erosion susceptibility in Nzoia Basin (Kenya).

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Abstract.

The study describes the application of the universal soil loss equation model, to quantify soil erosion in Nzoia Basin located entirely on the Kenyan side of Lake Victoria Basin using the geographic information service, remote sensing, and global positioning service technologies. The approach adopted involved calculation of six universal soil loss equation factors inform of distributed remote sensing and geographic information system data layers using arcGIS (arcMap) software. The data included spatial raster layers of soil, land cover, rainfall and digital elevation models ranging from 30 m to 1000 m spatial resolutions to adequately represent the surface characteristics. The soil erosion distribution map was generated as a product of the six raster layers using the spatial analyst tool in arcMap. Even with continental scale spatial resolutions, the predicted erosion levels had the same order of magnitude as predictions made with site specific parameters utilizing Google ™ Earth Pro. For a site at Moore's bridge along the Moiben sub-watershed the predicted erosion levels ranged between 31 – 51 tons $ha^{-1}yr^{-1}$ compared to the value of 97.2 tons $ha^{-1}yr^{-1}$ obtained using USLE and Google ™ Earth Pro. To improve the accuracy levels, use of recent land cover and land use data plus use of smaller variation of the data spatial resolution was recommended.

KEYWORDS: Erosion, Remote sensing, Geographic information systems, USLE.

Introduction

The soil erosion process is a complex phenomena determined by joint interaction of climatic, geological, and land use and land cover factors. The spatial extent and severity of environmental risk of this process can be analyzed on global, continental, and regional scales. Oldeman (1994) estimated that the global land area affected by water erosion was about 1094 x 10^6 hectares and on the continental scale, the problem being more severe in Asia, Africa, South America, and Europe in a descending order. The environmental risk posed by soil erosion is related to pollution activities due to runoff from agricultural lands, urban areas, construction sites, and industrial sites that introduce sediment, nutrients, bacteria, organic wastes, chemicals, and metals into surface waters. The economic implications of sedimentation of surface waters are due to increase in the cost of water purification, hydropower generation, increased flood risk (Hansen et al., 1999) and reduction in the productivity of the fishery industry. The fishing industry is greatly affected because sediment clogs and scrapes fish gills, suffocates fish eggs and aquatic insect larvae, and causes fish to modify feeding and reproductive behaviors (Blankenship, 2005).

One of the affected water bodies is Lake Victoria, the second largest source of fresh surface water. Lake Victoria Basin is a source of livelihood to the populace of Kenya, Uganda, and Tanzania given that it's a source of drinking and irrigation water, food, energy, and transport. Development activities, nutrient discharge, and population growth (3% on the Kenyan side) have caused changes in the lake's ecosystem leading to massive flourishing of algae and the water hyacinth (LVEMP, 1995). Studies indicate that the dramatic changes in the lake's water quality and fisheries have arisen from introduction of the exotic Nile Perch and human activities. The changes due to human activities are directly related to the nutrient enriched sediment that is discharged into the lake. Studies carried out by Sangale et al (2001) and Okungu and Opango

(2001) show that river Nzoia contributes the most sediment loading to Lake Victoria from the Kenyan catchment mainly because of its high discharge of 118 m^3/s.

<u>*The Nzoia river Basin*</u>*:* Nzoia Basin is entirely found in Kenya and is located between latitudes 1^0 30' N and 0^0 05' S and longitudes 34 ^{0} E and 35^0 45' E. The river Basin covers an area of 12,842 Km^2 and drains through several districts (government boundaries) on its way to Lake Victoria. These include Uasin Gishu and Trans Nzoia Districts in the Rift Valley Province, Mt. Elgon, Lugari, Teso, Bungoma, Kakamega, Butere-Mumias and Busia Districts in Western Province, and Siaya District- Nyanza Province (NRBMI, 2006). The total river line is 355 km long (the main river is about 225 Km) with a mean discharge of 118 m^3 s^{-1}. The river originates from Cherengany Hills and Mt Elgon at 4320 meters above sea level and is fed by several rivers. On the course to Lake Victoria the river drains through small and large-scale maize and wheat farms, coffee plantations, a paper factory and Sugar factories. The river greatly contributes to the periodic flooding of the Budalangi floodplains because of heavy silt it carries from the deforested upper catchment areas (NRBMI, 2006).

Figure 4.1: location of Lake Victoria and Nzoia Basin

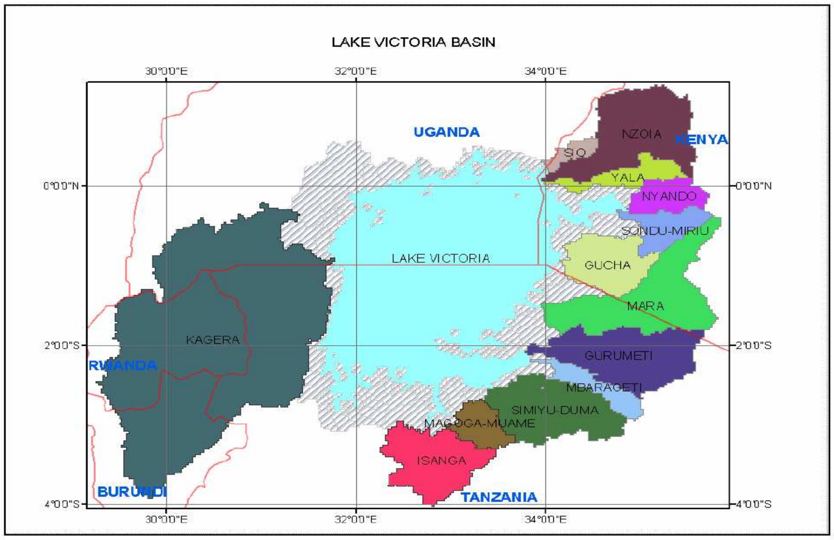

Figure 4.2: Lake Victoria Basins

According to Köppen's classification (McKnight et al., 2000), the climate of Nzoia Basin is mainly tropical humid and therefore its characterized by the tropical dry and wet type of climate. According to NRBMI (2006), the temperature varies from 16 ^{0}C in the highland areas of Cherangani and Mount Elgon to 28 ^{0}C in the lower semi-arid areas. The mean annual night temperatures vary between 4 ^{0}C in the highland areas to 16 ^{0}C in the semi-arid areas. The mean annual rainfall varies from a maximum of 1100 to 2700 mm to a minimum of 600 to 1100 mm while the humidity varies from 70 to 85 %. The Basin experiences four seasons in a year influenced by the Inter-Tropical Convergence Zone. The four seasons consist of two rainy and two dry seasons. The rainy seasons are characterized by short rains from October to December and long rains from March to May. The dry seasons are experienced in the months of January to February, and June to September. The variations in the seasonality are greatly influenced by Lake Victoria's climatology. The topography of the Basin is characterized by high western slopes of Chengani Hills and south eastern parts of Mount Elgon at mean elevation of about 2300 m above sea level and lower elevations as it drains into Lake Victoria at an elevation of about 1000 m. The soils of the floodplains in the lower of the Nzoia River are of alluvial type. The major parts of the river contain black cotton soils while other areas have coarse textured sand – silt mixture. The Basin's climatology, topography, and soils encouraged the sprouting of an intensive agricultural and agro-industrial sector that has encroached onto the riparian zones and wetlands.

As a control measure to reduce the amount of sediment deposition into the lake, the respective East African countries in collaboration with US agency for international aid (USAID) and aquaculture CRSP are encouraging the conservation and restoration of riparian buffers as part of an integrated natural resources management practice. Forested riparian zones and vegetative filter strips reduce sediment movement from agricultural land by intercepting flow, reducing the flow velocity, increasing the retention time, and accordingly decreasing the sediment delivery to the surface water bodies (Travis, 2003). All areas under the threat of soil erosion cannot be conserved at once due to financial and human resource constraints. Thus attention is focused on prioritizing sediment hotspots. The availability of continental and regional scale data in form of satellite images and global positioning system (GPS), as well as the new methodological approaches like remote sensing, integrated into geographical information systems (GIS) allow to model soil erosion distribution. Thus, for a given watershed sediment hotspots are identified and targeted for conservation practices and monitoring purposes. Therefore, this study set out to generate erosion map depicting the soil erosion distribution for the Nzoia River Basin using GIS and Remote sensing data.

Methods and materials

The assessment of erosion potential in Nzoia river Basin was based on the universal soil loss equation (USLE) model (Wischmeier and Smith, 1978). USLE quantifies soil erosion as the product of six factors representing rainfall and runoff erosiveness, soil erodibility, slope length, slope steepness, cover – management practices, and support conservation practices. The USLE is an empirical relationship expressed by equation 1;

$$A = RKSLCP \tag{1}$$

Where

A = Average Annual Soil loss in (tons acre^{-1} or Mg hectare^{-1})

R = Rainfall –Runoff erosive index factor in (MJ mm ha^{-1}hr^{-1}yr^{-1})

K = Soil erodibility factor (ton ha hr ha^{-1}MJ^{-1}mm^{-1})

S = Slope steepness factor (dimensionless)

L = Slope Length factor (dimensionless)

C = Crop-Management factor (dimensionless)

P = Conservation Practice factor (dimensionless)

Each factor is calculated independently and the derived product of the six factors is the average annual soil loss in tons/acre or Mg/hectare. The USLE model only predicts soil loss due to rill and sheet erosion. Neither does it predict erosion due to gullies nor sediment deposition within riparian buffers.

