*forests*

*Article*

# Soil Erosion Risk Assessment in Uganda

**Fidele Karamage [1,2,3,4,5], Chi Zhang [1,2,5,*], Tong Liu [1], Andrew Maganda [6] and Alain Isabwe [3,7]**

1 College of Life Science, Shihezi University, Shihezi 832003, China; fidelekaramage@yahoo.com (F.K.); betula@126.com (T.L.)
2 State Key Laboratory of Desert and Oasis Ecology, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi 830011, China
3 University of Chinese Academy of Sciences, Beijing 100049, China; alain@iue.ac.cn (A.I.)
4 Faculty of Environmental Studies, University of Lay Adventists of Kigali, P.O. Box 6392 Kigali, Rwanda
5 Joint Research Center for Natural Resources and Environment in East Africa, P.O. Box 6392 Kigali, Rwanda
6 Department of Forestry, Environmental and Geographical Sciences, College of Agriculture and Environmental Sciences, Makerere University, Kampala 256, Uganda; andrewmaganda@yahoo.com
7 State of Key Laboratory of Urban Environment and Health, Institute of Urban Environment, Chinese Academy of Sciences, Xiamen 361021, China
* Correspondence: zc@ms.xjb.ac.cn; Tel.: +86-991-782-3127

Academic Editors: Peter N. Beets and Timothy A. Martin
Received: 9 December 2016; Accepted: 17 February 2017; Published: 22 February 2017

**Abstract:** Land use without adequate soil erosion control measures is continuously increasing the risk of soil erosion by water mainly in developing tropical countries. These countries are prone to environmental disturbance due to high population growth and high rainfall intensity. The aim of this study is to assess the state of soil erosion by water in Uganda at national and district levels, for various land cover and land use (LCLU) types, in protected areas as well to predict the impact of support practices on soil loss reduction. Predictions obtained using the Revised Universal Soil Loss Equation (RUSLE) model indicated that the mean rate of soil loss risk in Uganda's erosion-prone lands was 3.2 $t{\cdot}ha^{-1}{\cdot}y^{-1}$, resulting in a total annual soil loss of about 62 million tons in 2014. About 39% of the country's erosion-prone lands were comprised of unsustainable mean soil loss rates >1 $t{\cdot}ha^{-1}{\cdot}y^{-1}$. Out of 112 districts in Uganda, 66 districts were found to have unsustainable estimated soil loss rates >1 $t{\cdot}ha^{-1}{\cdot}y^{-1}$. Six districts in Uganda were found to have mean annual soil loss rates of >10 $t{\cdot}ha^{-1}{\cdot}y^{-1}$: Bududa (46.3 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Kasese (37.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Bundibugyo (28.9 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Bulambuli (20.9 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Sironko (14.6 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) and Kotido (12.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$). Among the LCLU types, the highest soil loss rates of 11 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ and 10.6 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ were found in moderate natural forest and dense natural forest, respectively, mainly due to their locations in highland areas characterized by steep slopes ranging between 16% to 21% and their high rainfall intensity, ranging from 1255 $mm{\cdot}y^{-1}$ to 1292 $mm{\cdot}y^{-1}$. Only five protected areas in Uganda were found to have high mean estimated mean soil loss rates >10 $t{\cdot}ha^{-1}{\cdot}y^{-1}$: Rwenzori Mountains (142.94 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Mount Elgon (33.81 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Bokora corridor (12.13 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), Matheniko (10.39 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), and Nangolibwel (10.33 $t{\cdot}ha^{-1}{\cdot}y^{-1}$). To manage soil erosion in Uganda's protected areas, there is an urgent need to control wildfires and human-induced disturbances such as timber harvesting and soil compaction from domestic animals. Our study analysis revealed that well-established terraces and strip-cropping could significantly reduce soil loss rates in Uganda's croplands by 80% (from 1.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ to 0.3 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) and by 47% (from 1.5 $t{\cdot}ha^{-1}{\cdot}y^{-1}$ to 0.8 $t{\cdot}ha^{-1}{\cdot}y^{-1}$), respectively, well below the sustainable soil erosion tolerance rate (1 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) for land and water conservation.

**Keywords:** erosion-prone lands; erosion tolerance; GIS; land use; remote sensing; RUSLE

## 1. Introduction

Forest clearance on mountain slopes for agricultural purposes is the most likely cause of soil erosion in Uganda [1]. Agriculture together with natural factors such as abundant tropical rainfall and a steep topography increase soil erosion rates in highland areas [2,3]. More than 50% of the population in East Africa depend on agriculture for their livelihood [4]. It has been forecasted that $1 \times 10^9$ ha of natural ecosystems will be converted to agricultural farmalands by the year 2050 and this will be harmful to freshwater and near-shore marine biological communities due to 2.4- and 2.7-fold increases in nitrogen and phosphorus, respectively [5]. Agricultural intensification without soil conservation practices can have significant detrimental effects on soil, such as increased erosion and lower fertility, further leading to ground water pollution and eutrophication of rivers and lakes [6,7]. For instance, Mediterranean lands have suffered changes from land uses that resulted in organic matter exhaustion, erosion, soil degradation, salinization, and crusting due to both traditional land uses and human activities such as agriculture, grazing, mining, charcoal and biomass production, leading to low soil fertility and a highly eroded terrain [8,9].

Lake Victoria is the world's second largest freshwater lake with a surface area of about 68,000 km$^2$ shared by Kenya, Tanzania, and Uganda. Lake Victoria was listed among the top 10 severely polluted world water bodies [10,11]. High levels of eutrophication and water hyacinth infestation in Lake Victoria were attributed to soil erosion due to unsustainable agricultural practices in the East African region [12,13]. Uganda has been experiencing a long-term decline in vegetation cover and ecosystem productivity, and over 41,506 km$^2$ (17.58%) of the land has been degraded with an estimated total net primary productivity (NPP) loss of 1,513,211.6 tons of carbon in the last 23 years, affecting over 15.04% of the national population [14]. Forest degradation due to anthropogenic activities in Uganda has become an issue of serious concern apart from climatic forces [15,16]. Between 2000 and 2014, Uganda lost over 1.62% (645.32 km$^2$) and 21.72% (23,067.27 km$^2$) of its major forestlands and natural grasslands, respectively. During this period, Uganda's cropland increased significantly by 35% (23,604.62 km$^2$) [17]. Due to fertile soils and the need to expand agricultural farmlands, Uganda's protected areas have seen major population increases. Uganda's population growth rate is increasing at a rate of 3.3%, ranking second in Africa behind Niger. More than 80% of the land is used for small-scale farming and nearly 80% of households are farmers [18]. Uganda's population was estimated at about 41 million with a 16.1% urban population in 2015. By 2050 the population in Uganda will be more than 104 million, and about 32.1% of the total population will be residing in urban areas [19]. This increase in population growth will put enormous pressure on land and natural resources, increasing the risk of soil erosion by water if no adequate conservation practices are applied.

Although soil erosion has been assessed locally in a few case studies in Uganda [2,20,21], it has not been assessed systematically at district, national, and protected area levels. In addition, much of the land cover and land use changes during recent years have been driven by population growth pressure, resulting in environmental stress due to agricultural mechanization, deforestation, overgrazing, etc. Based on the available data, the objectives of the present study are: (a) to assess soil erosion by water in Uganda at national and district levels; (b) to estimate soil erosion for different land cover and land use types; and (c) to assess soil erosion risks for the 50 largest protected areas in Uganda using the Revised Universal Soil Loss Equation (RUSLE) model [22].

## 2. Materials and Methods

### *2.1. Description of the Study Area*

Uganda is located in the tropical zone of East Africa, between latitudes 4°12′ N and 1°29′ S and longitudes 29°34′ W, and 35°0′ E. The country shares borders with South Sudan in the north, Rwanda and Tanzania in the south, Kenya in the east and the Democratic Republic of Congo in the west. Its elevation ranges from 391 m to 5370 m. Uganda has a surface area of about 243,593.30 km$^2$ (Figure 1). More than two-thirds of the country's surface area is a plateau, lying between 1000 and

2500 m above sea level. Precipitation is reliable, varying from 750 mm in Karamoja in the Northeast to 1500 mm in the high rainfall areas on the shores of Lake Victoria, in the highlands around Mount Elgon in the east. Temperatures in the Rwenzori mountains in the southwest and some parts of Masindi and Gulu districts range from 15 to 30 °C with a mean of 21 °C [23]. In 2015 Uganda's population was estimated at 41 million in 2015 with a 16.1% urban population [19].

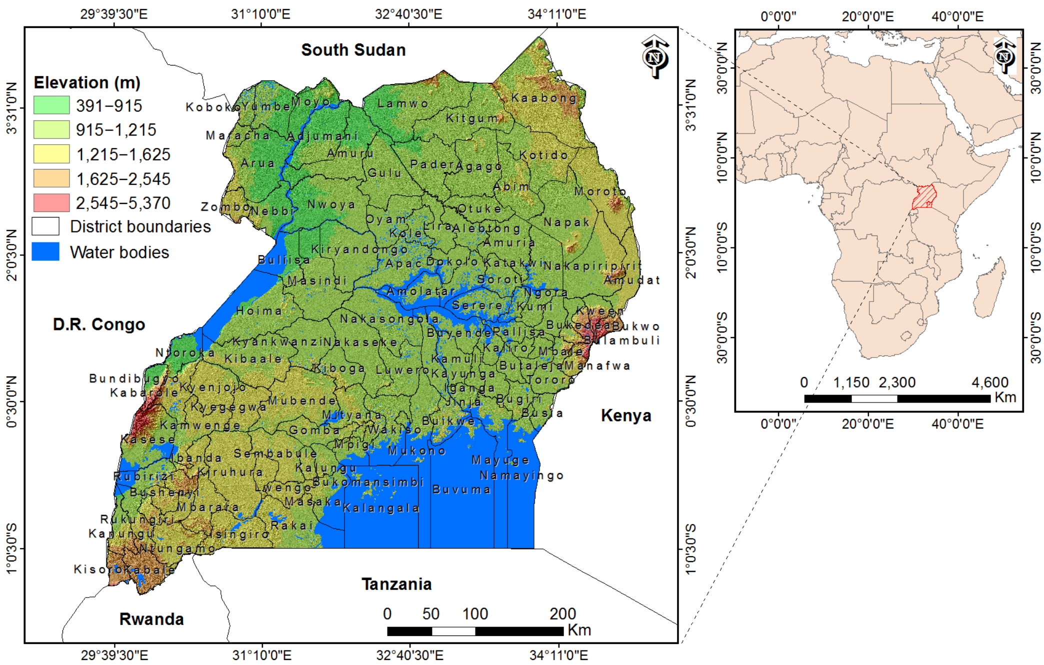


**Figure 1.** Map showing the elevation and district administrative boundaries of Uganda.

The updated administrative boundaries of Uganda utilized in this study were provided by the Energy sector GIS working group in Uganda [24]. Figure 2 presents the flowchart used for modeling the soil erosion risk by water in Uganda.

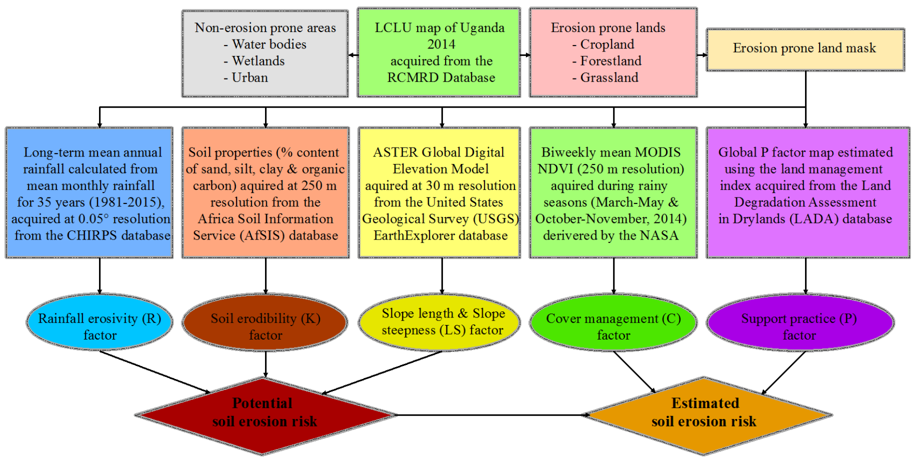


**Figure 2.** Flowchart used for modeling soil erosion risk by water in Uganda. LCLU: Land Use and Land Cover, RCMRD: Regional Centre for Mapping of Resources for Development, CHIRPS: Climate Hazards Group InfraRed Precipitation with Station data, ASTER: Advanced Space borne Thermal Emission and Reflection Radiometer, MODIS: Moderate Resolution Imaging Spectroradiometer, NDVI: Normalized Difference Vegetation Index, NASA: National Aeronautics and Space Administration.

### *2.2. Land Cover and Land Use*

Soil erosion rates are generally different for various land cover and land use types [25,26]. The 2014 land cover and land use map for Uganda (Figure 3) acquired from the Regional Center for Mapping of Resources for Development (RCMRD) Land Cover Viewer database [17] was used to separate erosion and non-erosion prone areas and to assess the rates of soil erosion risk for different land cover and land use types.

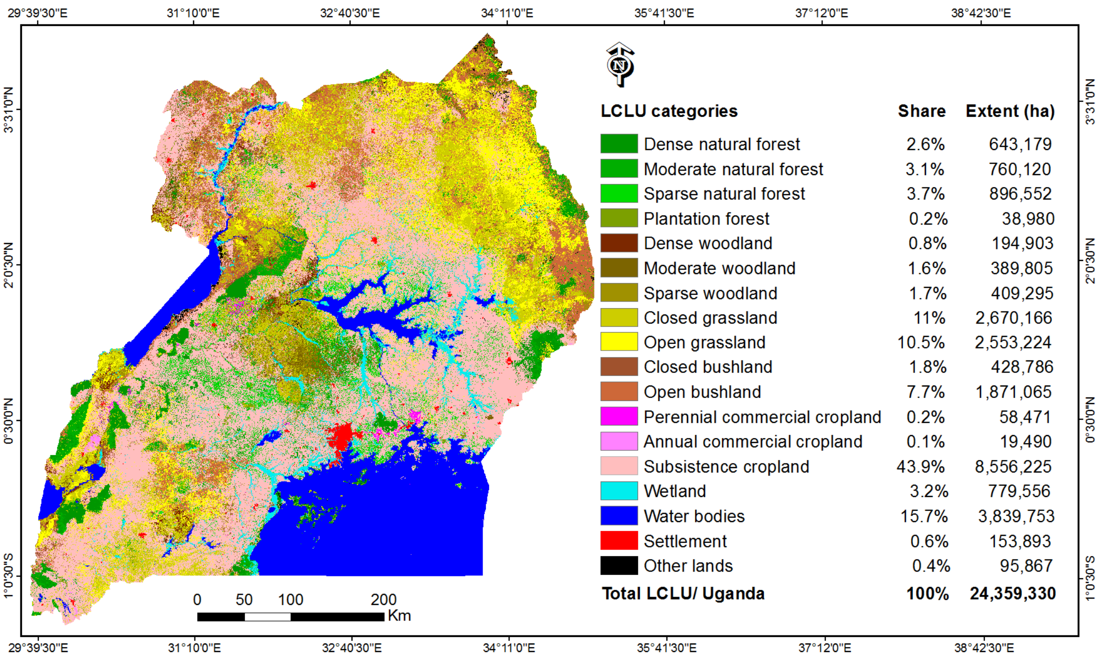


**Figure 3.** Land cover and land use (LCLU) map of Uganda in 2014.

### *2.3. RUSLE Model Application*

#### 2.3.1. RUSLE Model Description

The Revised Universal Soil Loss Equation (RUSLE) model is an update version of the Universal Soil Loss Equation (USLE) model [22]. The USLE was designed by the United States Department of Agriculture (USDA) in 1978 to predict longtime-average inter-rill and rill cropland soil losses by water under various effects such as land use, relief, soil and climate, and guide development of conservation plans to control erosion [27]. The RUSLE model contains a computer program to facilitate the calculations and includes the analysis of research data that were unavailable when USLE was completed. Although the USLE has been retained in RUSLE, but the technology for factor evaluation has been altered and new data have been introduced with which to evaluate the terms for specified conditions [22]. In the RUSLE model, the potential soil erosion risk consists of only the multiplication of three natural factors (rainfall erosivity, soil erodibility and slope length and slope steepness factors), to indicate the area under high vulnerability [27,28]. Contrary, the estimated soil erosion risk (Equation (1)) is estimated by the product of both natural and human induced factors (rainfall erosivity, soil erodibility, slope length and slope steepness, cover management and support practice factors) [22,27].