Data sources: Digital Elevation Model (DEM). The DEM data was obtained from the Global land covers facility (GLCF). The DEM data is under the shuttle radar and thematic mapper (SRTM) data category. The DEM data has a spatial resolution of 90 m and is available for all world regions. The data can be accessed through the website link below; http://glcfapp.umiacs.umd.edu:8080/esdi/index.jsp

Data sources: Land Use and Land Cover. The US Geological Survey (USGS) provides global land cover data. The data is available on continental scale with a spatial resolution of one kilometer. The data can be accessed through the website link below;

http://edcdaac.usgs.gov/glcc/glcc.html

Data sources: Soils Data. The soils data was accessed in a binary format from the north oceanic and atmospheric administration (NOAA) at a spatial resolution of 0.0833 arc degrees. The data can be accessed through the website link below;

http://www.ngdc.noaa.gov/seg/cdroms/reynolds/reynolds/reynolds.htm

Data sources: Annual Rainfall data. The rainfall data for Kenya was obtained from flood early warning system (FEWS), a program developed jointly by the USGS and USAID. The data can be accessed through the website link below; *http://edcinti.cr.usgs.gov/fewsnetdata.html*

Data sources: Nzoia river Basin outline. The Nzoia river Basin is classified as a level 6 under the Pfafstetter coding for African Basins. The data can be accessed through the FEWS network under the Hydro 1 Km dataset: The data can be accessed through the website link below; http://edc.usgs.gov/products/elevation/gtopo30/hydro/africa.html

Data sources: Nzoia river line. The Nzoia river line was obtained from the FEWS network under the Hydro 1 Km dataset.

http://edc.usgs.gov/products/elevation/gtopo30/hydro/africa.html

Data preparation: The Shuttle Radar Transmitter Mission (SRTM) DEM data is available by grid. The four grids covering the study area were mosaiced using ERDAS IMAGINE remote sensing program. The FAO soils map data from the north oceanic and atmospheric administration (NOAA) server is provided as a binary dataset. The dataset was imported into the ERDAS IMAGINE and saved as an image. The rainfall data was summarized for 102 Kenyan gauge stations with their respective latitude and longitude coordinates. The average rainfall amount ranging from 4 to 102 years was calculated and tabulated. From the

African level 6 Basins, the Nzoia Basin was clipped as a level three Basin for subsequent use as a sub-setting polygon. Figure 4.3 represents the process of deriving USLE layer maps from raw spatial data and the respective map calculations used to generate the soil erosion distribution map.

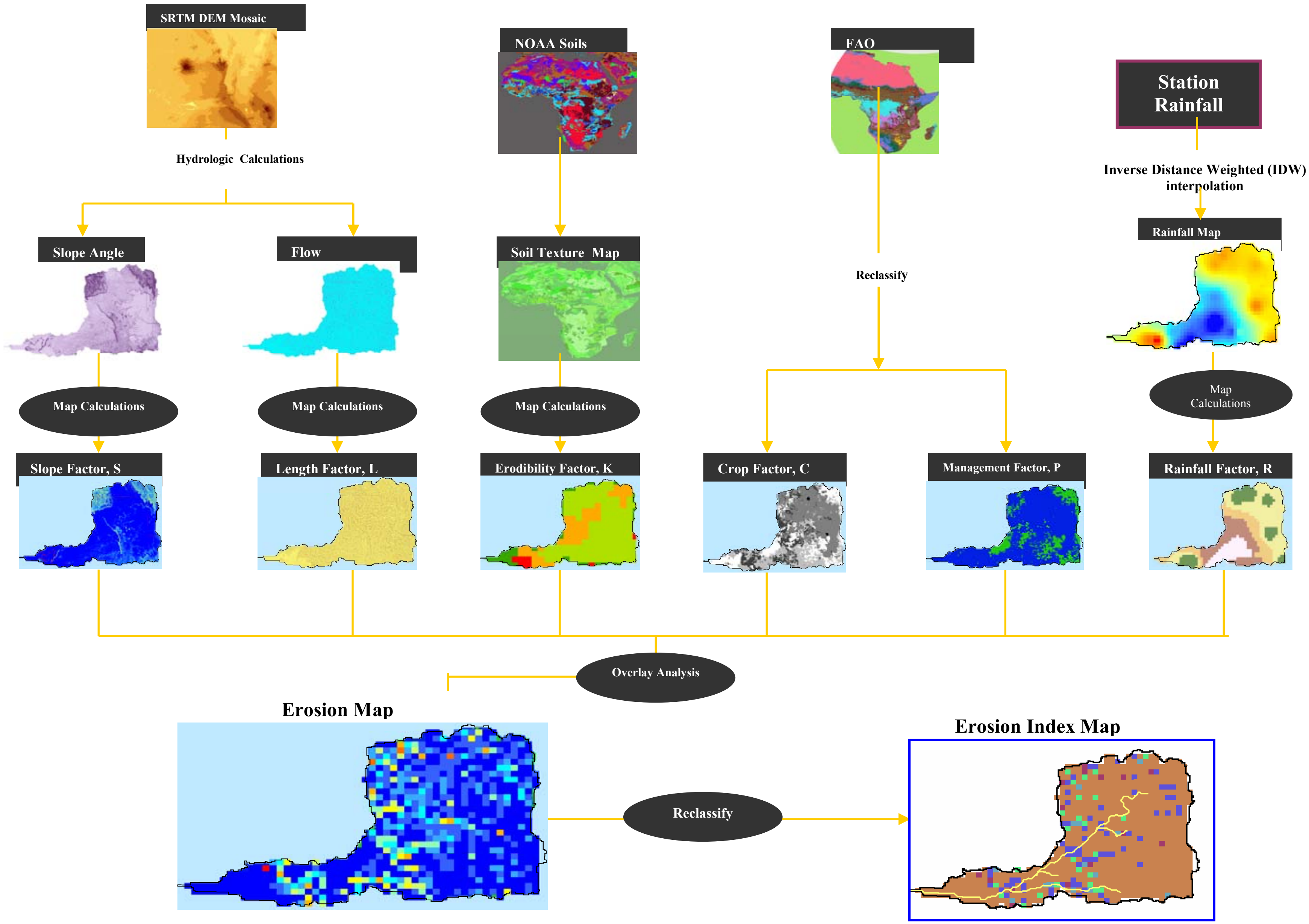

Figure 4.3: GIS erosion prediction flow chart

Generation of the thematic map layers

Rainfall erosivity (R factor): The rainfall factor quantifies the interrelated erosive forces of rainfall and runoff that are direct results of the rainstorms. It's an annual factor that represents all the erosive rains throughout the year and it's based on the rainfall energy and intensity values. However due to the limited availability of rainfall intensity data, model used to predict rainfall-runoff erosivity was developed by Renard and Freimund (1994) by regressing annual precipitation and the R values for 155 stations in the United States. The empirical relationship is given by equation 2.

$$R = \begin{cases} 0.0483P^{1.610}, & P \leq 850mm \\ 587.8 - 1.249P + 0.004105P^2, & P > 850mm \end{cases} \quad (2)$$

Where

R = rainfall erosivity (MJ mm / ha hr yr), and

P = annual precipitation in mm

The Renard and Freimund (1994) equation approximates the *R* values for most East African areas due to the similarity in the rainfall energy of US and most East African regions (Moore, 1979).

The annual precipitation was obtained by summarizing data from 102 stations in Kenya ranging from 4 to 102 years of rainfall data. A point feature was created for Kenya with the respective station geographical coordinates using arcMap. From the point feature map, a rainfall raster map was created using inverse distance weighted (IDW) interpolation method. The *R* raster layer (Figure 4.5) was then generated using the spatial analyst tool of arcGIS / arcMap with the math and map algebra tools.

Soil erodibility (K factor): The soil erodibility factor estimates the long term soil and soil profile response to the rainfall and runoff erosive forces. It relates the susceptibility of the soil to erode with respect to its inherent physical properties. According to Renard et al (1997), the K factor is determined using soil properties of soil texture, soil structure, soil permeability, and the soil organic matter content.

For this study due to absence of the soil permeability and soil structure data, the global erodibility equation recommended by Torri et al (1997) was used. Equation 3 expresses the global erodibility equation:

$$K = 0.0293\left(0.65 - D_g + 0.24 D_g^{\,2}\right)\exp\left\{-0.0021\frac{OM}{f_{clay}} - 0.00037\left(\frac{OM}{f_{clay}}\right)^2 - 4.02 f_{clay} + 1.72 f_{clay}^{\,2}\right\}$$

$$D_g = -3.5 f_{clay} - 2.0 f_{silt} - 0.5 f_{sand} \qquad (3)$$

Where

K = soil erodibility (ton ha hr ha^{-1}MJ^{-1}mm^{-1})

OM = percent organic matter

f_{sand} = sand fraction

f_{silt} = silt fraction

f_{clay} = clay fraction

D_g = the geometric mean of particle size

The data used was developed by Reynolds et al (1999). Reynolds et al (1999) explains the procedure used to extract soil properties for the FAO soil units by utilizing statistical analyses and taxo-transfer depth algorithms. The representative soil properties were estimated for two-layers of depths (0-30 and 30-100 cm). For this study the top layers of 0 to 30 cm shown in Figure 4.4 were used to generate the soil erodibility map (Figure 4.6).