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

where: A = annual soil loss ($t \cdot ha^{-1} \cdot y^{-1}$); R = rainfall-runoff erosivity factor ($MJ \cdot mm \cdot ha^{-1} \cdot h^{-1} \cdot y^{-1}$); K = soil erodibility factor ($t \cdot ha \cdot h \cdot ha^{-1} \cdot MJ^{-1} \cdot mm^{-1}$); LS = slope length and slope steepness factor; C = cover management factor; P = support practice factor.

2.3.2. Estimation of the RUSLE Factors

When estimating the soil erosion risk, it is recommended to exclude surfaces that are not prone to soil erosion such as urban areas, bare rocks, glaciers, wetlands, lakes, rivers, inland waters and marine waters [29,30]. The RUSLE input geospatial datasets utilized in this study were acquired from different sources with varying geospatial resolutions of 30 m for LCLU map and Advanced Space borne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) and 250 m for rainfall, soil properties, and Moderate Resolution Imaging Spectroradiometer (MODIS) Normalized Difference Vegetation Index (NDVI). In order to produce the maps of soil loss risks at a high resolution of 30 m, the data with 250 m resolution were first converted to point shapefiles. Then, these points were interpolated at 30 m resolution using the inverse distance weighting (IDW) tool available in the Interpolation toolset of the ArcGIS Map 10.2. Statistical analysis was achieved using the Zonal Statistics as Table Tool available in the Spatial Analyst Zonal Toolset of the ArcGIS Map 10.2 (ArcGIS software version 10.2, Environment Systems Research Institute (Esri) Inc., Redlands, CA, USA).

Estimation of the R factor using the Wischmeier and Smith (1978) method requires an average of Kinetic energy Intensity (EI) values of at least 20 years to accommodate apparent cyclical rainfall patterns [27,31,32]. However, this data is available on few stations worldwide [33,34] including Uganda [21]. Therefore, the R factor (Figure 4a) was estimated using another alternative equation (Equation (2)) proposed by Lo et al. (1985) that gives also reasonable results [3,35].

$$R = 38.46 + 3.48 \times P \tag{2}$$

where $P$ is the mean annual precipitation in mm.

The long-term mean annual precipitation from 1981 to 2015 was calculated from the monthly average precipitation provided by the Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) [36].

The K factor expresses the susceptibility of soil erodibility due to its soil properties [37,38]. Soil erodibility factor of Uganda (Figure 4b) was estimated based on the sand, clay, silt and organic carbon fractions compiled by the Africa Soil Information Service (AfSIS) [39] using Equation (3) proposed by Williams (1995) [38,40,41].

$$K_{USLE} = A \times B \times C \times D \times 0.1317 \tag{3}$$

where $A$ is a factor that gives low soil erodibility factors for soils with high coarse-sand contents and high values for soils with less sand (Equation (3a)); $B$ is a factor that gives low soil erodibility factors for soils with high clay to silt ratios (Equation (3b)); $C$ is a factor that reduces soil erodibility for soils with high organic carbon content (Equation (3c)); and $D$ is a factor that reduces soil erodibility for soils with extremely high sand contents (Equation (3d)). Practically, $A$, $B$, $C$ and $D$ were multiplied with 0.1317 value in order to convert the K factor from the American system to the metric system unity/International System of Units (SI) [22].

$$A = (0.2 + 0.3 exp(-0.0256\, SAN\, (1 - SIL/100)) \tag{3a}$$

$$B = \left(\frac{SIL}{CLA + SIL}\right)^{0.3} \tag{3b}$$

$$C = \left(1 - \frac{0.0256\, C}{C + exp(3.72 - 2.95\, C)}\right) \tag{3c}$$

$$D = \left(1 - \frac{0.7\, SN1}{SN1 + exp(-5.51 + 22.9\, SN1)}\right) \tag{3d}$$

where $SAN$ is the percent sand content (0.05–2.00 mm diameter particles); $SIL$ is the percent silt content (0.002–0.05 mm diameter particles); $CLA$ is the percent clay content (<0.002 mm diameter particles); $C$ is the percent organic carbon content of the layer; and $SN1 = 1 - SAN/100$.

The slope length and steepness factor (LS) is a product of two separate factors: slope length (L) and steepness (S). Slope length is defined as the horizontal distance from the origin of overland flow to the point at which either the slope gradient decreases significantly for deposition to begin or the runoff water enters a well-defined channel [42]. The recent advent of GIS and remote sensing technology has enabled more accurate estimation of slope length and steepness [43–45]. LS factor (Figure 4c) was estimated from the ASTER GDEM version 2 (30 m resolution) provided by the United States Geological Survey (U.S.G.S.) using the Raster Calculator tool from the Spatial Analyst extension of ArcMap 10.2 (Environment Systems Research Institute (Esri) Inc., Redlands, CA, USA) [46]. The L factor was estimated using the algorithm (equation 4) developed by Desmet and Govers (1996) [43,44]. Thus, the S factor was estimated using the McCool et al. (1987) method (Equation (5)) [44,47–49].

$$L_{i.j} = \frac{\left(A_{i.j-in} + D^2\right)^{m+1} - A_{i.j-in}^{m+1}}{D^{m+2}.x_{i.j}^{m}.(22.13)^{m}} \quad (4)$$

$$m = \frac{\beta}{1 + \beta} \quad (4a)$$

$$\beta = \frac{Sin\ \theta/0.0896}{3(Sin\ \theta)^{0.8} + 0.56} \quad (4b)$$

$$S_{i.j} = \begin{cases} 10.8 sin\theta_{i.j} + 0.03, & tan\ \theta_{i.j} < 9\ \% \\ 16.8 sin\theta_{i.j} - 0.50, & tan\ \theta_{i.j} \geq 9\ \% \end{cases} \quad (5)$$

where $L_{i.j}$ = slope length factor for the grid cell with coordinates (i.j); $D$ = the grid cell size (m); $x_{i.j}$ = $\left(sin\ a_{i.j} + cos\ a_{i.j}\right)$; $a_{i.j}$ = aspect direction for the grid cell with coordinates $(i.j)$; $A_{i.j-in}$ = Flow accumulation or contributing area at the inlet of a grid cell with coordinates (i.j) ($m^2$). The slope-length exponent m is related to the ratio β of rill erosion (caused by flow) to interrill erosion (principally caused by raindrop impact); β is the ratio of rill to interrill erosion for conditions when the soil is moderately susceptible to both rill and interrill erosion; θ is the slope angle in (degrees) [22,44].

The $C$ factor is the ratio of soil loss from land cropped under specified conditions to the corresponding loss from clean-tilled, continuous fallow land [27,42]. For Uganda, the C factor (Figure 4d) was estimated using the biweekly mean MODIS NDVI provided by the National Aeronautics and Space Administration (NASA) [50] for the rainy seasons (March–May and October–November 2014) using Equation (6) [51].

$$C = exp\left(-a * \frac{NDVI}{\beta - NDVI}\right) \quad (6)$$

where $\alpha = 2$ and $\beta = 1$ are the parameters that determine the shape of the NDVI-C curve.

The P factor represents erosion control practices, such as contouring, strip-cropping and terracing [27,52]. The P factor value of 0.75 utilized in this study was retrieved from the Land Degradation Assessment in Drylands (LADA) project that estimated the global P factor values using a land management index related to overall crop performance [3].

This study predicted the soil erosion rates in Uganda's croplands (86,341.86 $km^2$) assuming the most three known soil erosion control measures (contouring, strip-cropping and terracing) based on the slope grades and their corresponding P factor values proposed by Shin (1999) (Table 1) [52,53].

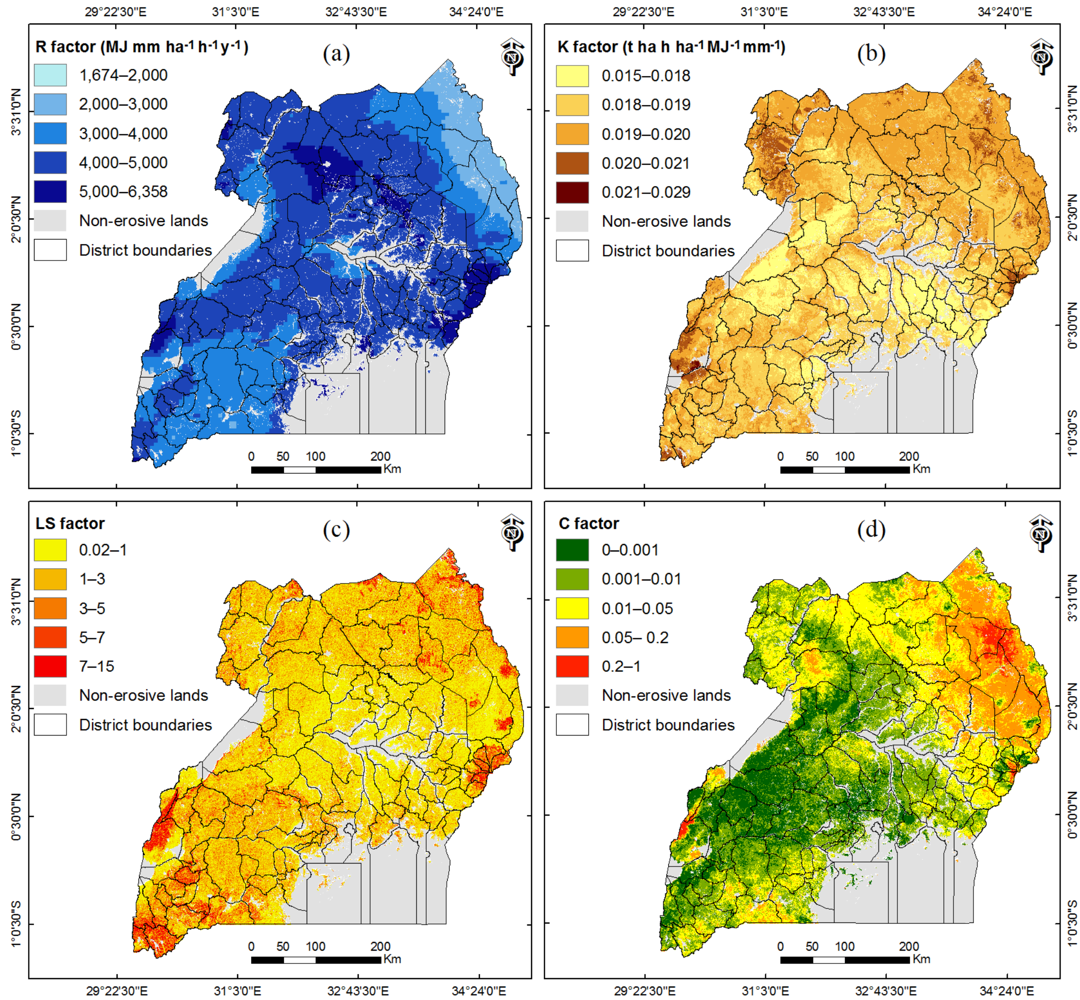


**Figure 4.** The Revised Universal Soil Loss Equation (RUSLE) factor maps: (**a**) rainfall-runoff erosivity factor; (**b**) soil erodibility factor; (**c**) slope length and slope steepness factor; and (**d**) cover management factor.

**Table 1.** P factor values for contouring, strip-cropping, and terracing focusing on the slope classes.

| Slope (%) | Conservation Support Practices (P Factor) | | |
|---|---|---|---|
| | Contouring | Strip Cropping | Terracing |
| 0.0–7.0 | 0.55 | 0.27 | 0.10 |
| 7.0–11.3 | 0.60 | 0.30 | 0.12 |
| 11.3–17.6 | 0.80 | 0.40 | 0.16 |
| 17.6–26.8 | 0.90 | 0.45 | 0.18 |
| >26.8 | 1.00 | 0.50 | 0.20 |

## 3. Results

### *3.1. Assessment of Soil Erosion Risk at National Level*

For the purpose of facilitating the analysis and identifying soil erosion hotspot areas that are high priorities for conservation practices, the grid cells were classified into eight categories. The erosion-prone area was estimated at 194,902.61 km$^2$ (80%) of Uganda's total surface area (243,593.30 km$^2$). The remaining 20% (48,690.69 km$^2$) was occupied by the non-erosive lands according to the land cover and land use map of Uganda in 2014 [17]. The mean rate of the potential soil loss risk was estimated at 144.3 t·ha$^{-1}$·y$^{-1}$. The total potential erosion risk was estimated at 2821 million tons of the entire erosive lands of Uganda in 2014 (Figure 5a and Table 2). The rate of the mean estimated soil erosion risk by water was 3.2 t·ha$^{-1}$·y$^{-1}$ for the erosion-prone lands in Uganda. The total national predicted soil loss was about 62 million tons per year in 2014 (Figure 5b and Table 3).

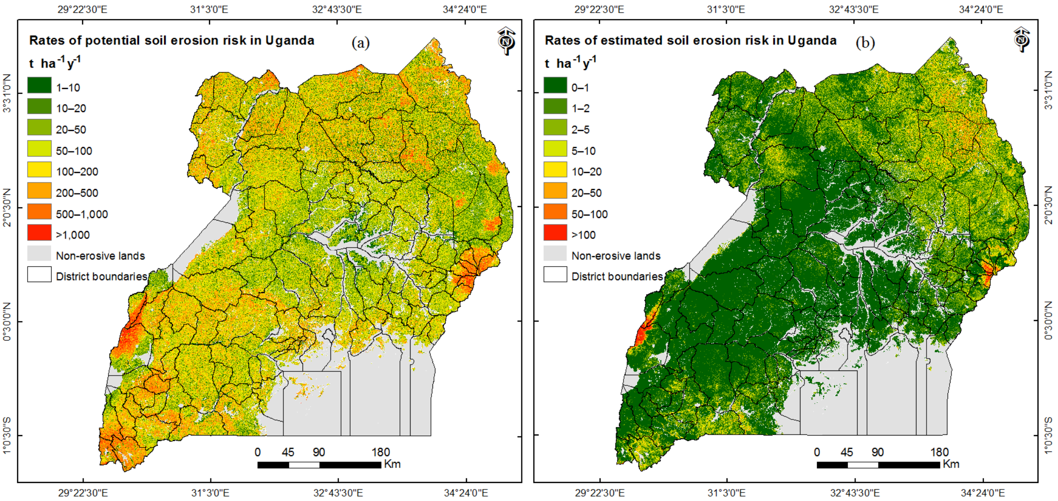


**Figure 5.** Maps of the soil erosion risk by water in the whole erosion-prone area (194,902.61 km$^2$) of Uganda in 2014: (**a**) potential soil erosion risk and (**b**) estimated soil erosion risk.