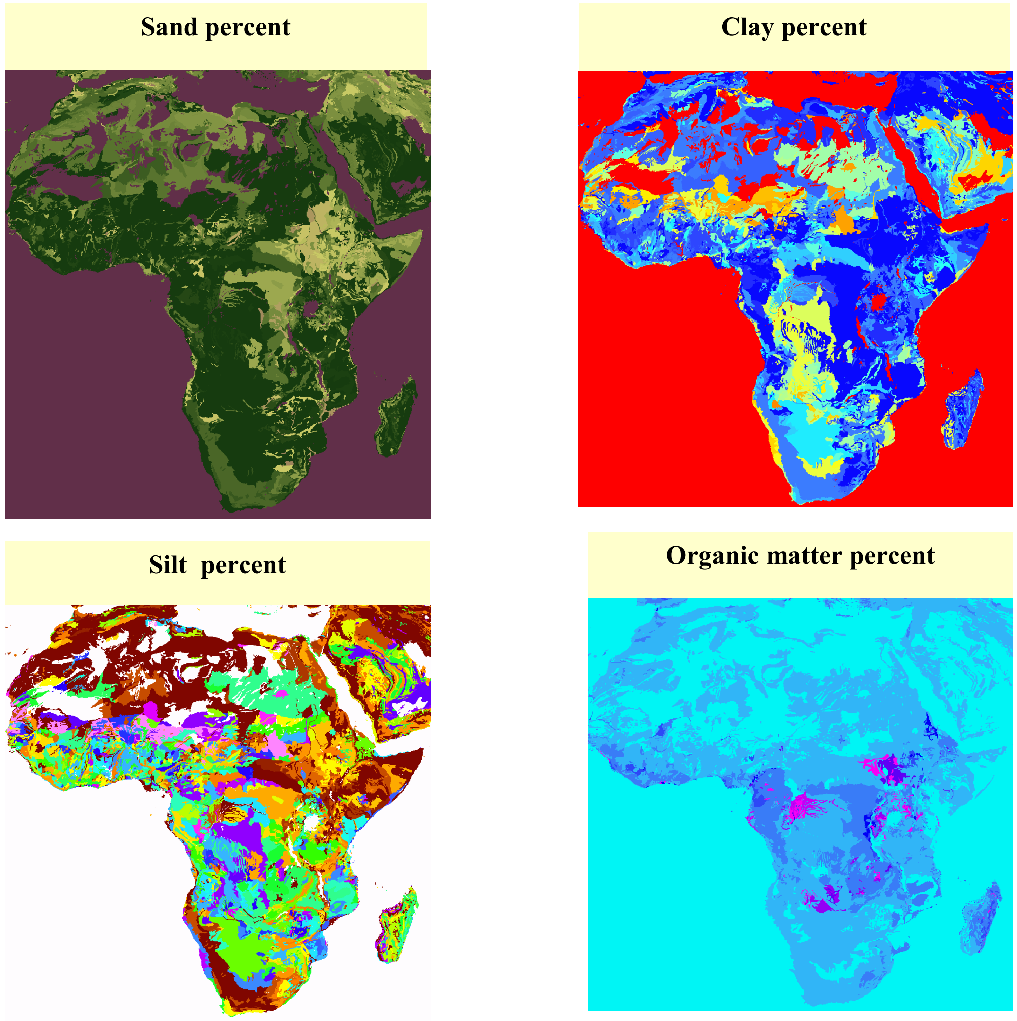

Figure 4.4: Maps depicting the African soil properties extracted from the NOAA server

The Slope Length (L factor): The slope length factor relates the effect of the slope length on soil loss because there is greater accumulation of runoff on longer lengths and more runoff volume leads to high runoff velocities According to Renard et al (1997), the slope factor depends on the plot flow length and slope gradient. With raster data, map calculations are carried out on pixel basis. The approach used in this study (equation 4) was developed by Desmet and Govers (1996) and takes into account the fact that raster layer calculations are carried out at pixel level. It estimates the slope length factor by incorporating pixel (cell) size and flow accumulation using expressions in equation 4. The resulting slope length factor layer is shown in Figure 4.7.

$$
\begin{aligned}
&\lambda = FlowAccumulation * CellSize \\
&\lambda^{\otimes} = \lambda + CellSize \\
&L = \frac{\left(\lambda^{\otimes}\right)^{1.4} - \lambda^{1.4}}{CellSize * 22.13^{0.4}}
\end{aligned}
\tag{4}
$$

Slope Steepness (S factor): Renard et al (1997) recommend different relationships for determining slope steepness factor depending on the slope length and slope steepness (gradient). The relationship used in this study for its simplicity was developed by Smith and Wischmeier (1957) and is given as

$$
S = \frac{\left[0.43 + 0.30s + 0.043s^2\right]}{6.613} \tag{5}
$$

Where

S = slope steepness factor, and

s = the percent slope.

This relationship is accurate for slope gradients less than and equal to 20%. For slope gradients greater than 20%, equation 5 is best used for comparison purposes. Figure 4.8 depicts the slope steepness factor layer.

Crop management (C factor) and conservation practice (P factor): The *C* and *P* factors were determined from the land use / land cover map. An attribute table was created relating the land use / land cover type to the crop management and conservation practice factors. Some of the C and P factors can be found in Renard et al (1994), Renard et al (1997), and Tollner (2002). The attribute table used in this study is shown in Table 4.1. The *C* and *P* layers are shown in Figure 4.9 and Figure 4.10 respectively.

The erosion map (Figure 4.11) was generated as a product of the six USLE factor layers using map algebra and map calculations in arcMap / arcGIS.

Table 4.1: *C* and *P* factors for different land use / land cover type

Land classes	**Crop management factor, C**	**Management practice Factor, P**
Urban and built-up land	0.01	1
Dryland cropland and pasture	0.013	0.1
Irrigated cropland and pasture	0.013	0.1
Cropland / grassland mosaic	0.3	0.12
Cropland / woodland mosaic	0.3	0.12
Grassland	0.04	0.12
Shrubland	0.036	0.12
Savanna	0.039	0.12
Deciduous broadleaf forest	0.006	0.8
Evergreen broadleaf forest	0.006	0.8
Herbaceous wetland	0	1
Wooden wetland	0	1
Barren and sparsely vegetated	0.4	1