**Table 2.** The rates of potential erosion risk per class (of the entire erosive lands of 194,902.61 Km$^2$) corresponding to Figure 5a and focusing on the croplands, rainfall intensity, and slope gradient.

| Soil Loss Class (t·ha$^{-1}$·y$^{-1}$) | % of Total Area | Mean Soil Loss in the Class (t·ha$^{-1}$·y$^{-1}$) | % of Contribution to Total Soil Loss | % of Cropland | Mean Rainfall in the Class (mm·y$^{-1}$) | Mean Slope% in the Class |
|---|---|---|---|---|---|---|
| 1–10 | 9.2 | 3.6 | 0.2 | 7.9 | 1157 | 0.2 |
| 10–20 | 5.0 | 15.2 | 0.5 | 4.6 | 1141 | 1.5 |
| 20–50 | 17.7 | 35.2 | 4.3 | 17.4 | 1159 | 3.6 |
| 50–100 | 24.2 | 72.7 | 12.2 | 26.0 | 1192 | 7.2 |
| 100–200 | 21.5 | 143.7 | 21.4 | 23.0 | 1185 | 12.4 |
| 200–500 | 17.7 | 301.7 | 37.1 | 17.7 | 1191 | 22.6 |
| 500–1000 | 4.1 | 669.3 | 18.8 | 3.2 | 1236 | 46.3 |
| >1000 | 0.6 | 1,242.7 | 5.5 | 0.2 | 1482 | 69.1 |
| Total erosive lands | 100 | 144.3 | 100 | 100 | 1182 | 11.4 |

**Table 3.** The rates of estimated erosion risk per class (of entire erosive lands of 194,902.61 Km$^2$) corresponding to Figure 5b and focusing on the croplands, rainfall intensity, and slope gradient.

| Soil Loss Class (t·ha$^{-1}$·y$^{-1}$) | % of Total Erosive Lands | Mean Soil Loss in the Class (t·ha$^{-1}$·y$^{-1}$) | % of Contribution to Total Soil Loss | % of Cropland | Mean Rainfall in the Class (mm·y$^{-1}$) | Mean Slope % in the Class |
|---|---|---|---|---|---|---|
| 0–1 | 61.8 | 0.2 | 4.7 | 69.6 | 1215 | 8.1 |
| 2–5 | 11.7 | 1.4 | 5.3 | 11.7 | 1187 | 11.6 |
| 5–10 | 13.8 | 3.2 | 13.9 | 11.5 | 1142 | 14.4 |
| 10–20 | 6.9 | 7.0 | 15.1 | 4.6 | 1082 | 19.6 |
| 20–50 | 3.6 | 13.8 | 15.5 | 1.9 | 1016 | 26.1 |
| 20–50 | 1.6 | 29.3 | 15.0 | 0.6 | 972 | 33.5 |
| 50–100 | 0.3 | 67.0 | 5.9 | 0.1 | 1188 | 42.3 |
| >100 | 0.3 | 300.5 | 24.6 | 0.0 | 1658 | 59.6 |
| Total erosive lands | 100 | 3.2 | 100 | 100 | 1182 | 11.4 |

Apart from the rainfall and topographic factors, soil properties and cover management conditions influence the variation of soil loss rates. However, there are big variations in rainfall distribution and slope gradient, which lead to high fluctuations in the soil erosion risk from one place to another.

The rate of the potential erosion risk in Uganda is increasing with the increase of the rainfall intensity, slope gradient, and soil erodibility (Table 2).

Although the soil erosion tolerance threshold for tropical ecosystems has been estimated at 10 $t \cdot ha^{-1} \cdot y^{-1}$ [54,55], it seems high compared to the impact of soil erosion on crop productivity and water quality. In the United States of America and Europe, a limit of 1 $t \cdot ha^{-1} \cdot y^{-1}$ has been set as the upper soil loss tolerance for environmental protection, when considering the impact of soil erosion/sediment production rates, for soil to reach its finite point (i.e., the minimum soil depth required before it becomes economically unsustainable to maintain the current land use on water quality) [56–58]. Therefore, in this study a mean estimated soil loss rate of 1 $t \cdot ha^{-1} \cdot y^{-1}$ was considered as a recommendable sustainable soil loss tolerance, while areas that are comprised of a soil loss rate >10 $t \cdot ha^{-1} \cdot y^{-1}$ were considered as highly exposed lands that require serious soil erosion control measures. About 76,012.02 $km^2$ (39% of the country's erosion-prone lands) have an unsustainable mean estimated soil loss rate >1 $t \cdot ha^{-1} \cdot y^{-1}$ (Figure 5b and Table 3). The variations of the predicted soil loss rates in Uganda were mainly influenced by topographic, rainfall, and cover management factors.

### 3.2. Assessment of Estimated Soil Erosion Risk at District Level

Soil loss analysis at the district level indicated that out of 112 districts in Uganda, 66 districts are comprised of unsustainable mean estimated soil loss rates >1 $t \cdot ha^{-1} \cdot y^{-1}$. Hence, soil erosion control measures should be primarily focused on the following six districts that had mean estimated soil loss rates >10 $t \cdot ha^{-1} \cdot y^{-1}$: Bududa (46.3 $t \cdot ha^{-1} \cdot y^{-1}$), Kasese (37.5 $t \cdot ha^{-1} \cdot y^{-1}$), Bundibugyo (28.9 $t \cdot ha^{-1} \cdot y^{-1}$), Bulambuli (20.9 $t \cdot ha^{-1} \cdot y^{-1}$), Sironko (14.6 $t \cdot ha^{-1} \cdot y^{-1}$) and Kotido (12.5 $t \cdot ha^{-1} \cdot y^{-1}$). Except the Kotido district , which has a mean gentle slope of 11.1% and a moderate rainfall intensity (833 $mm \cdot y^{-1}$), the other five districts have steep slopes, ranging from 14.3% to 35.9%, and high mean rainfall intensities, ranging from 1150 to 1626 $mm \cdot y^{-1}$. Out of 112 Uganda districts, 65 districts had croplands with unsustainable estimated soil loss rates >1 $t \cdot ha^{-1} \cdot y^{-1}$. There were only two districts (Kotido and Moroto) that had croplands associated with the highest estimated soil loss rates of 14.17 $t \cdot ha^{-1} \cdot y^{-1}$ and 12.65 $t \cdot ha^{-1} \cdot y^{-1}$, respectively (Table A1).

### 3.3. Analysis of Estimated Soil Loss Per Land Cover and Land Use Types in Uganda

The RCMRD LCLU map of Uganda from 2014 (Figure 3) and the map of the estimated soil erosion risk (Figure 5b) were used to analyze the state of soil loss per LCLU types. Figure 6 indicates the highest estimated soil loss rates >10 $t \cdot ha^{-1} \cdot y^{-1}$ were found in moderate natural forest (11 $t \cdot ha^{-1} \cdot y^{-1}$) and dense natural forest (10.6 $t \cdot ha^{-1} \cdot y^{-1}$) because these forests are located in highland areas with a steep topography (mean slope of 21% for dense natural forest and 16% for moderate natural forest) and a high mean rainfall intensity of 1292 $mm \cdot y^{-1}$ for dense natural forest and 1255 $mm \cdot y^{-1}$ for moderate natural forest. The croplands that are distributed in the areas with a gentle mean slope of 11% and a mean rainfall intensity of 1243 $mm \cdot y^{-1}$ had a moderate mean soil loss of 1.5 $t \cdot ha^{-1} \cdot y^{-1}$ (50% less than the mean soil loss rate of 3.2 $t \cdot ha^{-1} \cdot y^{-1}$ for the total erosion-prone lands).