Results and discussions

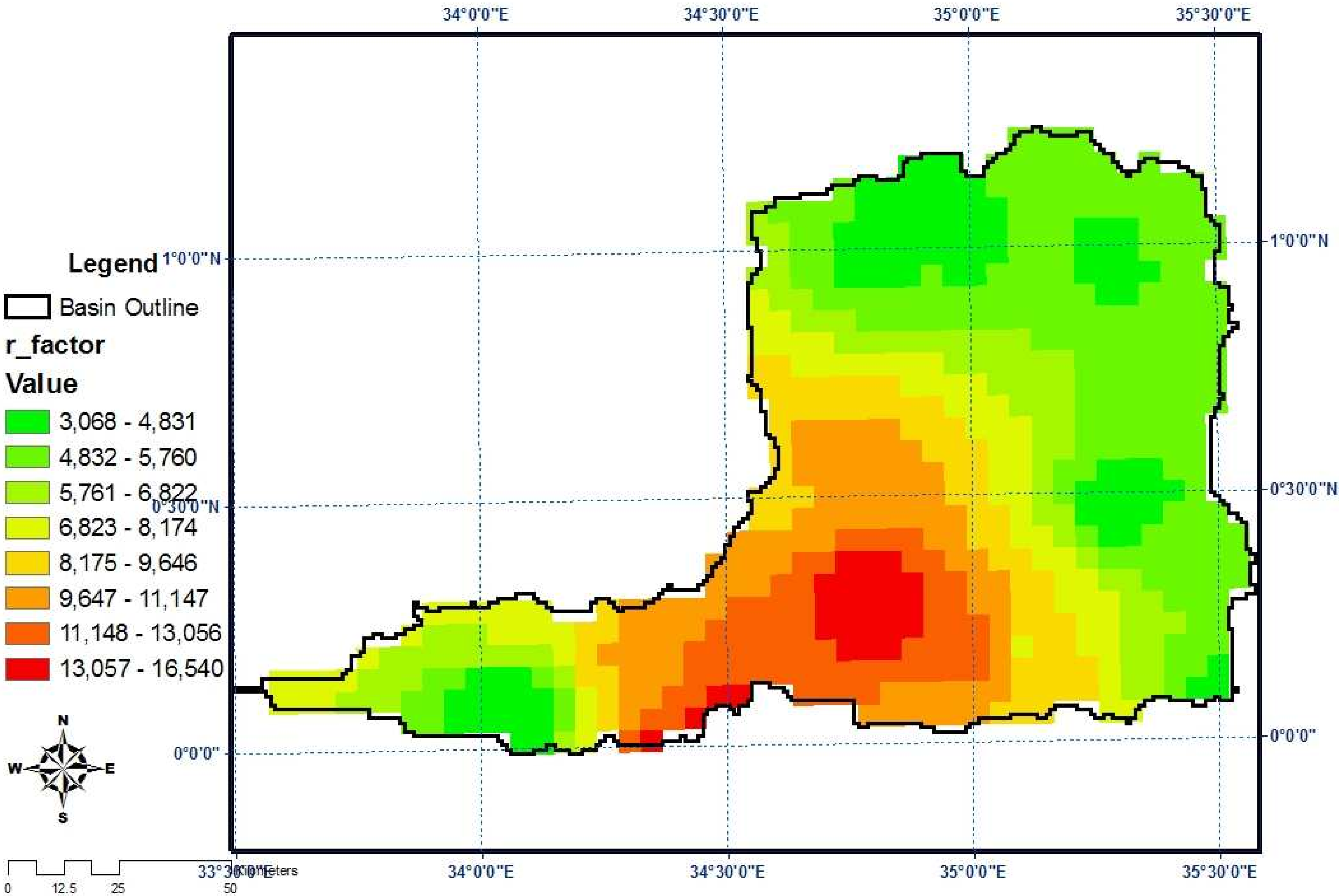

Figure 4.5: Rainfall erosivity, *R*

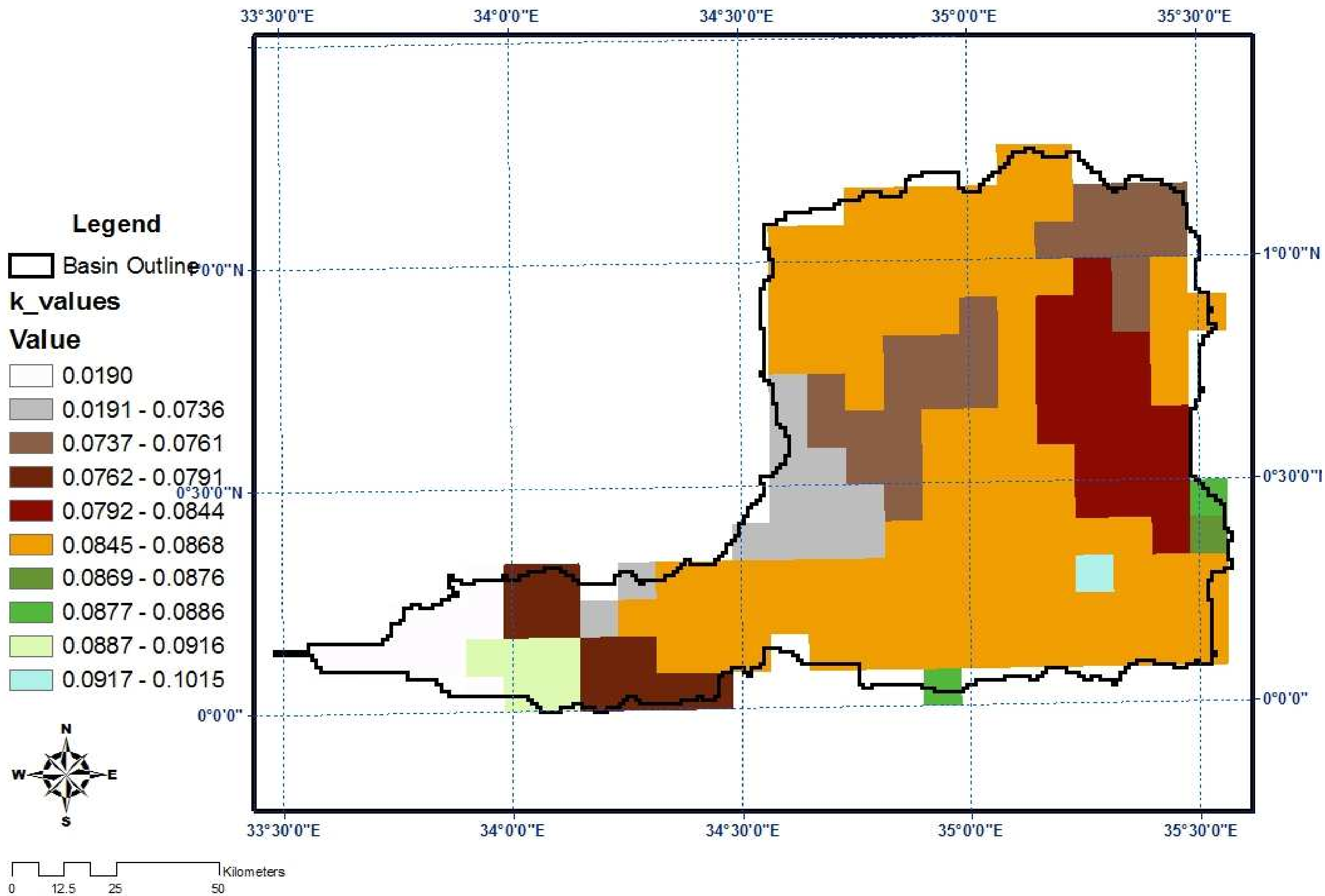

Figure 4.6: Soil erodibility, *K*

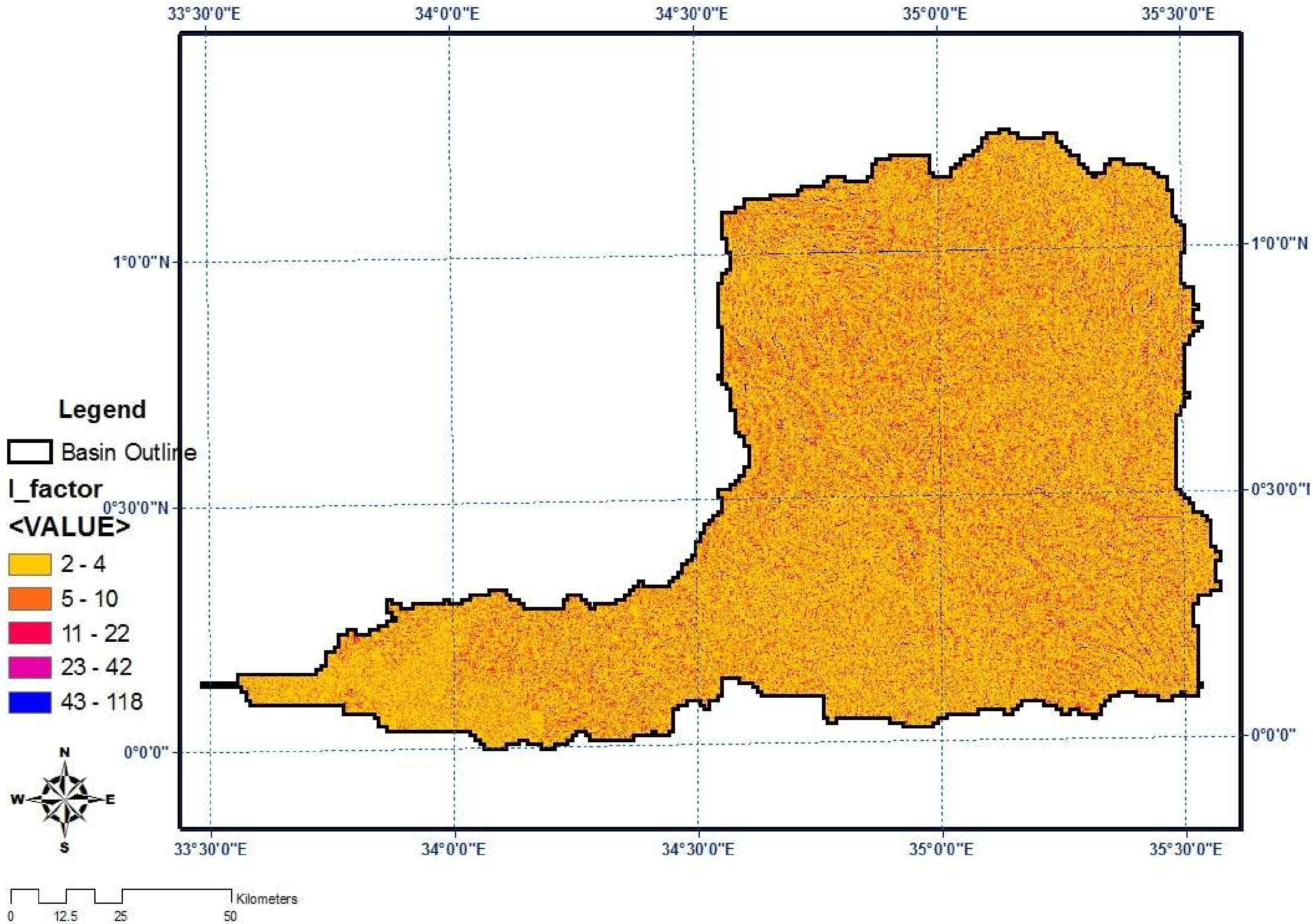

Figure 4.7: Length factor, *L*

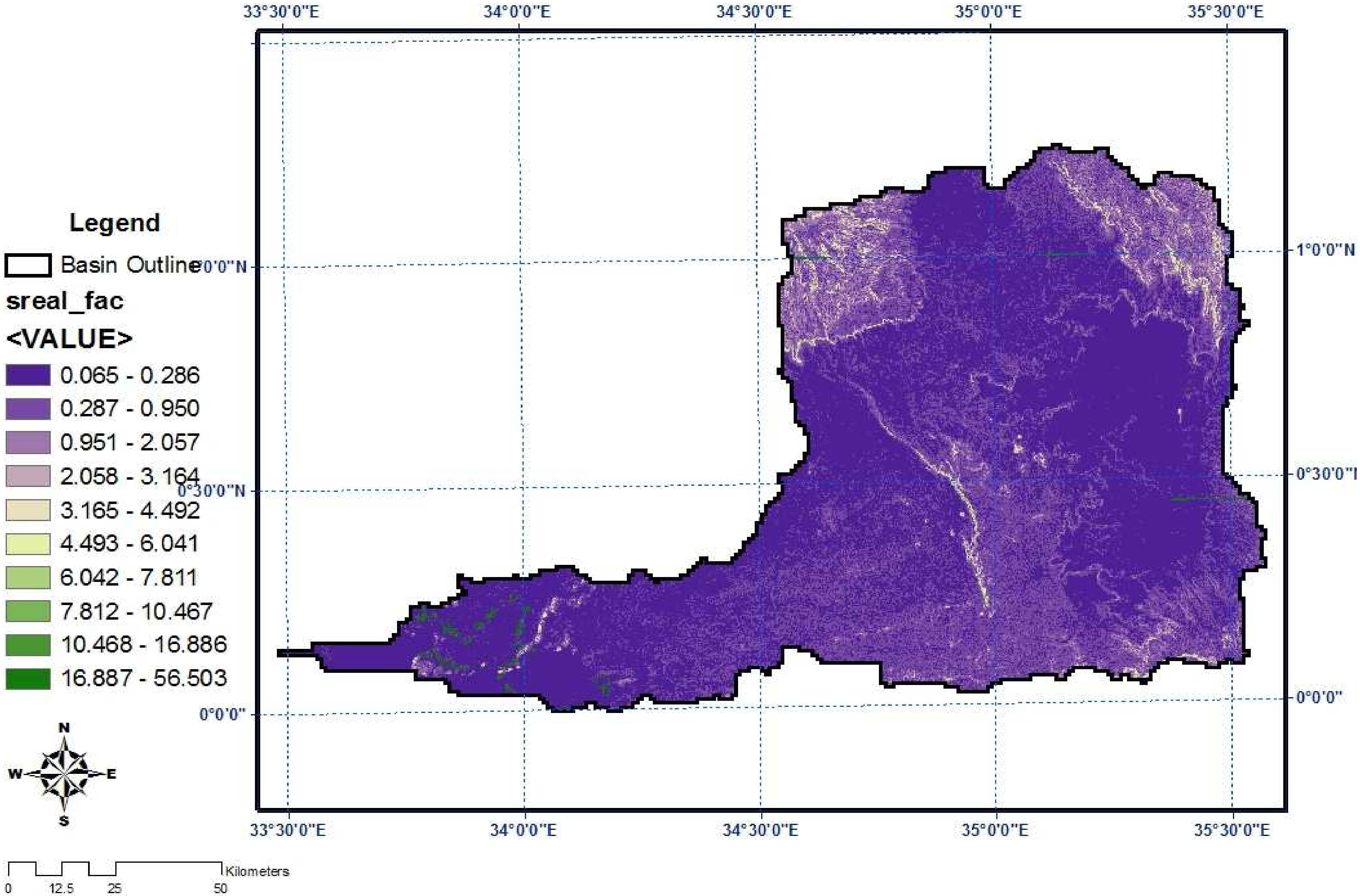

Figure 4.8: Slope steepness factor, *S*

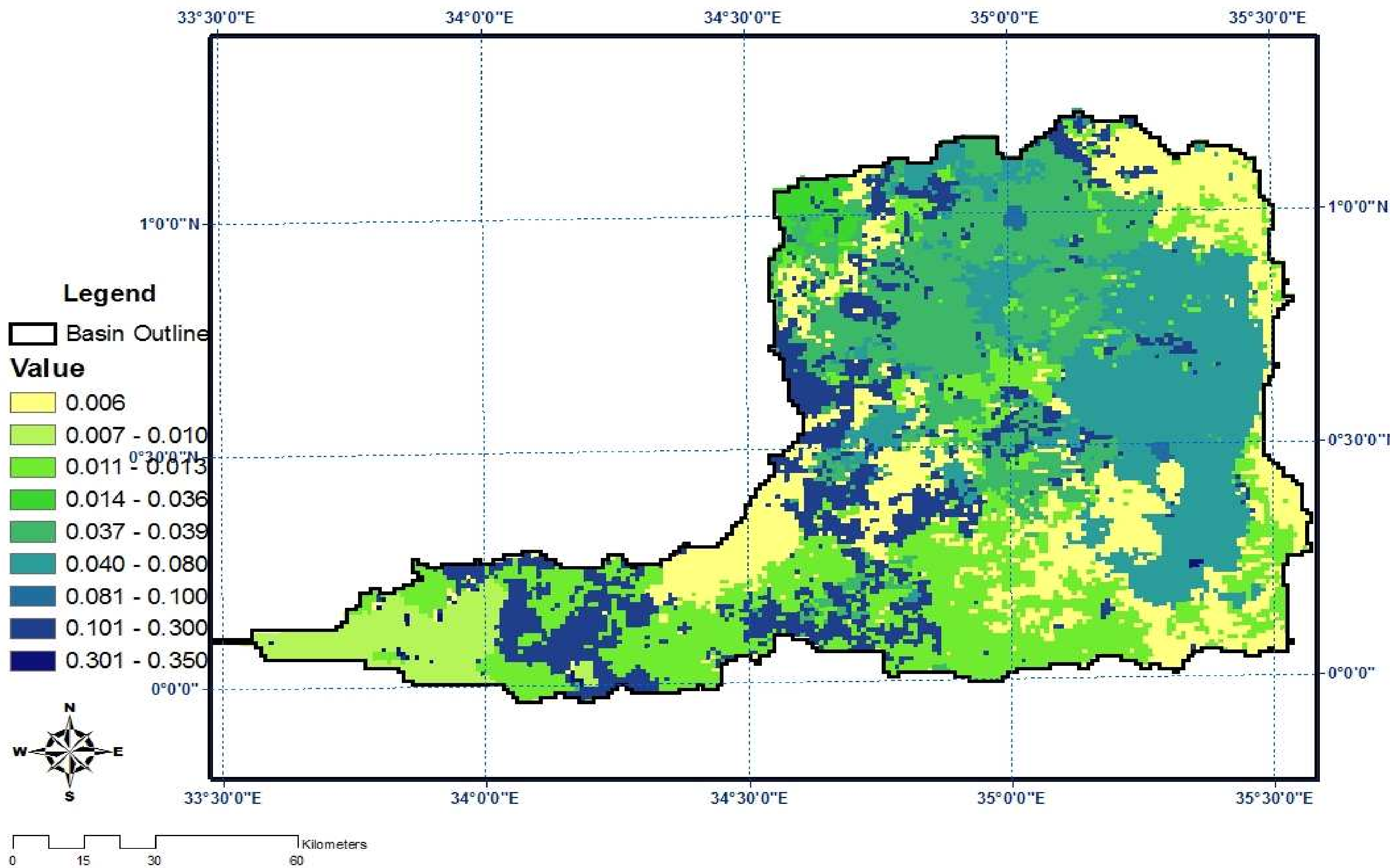

Figure 4.9: Crop factor, *C*

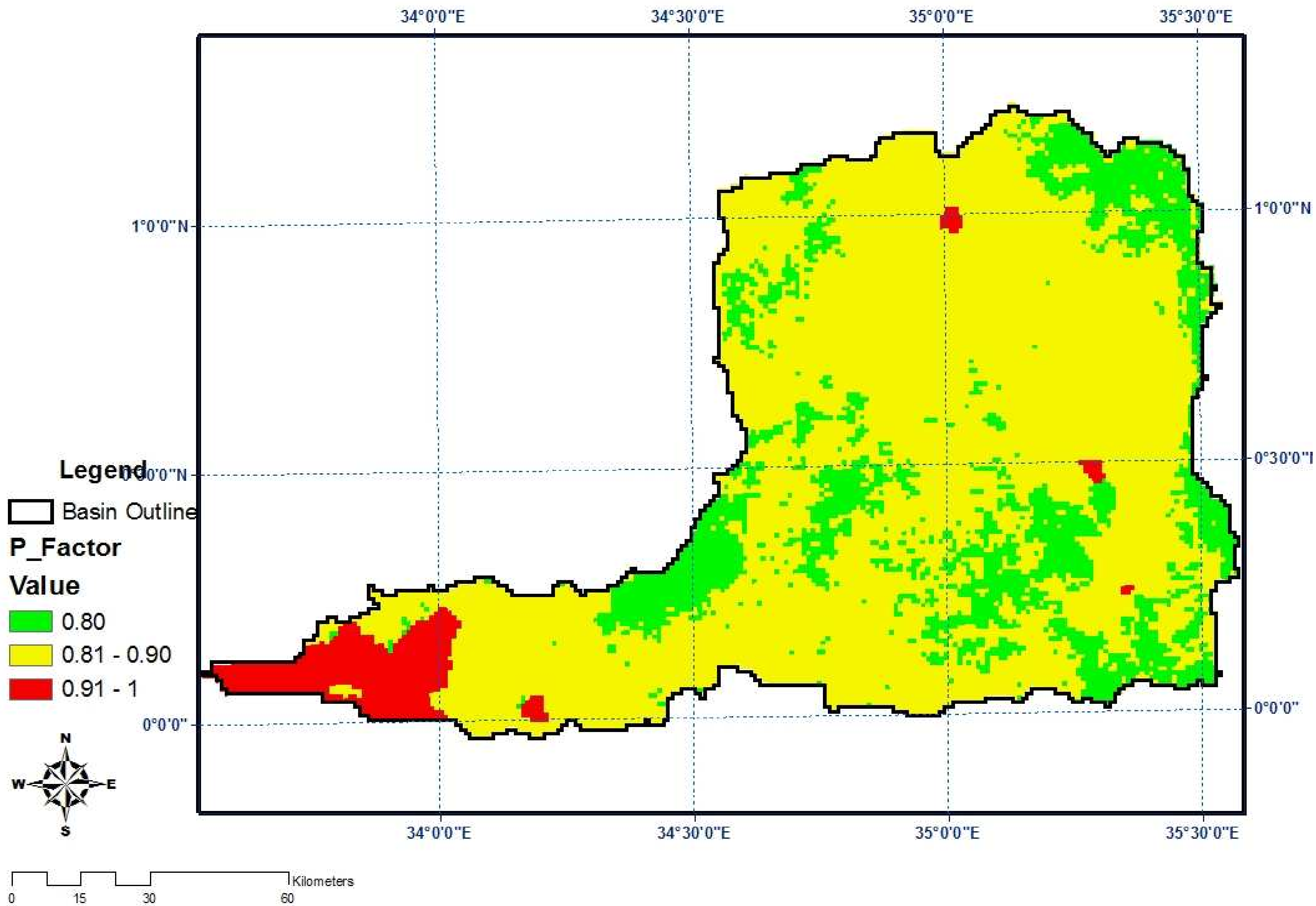

Figure 4.10: Practice management factor, *P*

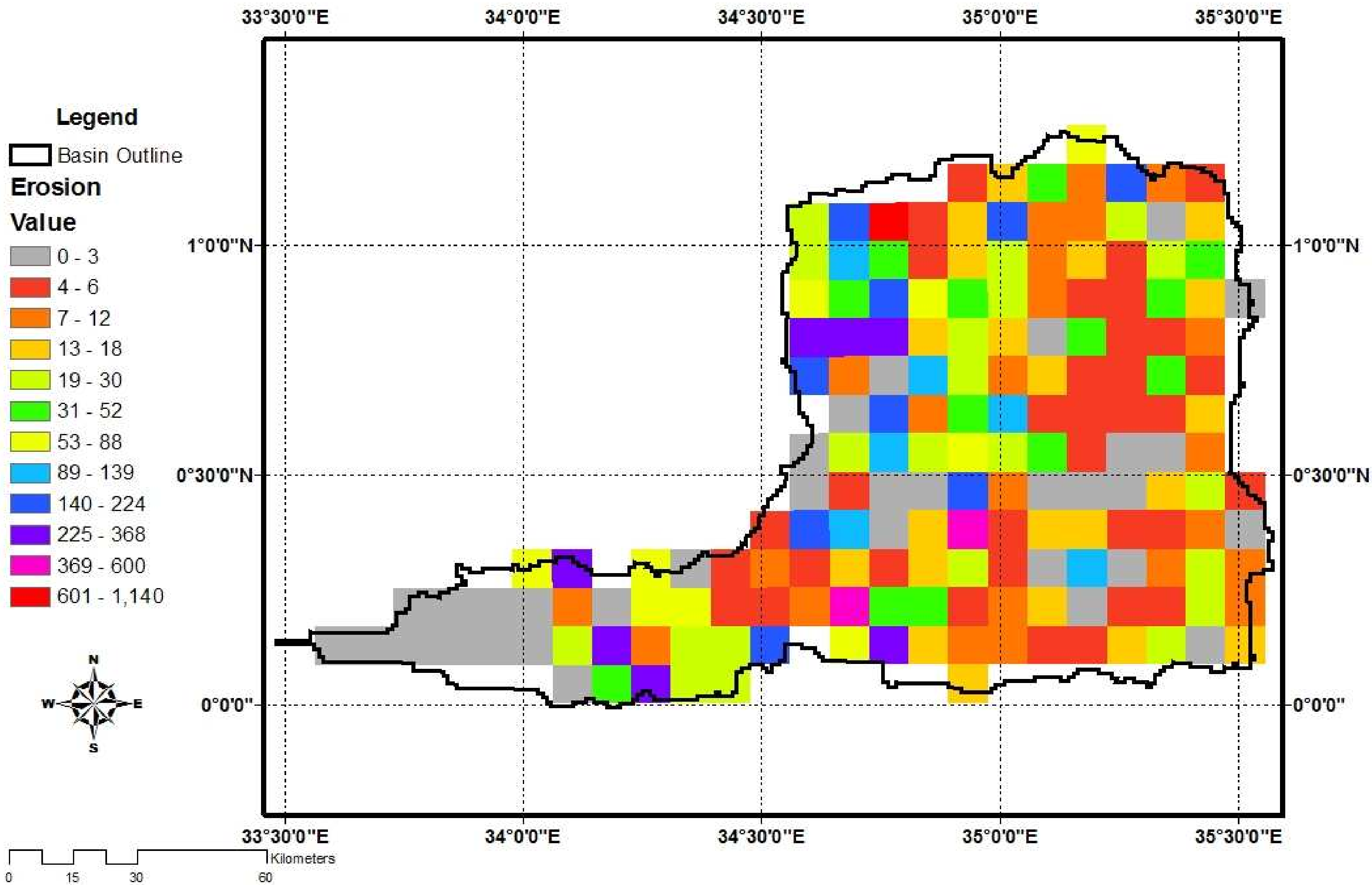

Figure 4.11: Soil erosion distribution

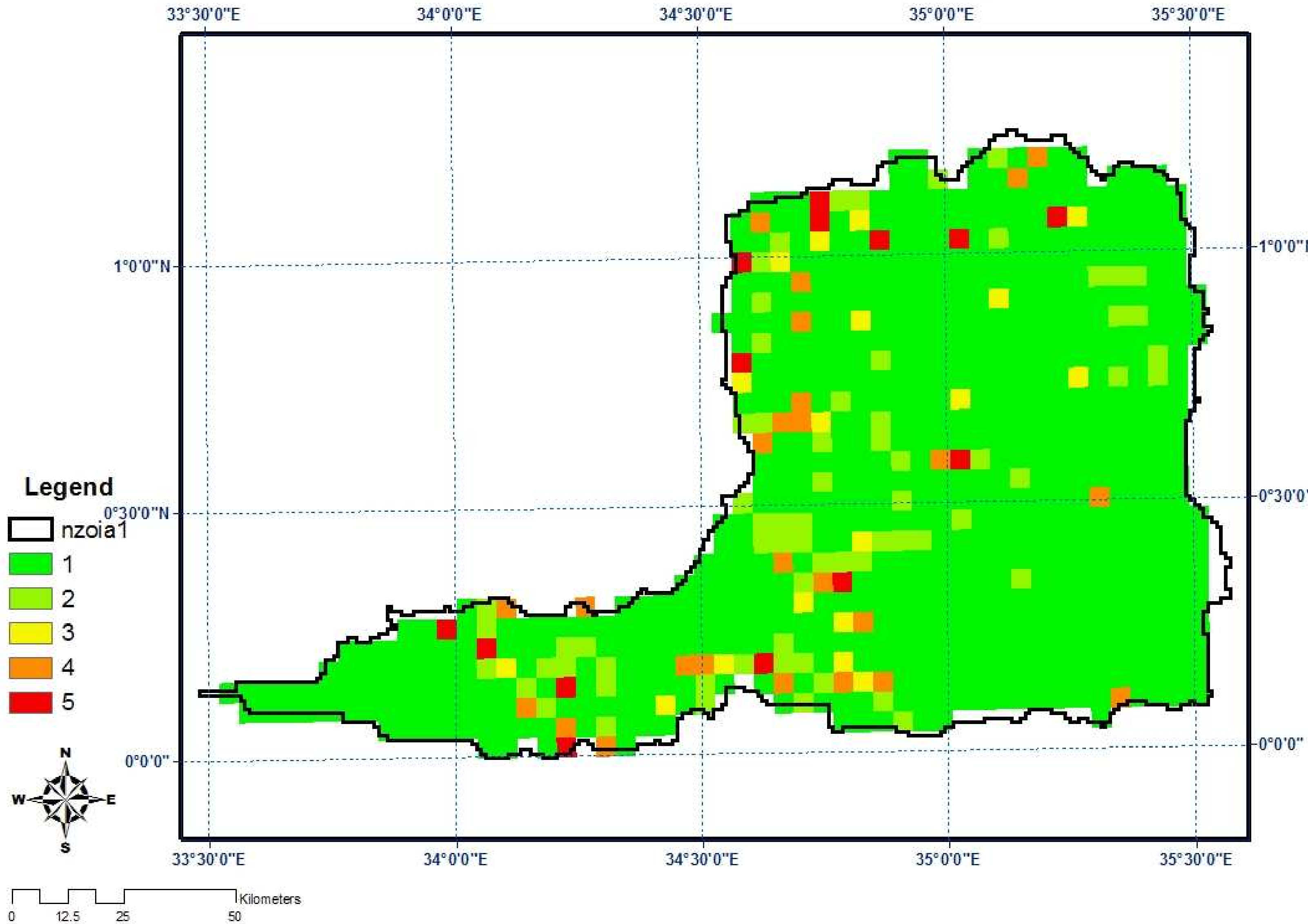

Figure 4.12: Soil erosion index

The erosion index map was created based on the classification in the Table 4.2.

Table 4.2: Erosion Index classification

Soil Erosion (tons ha^{-1}yr^{-1})	**Soil Erosion class**	**Erosion Map Index**
0 - 5	Slight	1
5 - 10	Moderate	2
10 - 20	High	3
20 - 80	Very High	4
> 80	Severe	5

Figures 4.5 to Figure 4.10 depicts the respective USLE thematic map layers used in the generation of soil erosion distribution for Nzoia river Basin (Figure 4.11 and Figure 4.12). The majority of the areas within the Basin are under the low or slight sediment risk (0 – 5 tons ha^{-1} yr^{-1}) (Figure 4.12). This is attributed to the forest and grassland cover in combination with mostly flat topography. However areas at high elevations are among the high - severe risk areas due to the high rainfall amounts and encroachment on the forest and woodlands as more land is being cleared for agricultural use. The erosion amount obtained by GIS, RS, and USLE model for a site at Moore's bridge along the Moiben sub-watershed is 31 – 51 tons/ha-yr compared to the value of 97.2 tons/ha-yr obtained using USLE with more detailed site description. The order of magnitude is the same and the difference can be attributed to the accuracy of the C factor for the site since C is a very sensitive factor in erosion prediction using USLE model. The more accurate C factor aggregates the different cover stages over the year against the respective rainfall amount yet in the GIS, RS, USLE approach; the C factor was estimated depending on the cover type. Another possible source of variation is the different input data resolutions ranging from 0.083 – 1000 m. Work done by Lee and Lee (2006) depicted that a resolution of 125 m was best suited for predicting erosion in Korea when using USLE/RUSLE and GIS.