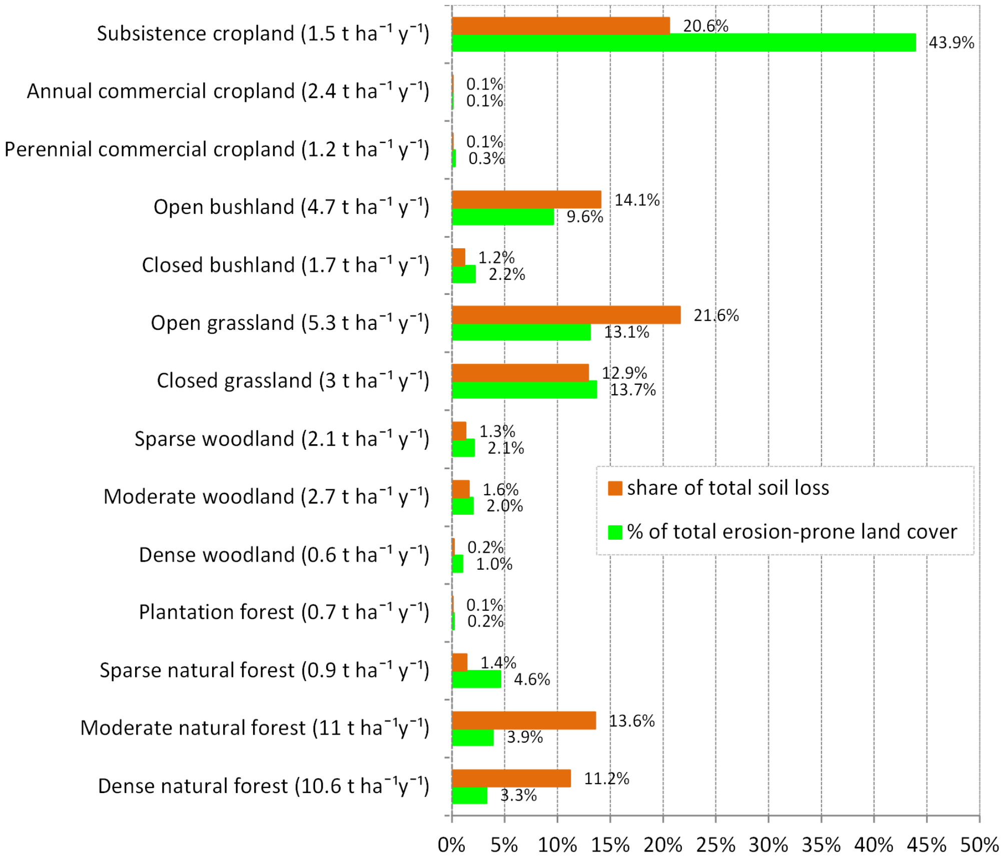


**Figure 6.** Rates of mean estimated soil loss per land cover and land use types and their corresponding shares of soil loss.

### *3.4. Assesssment of Estimated Soil Erosion Risk in the Protected Areas of Uganda*

According to the United Nations Environment Program (UNEP) and the World Conservation Monitoring Center (WCMC), Uganda has 705 protected areas covering over 35,960.95 km$^2$ (14.8% of the total national extent) [59]. Erosion-prone lands occupied 34,635.53 km$^2$ (96.3% of the total protected areas). In the entire erosion-prone protected areas, the total soil loss, overall mean estimated soil loss, mean rainfall and slope were 29 million t·y$-^1$, 8.3 t·ha$-^1$·y$-^1$, 1113 mm·y$^{-1}$ and 15%, respectively. Deep soil loss analysis was conducted on the 50 largest soil erosion-prone protected areas, covering over 32,652.57 km$^2$ (94% of the total erosion-prone protected areas or 76% of the total national protected areas). In all 50 largest protected areas, the estimated soil loss amount, soil erosion rate, mean rainfall, and slope were estimated at about 28 million t·y$-^1$, 9.6 t·ha$-^1$·y$-^1$, 1091 mm·y$^{-1}$ and 15%, respectively (Table A2). Twenty-seven out of the 50 largest protected areas had an unsustainable mean estimated soil loss rate >1 t·ha$^{-1}$·y$^{-1}$. The following five protected areas are exposed to the highest estimated mean soil loss rates >10 t·ha$^{-1}$·y$^{-1}$: Rwenzori Mountains (142.94 t·ha$-^1$·y$-^1$), Mount Elgon (33.81 t·ha$-^1$·y$-^1$), Bokora corridor (12.13 t·ha$-^1$·y$-^1$), Matheniko (10.39 t·ha$-^1$·y$-^1$), and Nangolibwel (10.33 t·ha$-^1$·y$-^1$) (Figure 7; Table A2).

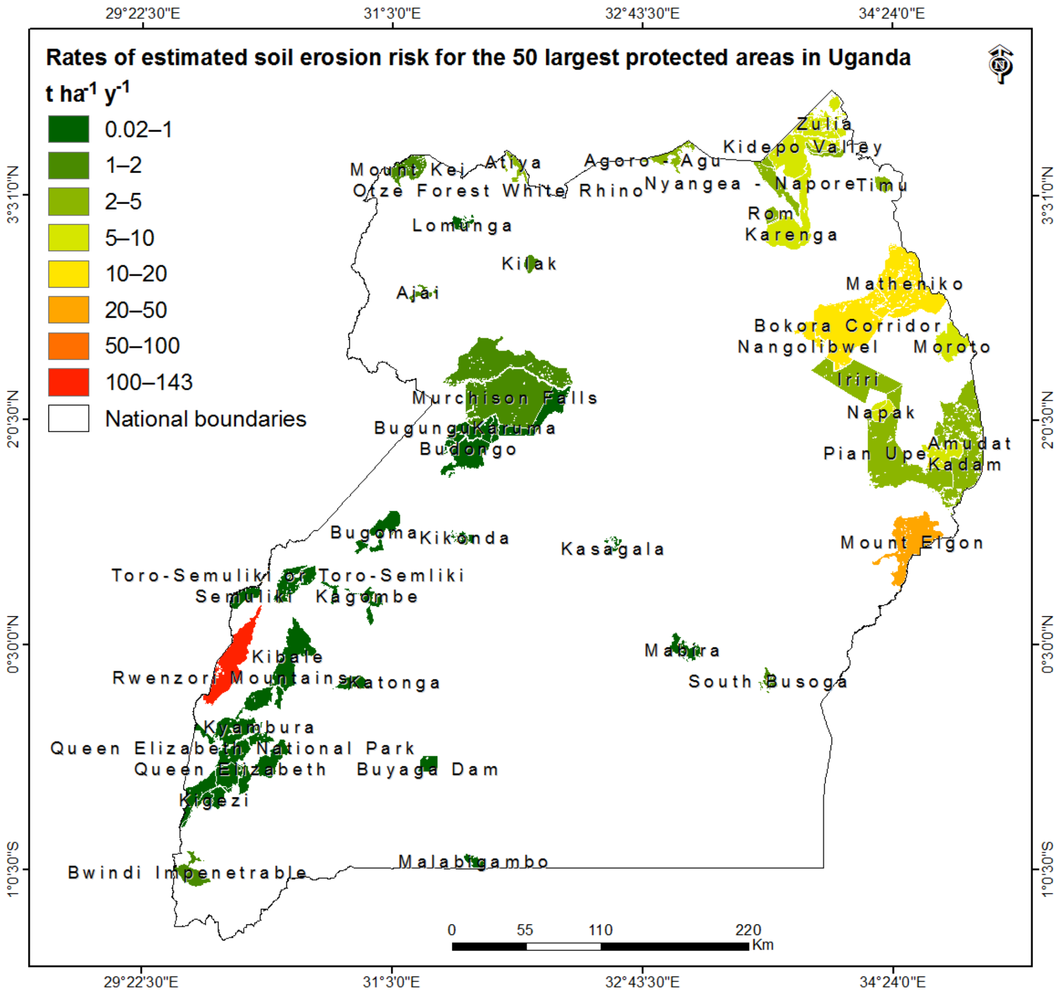


**Figure 7.** Map of estimated soil erosion rates for the 50 largest protected areas in Uganda.

These severe soil loss rates observed from the forestland and grassland areas indicate an unhealthy or disturbed ecosystem as previously stated by other studies, where the removal or alteration of vegetation, mining, destruction of forest, human-caused fires, and soil compaction from domestic animals grazing significantly increase the soil erosion risk [25,27]. Furthermore, the study of Panagos et al. (2015) showed that in southern Spain, very high soil loss rates (40.16 t·ha$^{-1}$·y$^{-1}$) existed mainly at high altitudes with scattered vegetation [60].