Conclusions

The study described application of the RUSLE model, to quantify soil loss in Nzoia Basin located within the Lake Victoria Basin (Kenyan side), using the GIS, RS, and GPS technologies. The approach adopted, first calculated the six USLE factors using distributed RS and GIS data layers (e.g. soil data, land use and land cover, and DEM) to adequately represent the surface characteristics. Then, the spatial distribution of soil loss in the Basin was estimated as a product of six GIS layers. The majority of the areas within the Basin are under the low or slight sediment risk (0 – 5 tons ha^{-1} yr^{-1}) with some erosion hotspots characterized by high elevations and low land cover. The accuracy of the prediction can be enhanced by improving the temporal aspect of the data and spatial resolution. The land use map and soils map used in this study had spatial resolution of one kilometer and 0.0833 arc degrees respectively. Land cover - land use satellite images that depict the current land use patterns should be used to provide the required temporal details for more precise watershed assessments.

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5 CONCLUSIONS AND FUTURE DIRECTION

The study set out to evaluate tools for remotely assessing the impact of riparian buffers protecting streams from sediment pollution. The core thesis of the study focused on a two step process of initially predicting soil erosion and then the amount that is deposited within the riparian buffers. For erosion prediction two approaches were employed. The first approach integrated Google ™ Earth Pro and USLE to predict soil erosion on a site specific basis. Google ™ Earth Pro was used to estimate watershed topographic parameters used in the USLE erosion prediction model. The second approach integrated GIS, remote sensing, and USLE to estimate soil erosion distribution potential in Nzoia Basin. Sediment deposition along the buffer length was estimated using the US forest service (1980) sediment delivery ratio method.

For erosion prediction, ground truthing results from ten small watersheds comparing the measured and predicted data yielded a mean absolute error of 0.76 tons ha^{-1} yr^{-1} with a coefficient of determination of 0.95. The results depict the usefulness of Google ™ Earth Pro for estimating topographic watershed parameters on small catchments. For example estimating erosion from a given farm plot or disturbed land for development activities. Google ™ Earth Pro can also be integrated into other erosion prediction and integrated nutrient management systems. For example it's recommended to apply poultry litter on lands with slopes less than 15 % therefore; Google ™ Earth Pro can be used to remotely asses the best farm sites. For sediment deposition, USFS (1980) sediment delivery ratio overestimated the amount of sediment deposited in the riparian buffers. This is because the approach does not account for channelization within the buffer. The sediment yield prediction model can be improved by accounting for channelization within the buffer based on the soil type, land cover – land use, and runoff rate parameters. . Thus the study stretched the applications of Google ™ Earth Pro,Pro from a location search and 3D Earth observatory tool to a remote sensing tool useful in extracting micro-watershed topographic parameters. Also, the study established an approach that integrates Google ^{TM} Earth Pro,derived elevations and Surfer ® 7.0 3D modeling software to estimate the slope length used in estimation of USLE slope length and slope steepness factors.

The integration of GIS, remote sensing, and USLE yielded a soil erosion distribution map for the Nzoia Basin. Generally most of the Basin is under slight erosion (0 – 5 tons ha^{-1} yr^{-1}) with some erosion hotspots. Areas with potential high erosion levels are characterized by high rainfall values and high activity of subsistence agricultural activities thus leaving the land exposed to the rainfall erosive forces. The accuracy of the prediction can be enhanced by improving the temporal aspect of the data and spatial resolution. The land use map and soils map used in this study had spatial resolution of one kilometer and 0.0833 arc degrees respectively. Land cover - land use satellite images that depict the current land use patterns should be used to provide the required temporal details for more precise watershed assessments. Therefore, Google ^{TM} Earth Pro, GIS, and remote sensing technologies can be integrated with erosion, sediment yield, and nutrient transport prediction models to asses the effectiveness of riparian buffers protecting streams from agricultural and sediment pollution.

Most field based watershed assessments within the Lake Victoria Basin have focused on smaller sub – watersheds like Nyando due to the time requirements, limited human and financial resources. With GIS and remote sensing technologies, analysis of sediment sources, sediment hotspots, nutrient sources, and transport mechanisms within Lake Victoria and the River Nile Basins can be made.

There are miles of streams placed on the USEPA 303d impaired streams list in Georgia US in part due to sediment impairments since sediment is the leading pollutant in terms of pollutant mass. The methodology can be integrated with Total maximum daily load (TMDL) tools to carry out TMDL related assessment in Georgia, US, and other countries.

The combination of Google ™ Earth Pro, sediment prediction, and riparian buffer evaluation may enable the needed fine grained approach to setting workable setbacks that account for parameters affecting erosion and sedimentation compared to the coarse grained approach of dictating “a legislated single value setback”. Assigning a single riparian buffer width overlooks the differences in sediment transport mechanics caused by difference in watershed characteristics. This combination of tools may be very useful for assessing areas for receiving agricultural wastes such as poultry liter as part of a comprehensive nutrient management planning. Thus, this work has much promise for Georgia and the US agriculture as well as for the developing countries.

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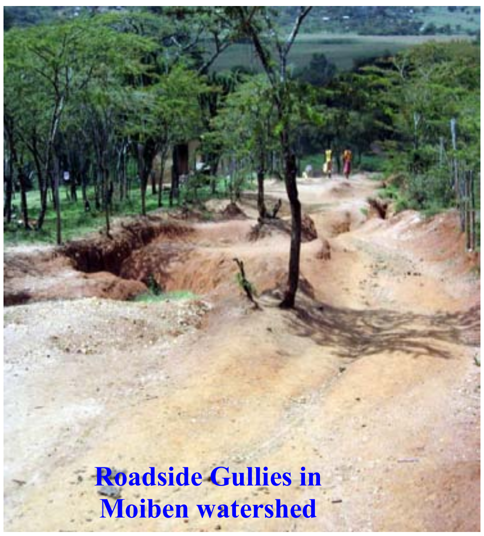
APPENDICES

Appendix A: Reconnaissance survey pictures along Moiben and Tangasir rivers



Appendix B: Moiben Watershed GPS positions and Elevations at selected sites

Site	Northing	Easting	Elevation (ft)	Elevation (m)	Site Description
*Sergoit Stream Bridge	00°40.080’	035°18.248’	6768	2064	• Shrubs and Rangeland • Maize and Wheat fields About 90% cover • Stream bed Rocky • Relatively clear water Moderate slope
Lolkinyei Swamp	00°45.667’	035°17.834’	6778	2067	• Swamp • Land cover about 85% Slope relatively flat
*Kapsumbeiywet River	00°50.400’	035°15.461’	6541	1994	• Sedges [swamp grass] • Agric. Land about 40% • Developed land about 15% • Rangeland about 40% • Swamp about 5%
Zia Dam	00°50.202’	035°14.600’	6522	1989	• Water reservoir for cattle and drinking water • Water level low yet its rainy season • Sediment deposits visible
				Moiben River	
Bridge	00°55.915’	035°16.367’	6115	1864 (1866)	• Besides the bridge • Cattle drinking point • Mucky waters • High sediment loading • Rangelands Sedimentation mainly due to roadside gullies
Tyigoin station [08]	00°55.832’	035°16.388’	6118	1865	• Before the bridge and cattle drinking point • Mucky waters • High sediment loading • Rangelands

	Northing	Easting	Elevation (ft)	Elevation (m)	Comments
Cheuta sampling point [07]	00°53.078'	035°18.535'	6210	1893	• Cattle drinking point • Water very mucky with high sediment loading • Agric. Land is small • Almost no buffer
Koisagat sampling point [06]	00°53.387'	035°20.597'	6319	1927	
Moore's Bridge	00°52.325'	035°21.846'	6370	1942	• Riparian zone of trees and shrubs • High sediment loading Sediment deposit on log obstructions High channel side erosion
Karandir II bridge Wooden bridge [05]	00°50.259'	035°25.330'	6504	1983	• Water relatively clear • Relatively steep slope – convex slope • Stream buffer • Rangelands
*Tangasir river dam sampling point [04]	00°49.793'	035°25.729'	6575	2005	• Erosion mainly from nearby cattle market that is exposed • Near the Karandir shopping center
Karandir I sampling point [03]	00°48.918'	035°25.755'	6562	2001	• Water clear and less sediment loading • A large buffer zone mainly forest upstream
Chebara, sampling point [01]	00°51.280'	035°29.545'	7444	2270	• Uppermost point on moiben river • A large riparian buffer zone mainly forest upstream Less but emerging agric. activities
*Sergoit upper	00°41.543'	035°25.426'	7134	2175	Uppermost point on Sergoit river

*Locations that are not along the Moiben River. Note: All sampling points are Cattle drinking points.