## 4. Discussion

### *4.1. Overview of Estimated Soil Erosion Risk in Uganda*

The soil loss tolerance value serves as a basis for judging whether soil has a potential risk for productivity loss or generally for soil degradation [61]. About 39% of Uganda's erosion-prone lands had an unsustainable mean estimated soil erosion rate >1 t·ha$^{-1}$·y$^{-1}$ (Figure 5b and Table 3) [56–58]. Of Uganda's total soil loss, 76.1% was in areas with a high soil loss risk of about 12.7% (>10 t·ha$^{-1}$·y$^{-1}$) (Figure 5b and Table 3) characterized by steep slope range of 19.6%–59.6% and a high overall mean rainfall intensity (1183.2 mm·y$^{-1}$). A spatial analysis of the estimated soil loss risk at a district level demonstrated that 66 of the 112 districts of Uganda are exposed to an overall mean erosion risk rate >1 t·ha$^{-1}$·y$^{-1}$ and six districts including Bududa, Kasese, Bundibugyo, Bulambuli, Sironko and Kotido have seriously suffered from the estimated soil loss rates >10 t·ha$^{-1}$·y$^{-1}$ and hence require emergency soil erosion control measures (Table A1). A spatial analysis by LCLU types indicated that except for dense woodland, plantation forest and sparse natural forest, all other land cover types had unsustainable soil loss risk rates >1 t·ha$^{-1}$·y$^{-1}$.

The highest mean soil loss rates >10 t·ha$^{-1}$·y$^{-1}$ were found in moderate natural forest (11 t·ha$^{-1}$·y$^{-1}$) and dense natural forest (10.6 t·ha$^{-1}$·y$^{-1}$) due to their location in highland areas with mean steep slopes of 21% and 16% for dense natural forest and moderate natural forest, respectively, and high mean rainfall intensities of 1292 mm·y$^{-1}$ and 1255 mm·y$^{-1}$ and for dense natural forest and moderate natural forest, respectively. Subsistence croplands that occupied 43.9% of the total erosion-prone lands had a moderate mean soil loss risk (1.5 t·ha$^{-1}$·y$^{-1}$) and contributed about 20.6% of the total soil loss in Uganda (Figure 6). These soil loss rates observed in Uganda are comparable with the other estimated soil loss risk rates for tropical lands with similar RUSLE factor characteristics. For instance, within the Sierra de Manantlán Biosphere Reserve in Mexico, a region characterized by a mountainous topography and a tropical uni-modal precipitation regime, had an estimated soil erosion risk ranging from 0 to 100 t·ha$^{-1}$·y$^{-1}$ [45]. In the Chemoga watershed in Ethiopia, the soil erosion risk ranges from 0 in the downstream part of the watershed to over 80 t·ha$^{-1}$·y$^{-1}$ in much of the midstream and upstream parts, and >125 t·ha$^{-1}$·y$^{-1}$ in some erosion hotspot areas [62].

### 4.2. Impact Assessment of Support Practices on Soil Erosion Reduction in Uganda

According to the Land Degradation Assessment in Drylands (LADA) project (2010), the study conducted on the global land degradation indicated that the Sub-Saharan African lands were poorly managed with an estimated support practice value of 0.75 [3]. A lack of soil erosion control measures reduces the productivity of all natural ecosystems (agriculture, forest, and pasture) due to the loss of soil nutrients [63,64]. Soil erosion leads to food insecurity and water pollution. Currently, about 66% of the world's population is malnourished [63]. In Uganda, the effects of stunting are largely irreversible beyond two years of age, and 54% of adults today suffered from stunting as children. More than eight million people of working age are not able to achieve their potential as a consequence of childhood malnutrition. It has been indicated that stunting alone will cost Uganda more than U.S. $7.7 billion in lost productivity by 2025 [65]. Soil erosion is also threatening the water quality and leading to invasive aquatic plants, where the peak water hyacinth in Lake Victoria was estimated at the extent of 4732 ha on the Ugandan part for the period between December 1995 and October 2001 [12].

Soil erosion in undisturbed forest is extremely low, generally under 1 mg·ha$^{-1}$·y$^{-1}$. Disturbances, however, can dramatically increase soil erosion to levels exceeding 100 mg·ha$^{-1}$·y$^{-1}$. These disturbances include natural events such as wildfires and human-induced disturbances such as road construction and timber harvesting. Soil erosion, combined with other impacts from forest disturbance, such as soil compaction, can reduce forest sustainability and soil productivity [66]. Soil erosion that was considered a severe problem associated with unsustainable farming methods [66,67] could be controlled by promoting anti-erosion measures such as terracing, strip-cropping, contouring, the planting of cover crops, keeping plant residues at the soil surface, the maintenance of stone walls, and the increased use of grass margins [52,60,67]. Under the state of 2014 land management in Uganda with a P factor value of 0.75 reported by the LADA project [3], the total cropland (86,341.86 Km$^2$) was exposed to a moderate mean estimated soil erosion rate of 1.5 t·ha$^{-1}$·y$^{-1}$ in 2014; 30.4% of the croplands comprised an unsustainable mean soil loss >1 t·ha$^{-1}$·y$^{-1}$, while 2.6% of the croplands that had high soil loss rates >10 t·ha$^{-1}$·y$^{-1}$ were located on very steep slopes ranging from 28% to 38% with an abundant rainfall intensity ranging from 1143 to 1147 mm·y$^{-1}$ (Figure 8a). Our study analysis revealed that well-established terraces and strip-cropping could significantly reduce the estimated soil loss rate in croplands by 80% (from 1.5 t·ha$^{-1}$·y$^{-1}$ to 0.3 t·ha$^{-1}$·y$^{-1}$) and by 47% (from 1.5 t·ha$^{-1}$·y$^{-1}$ to 0.8 t·ha$^{-1}$·y$^{-1}$), respectively (Figure 8a,c). With a moderate mean erosion rate of 1.6 t·ha$^{-1}$·y$^{-1}$, the cropland with an assumed contouring support practice presents almost the same soil loss rate as the 2014 land management status where the mean estimated soil erosion rate was estimated at 1.5 t·ha$^{-1}$·y$^{-1}$ (Figure 8d).