Appendix C: Watershed data for ground truthing

Watkinsville Watershed - P1 Watershed (24 year Conservational Tillage)		
Area = 2.71 ha		Location: Lat. 33.887614^0 Long. -83.420365^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	301	24 year average annual rainfall = 1210mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.28	From NRCS P1 watershed soil survey map. Predominantly Cecil Sandy loam soils
C	0.08	Conservational tillage (CT)
L	1.43	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Ridges in the middle of the field and at the watershed outlet were introduced during CT. Slope length measured = 70m
S	0.34	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 2.9% . The difference is due to the ridge introduction.
P	0.3	Row crops along the contour, s = 2.9% and l = 70m with moderate ridges
A [tons / acre-yr]	**0.98**	
A [tons / ha-yr]	**2.20**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Coshocton, Ohio 109 Watershed		
Area = 0.68 ha		Location: Lat. 40.370278^0 Long. -81.799444^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	195	11 year average annual rainfall = 976.7mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.37	From NRCS soil survey map. Predominantly Berks shaly Silt loam and Rayne silt loam soils
C	0.04	Corn, soybean, wheat, meadow [No till]
L	0.363	Used Google ^{TM} Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length initially measured = 53m and slope = 5.66% , however, the plot was contoured at about 2m.
S	0.86	Used Google ^{TM} Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 5.66% . S = 3.0sin(theta)^0.8 + 0.56
P	0.3	Row crops along the contour, s = 5.66% and l = 2m with moderate ridges created by chisel plough
A [tons / acre-yr]	**0.27**	
A [tons / ha-yr]	**0.61**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Tifton, TZ Watershed Georgia		
Area = 0.34 ha		Location: Lat. 31.47500^0 Long. -83.531944
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	298.4	8 year average annual rainfall = 1205 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.1	From NRCS watershed soil survey map. Cowarts Sandy loam soils
C	0.07	Corn, Oats, Peanuts, Soybeans, Rye
L	1.15	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 35m and slope = 2.86%
S	0.34	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 2.86% .
P	1	No contouring
A [tons / acre-yr]	**0.82**	
A [tons / ha-yr]	**1.83**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Riesel, Texas W-12 watershed		
Area = 4.01 ha		Location: Lat. 31.465556^0 Long. -96.885278^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	215.4	6 year average annual rainfall = 1027 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.32	From NRCS watershed soil survey map. Black clay and Heiden clay soils
C	0.08	Wheat, Corn, Sorghum
L	1.44	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length initially measured = 130 m.
S	0.196	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 1.54 % .
P	1	Row crops along the contour, s = 1.54% and l = 130 m
A [tons / acre-yr]	**1.56**	
A [tons / ha-yr]	**3.49**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Riesel, Texas W-13 watershed		
Area = 4.57 1ha		Location: Lat. 31.465833^0 Long. -96.885556^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	215.4	6 year average annual rainfall = 1027mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.32	From NRCS watershed soil survey map. Predominantly Cecil Sandy loam soils
C	0.08	Wheat, Corn, Sorghum
L	1.24	Used Google ™ Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length initially measured = 140 m. Slope of 0.7 %
S	0.107	Used Google ™ Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 0.7 % .
P	1	Row crops along the contour, s = 0.7 % and l = 140 m
A [tons / acre-yr]	**0.73**	
A [tons / ha-yr]	**1.64**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Watkinsville Watershed - P2 Watershed, Georgia		
Area = 1.29 ha		Location: Lat. 33.884722^0 Long. -83.427222^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	428	3 year average annual rainfall = 1434 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.28	From NRCS watershed soil survey map. Predominantly Cecil Sandy loam soils
C	0.07	Corn, Bermuda grass
L	1.19	Used Google ™ Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 42 m
S	0.29	Used Google ™ Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 1.86 % .
P	1	No contour cropping
A [tons / acre-yr]	**2.89**	
A [tons / ha-yr]	**6.49**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Watkinsville Watershed - P3 Watershed, Georgia		
Area = 1.26 ha		Location: Lat. 33.868889^0 Long. -83.452778^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	320	11 year average annual rainfall = 1247 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.28	From NRCS watershed soil survey map. Predominantly Cecil Sandy loam soils
C	0.07	Sorghum, barley, Soybeans, Rye
L	1.23	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 54 m
S	0.23	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 1.85 % .
P	1	No contour cropping
A [tons / acre-yr]	**1.8**	
A [tons / ha-yr]	**3.98**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Watkinsville Watershed - P4 Watershed, Georgia

Area = 1.4 ha		Location: Lat. 33.870000^0 Long. -83.452778^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	363	10 year average annual rainfall = 1325 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.28	From NRCS watershed soil survey map. Predominantly Cecil Sandy loam soils
C	0.04	Barley, Soybeans, rye, corn, wheat
L	1.24	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 56 m and slope of 1.8 %.
S	0.22	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 1.8 % .
P	1	No contour cropping
A [tons / acre-yr]	**1.1**	
A [tons / ha-yr]	**2.49**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Chickasha, Oklahoma C-5 watershed		
Area = 2.71ha		Location: Lat. 35.033333^0 Long. -97.909167^0
Factor	**Value**	**Comments**
R [100s of ft tonf-in / acre-hr-yr.]	127.7	4 year average annual rainfall = 776.5 mm, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft tonf-in]	0.37	From NRCS watershed soil survey map. Silty loam and silty clay loam soils
C	0.07	winter wheat
L	1.25	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Ridges in the middle of the field and at the watershed outlet were introduced during CT. Slope length measured = 70m
S	0.12	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 2.9% . The difference is due to the ridge introduction.
P	1	No contour cropping
A [tons / acre-yr]	**0.50**	
A [tons / ha-yr]	**1.11**	**A [tons / ha-yr] = A[tons/ha-yr] x 2.242**

Bukora micro-catchment [Uganda] - Degraded ranges with annuals		
Location: Lat. -0.85^0		Long. 31.4833^0
Factor	**Value**	**Comments**
R [100s of ft-tonf-in / acre-hr-yr.]	322	Average annual rainfall = 1250mm - Lake victoria Basin, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr], Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft-tonf-in]	0.275	From FAO document (Land Husbandry) for degraded soils K increases to 0.2 or 0.35. The soils are Sandy clay loams [0.2].
C	0.4	Degraded ranges with annuals
L	2.9	Used Google ™ Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 1198m
S	0.28	Used Google ™ Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 2.3%.
P	1	No noticeable or documented conservation sopport system
A [tons / acre-yr]	**28.8**	
A [tons / ha-yr]	**64.6**	tons / ha-yr = tons/acre-yr *2.242

Bukora micro-catchment [Uganda] – Perennials mixed with annuals		
	Location: Lat. -0.85^0 Long. 31.4833^0	
Factor	**Value**	**Comments**
R [100s of ft-tonf-in / acre-hr-yr.]	322	Average annual rainfall = 1250mm - Lake victoria Basin, R = 587.8 - 1.219P + 0.004105P^2, for P > 850mm, [MJ.mm/ha.hr.yr] Based on Renard and Freimund (1994), Divide by 17.02 to obtain [100s of ft tonf.in / acre.hr.yr.]
K [tons-acre-hr / 100s of ft-tonf-in]	0.2	The soils are Sandy clay loams [0.2].
C	0.2	Perennials mixed with annuals
L	2.9	Used Google TM Earth Pro to obtain the slope length and steepness from which L was calculated. Slope length measured = 1198m
S	0.28	Used Google TM Earth Pro to obtain the slope steepness from which S was calculated. Slope steepness = 2.3%.
P	1	No noticeable or documented conservation support system
A [tons / acre-yr]	**10.5**	
A [tons / ha-yr]	**23.5**	tons/ha-yr = tons/acre-yr *2.242

Appendix D: Watershed Google ™ Earth Pro Images

Watkinsville W1, Watershed, Georgia

Watkinsville P1, Watershed, Georgia

Tifton, TZ watershed, Georgia

Chickasha, Oklahoma C-5 and C-6 watersheds

Coshocton, Ohio 109 Watershed

Appendix E: Pseudo code for calculating stiff diagram coordinates, polygon area, and sediment delivery ratio

Texture of eroded material

$$X_1 = 0.5$$
$$Y_1 = 0.5 + 0.005 texture$$

Surface runoff

$$X_2 = 0.5 + 5 runoff$$
$$Y_2 = 0.5 + 5 runoff$$

Note: If runoff >0.1cfs/ft, then set X_2 and Y_2 to 0.1

Slope gradient

$$X_3 = 0.5 - 0.005 slope$$
$$Y_3 = 0.5 + 0.005 slope$$

Delivery distance (DD)

$$X_4 = 0.125 \log_{10}(DD)$$
$$Y_4 = 0.125 \log_{10}(DD)$$

Surface roughness

$$X_5 = 0.5$$
$$Y_5 = 0.125 Roughness$$

Slope shape

$$X_6 = 0.125 Slope\_Shape$$
$$Y_6 = 0.5$$

Percent cover

$$X_7 = 0.1085736205 \ln(Percent\_Cover)$$
$$Y_7 = 1 - 0.1085736205 \ln(Percent\_Cover)$$

Calculating the stiff diagram polygon area

$$-2 HatchArea = (X_1Y_2 + X_2Y_3 + X_3Y_4 + X_4Y_5 + X_5Y_6 + X_6Y_7 + X_7Y_1) -$$
$$(X_2Y_1 + X_3Y_2 + X_4Y_3 + X_5Y_4 + X_6Y_5 + X_7Y_6 + X_1Y_7)$$

Regression model for estimating the SDR using the stiff diagram polygon area

$$SDR = 1.02157 - \frac{1.04193}{1 + e^{(Hatched\_Area * 100 - 49.90058)/11.72872}}$$