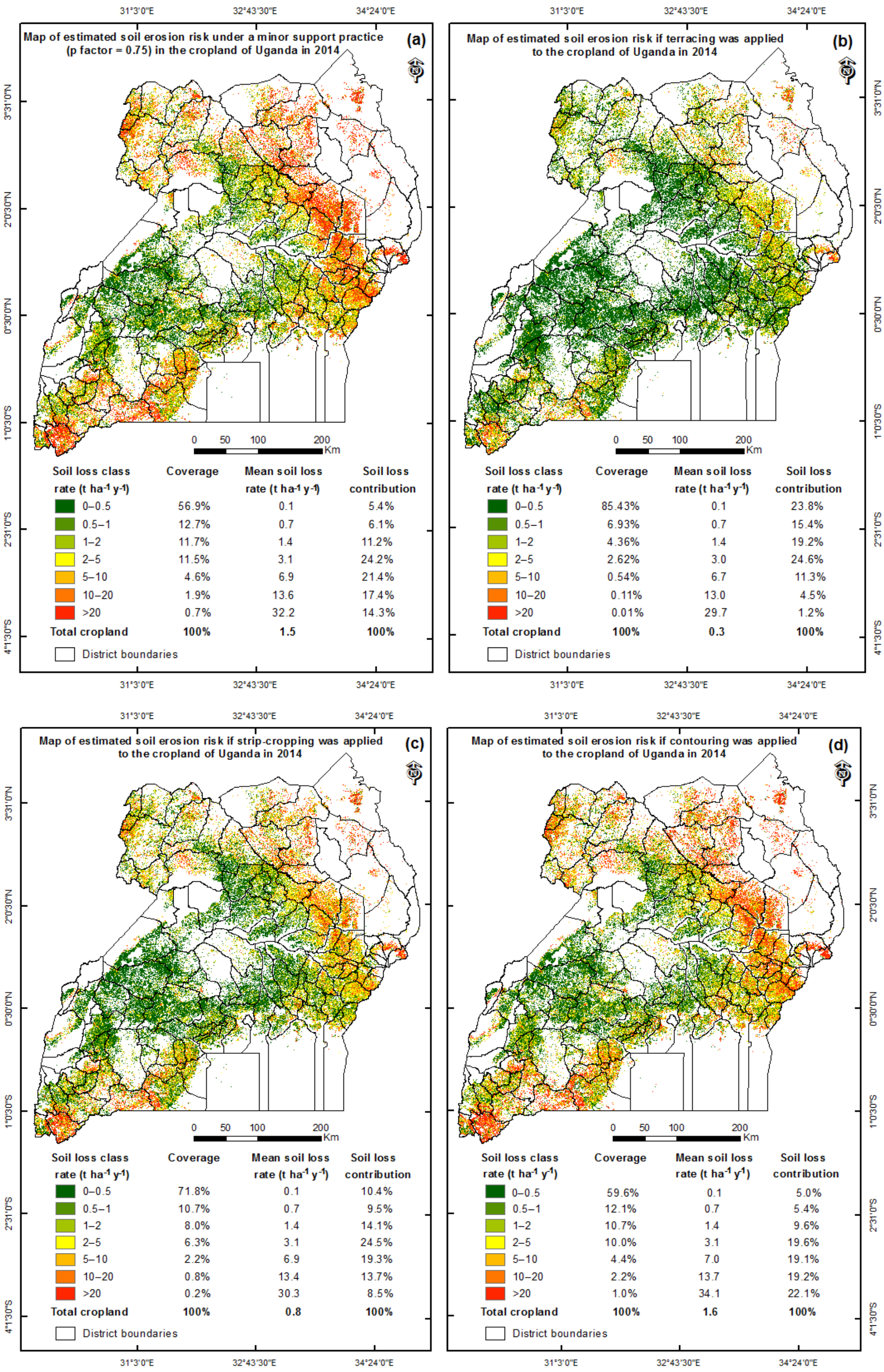


**Figure 8.** Maps of the estimated soil loss risk for Uganda's croplands (86,341.86 km$^2$) under different support practices: (**a**) minor conservation in 2014 (P = 0.75); (**b**) terracing; (**c**) strip-cropping; and (**d**) contouring.

### *4.3. Advantages and Uncertainties of the RUSLE Model*

It should be noted that the RUSLE model was selected because of the relatively limited data required and its simplicity, as already stated by other authors [68,69]. The RUSLE model is well studied and it has been widely applied at different scales to estimate soil erosion loss, and to plan erosion control for different land cover categories such as croplands, rangelands, and disturbed forest lands [21,31,41,70,71]. When comparing the RUSLE model with the other soil erosion modeling methods such as Co-ordinated Information on theEnvironment (CORINE), the Netherlands National Institute for Public Health and the Environment (Dutch: *Rijksinstituut voor Volksgezondheid en Milieu* (RIVM)), the Global Assessment of Soil Degradation (GLASOD) and Hot Spot approaches, the RUSLE model gives the most detailed information on the soil erosion risks [72]. The RUSLE model often uses secondary data freely available in a Geographic Information System as an alternative approach because the measurement of soil erosion is expensive and time-consuming [21].

Although the RUSLE model is considered as a leading model in soil erosion assessment, the data available to derive some of the RUSLE parameters constitute a major limitation for maximizing the accuracy of and harmonizing the RUSLE processing methods worldwide. The model-based approach implies uncertainties in the calculation of each factor. This disadvantage is common among all approaches produced with model-based methods [51,73].

## 5. Conclusions

The assessment of soil erosion risk using the freely available geospatial datasets (rainfall, soil properties, Digital Elevation Model (DEM), Normalized Difference Vegetation Index (NDVI) and Land Cover and Land Use (LCLU) maps by means of the RUSLE model and GIS techniques gives reasonable results and is economical when assessing soil erosion risk on a large watershed or at the national level. The results of this study indicated that the highest soil loss rates >10 $t \cdot ha^{-1} \cdot y^{-1}$ occurred in the natural forests distributed in the highlands of Uganda, mostly due to the high rainfall intensity, the steep slopes and the high cover management factor value, which indicated unhealthy biomass or a disturbed ecosystem. Policy-makers should reduce soil erosion rates from the grasslands, forests, and protected areas through the control of wildfires, mass movements, and human-induced disturbances, such timber harvesting and soil compaction from domestic animals, which increase the risk of soil erosion likelihood. Although the croplands are associated with a moderate mean estimated soil loss rate (1.5 $t \cdot ha^{-1} \cdot y^{-1}$), over 30.4% of the croplands had unsustainable mean soil loss rates >1 $t \cdot ha^{-1} \cdot y^{-1}$ and they require soil erosion control measures using either terracing or strip-cropping support practices which have high potential in soil loss reduction, to bring them down well below the rate of sustainable soil loss tolerance (>1 $t \cdot ha^{-1} \cdot y^{-1}$).

**Acknowledgments:** The authors would like to thank the editor and anonymous reviewers for their valuable comments and suggestions to improve the quality of this paper. This study was supported by the National Basic Research Programs of China (#2014CB954204) and the National Natural Scientific Foundation of China (#U1503301).

**Author Contributions:** Fidele Karamage, Chi Zhang, Tong Liu and Andrew Maganda derived the RUSLE factors and wrote the manuscript. Alain Isabwe helped in statistical analysis and discussion.

**Conflicts of Interest:** The authors declare no conflicts of interest.

## Abbreviations

| | |
|---|---|
| ft | foot |
| ha | hectare |
| h | hour |
| t | ton |
| y | year |
| g | gram; |
| MJ | Megajoule |
| mm | millimeter |
| mg | milligrams |
| km | Kilometer |

## Appendix A

**Table A1.** Mean estimated soil loss rates per district (erosion prone lands, croplands), share of soil loss in the total erosion-prone lands, proportion of the total cropland, mean annual rainfall intensity and mean slope for the erosion-prone lands in Uganda (2014).

| District Names | % of the Total Erosive Landcover | Overall Mean Soil Loss ($t \cdot ha^{-1} \cdot y^{-1}$) | Mean Soil Loss in Croplands ($t \cdot ha^{-1} \cdot y^{-1}$) | % of the Total Soil Loss in Erosive Landcover | % of the Cropland in Uganda | Mean Rainfall in the Erosive Lands ($mm \cdot y^{-1}$) | Mean Slope % in the Erosive Lands |
|---|---|---|---|---|---|---|---|
| Abim | 1.41 | 7.0 | 8.62 | 3.10 | 0.002 | 1157 | 15.1 |
| Adjumani | 1.50 | 1.6 | 1.65 | 0.76 | 1.28 | 1291 | 12.0 |
| Agago | 1.79 | 4.6 | 4.56 | 2.57 | 1.57 | 1237 | 11.9 |
| Alebtong | 0.76 | 1.9 | 1.97 | 0.46 | 1.32 | 1427 | 6.0 |
| Amolatar | 0.45 | 0.2 | 0.21 | 0.03 | 0.76 | 1170 | 1.9 |
| Amudat | 0.82 | 3.4 | 3.95 | 0.88 | 0.03 | 860 | 6.5 |
| Amuria | 1.23 | 3.4 | 3.46 | 1.33 | 1.88 | 1320 | 6.6 |
| Amuru | 1.83 | 1.9 | 1.28 | 1.09 | 1.34 | 1350 | 10.4 |
| Apac | 1.38 | 0.3 | 0.30 | 0.11 | 1.83 | 1250 | 5.1 |
| Arua | 2.10 | 1.6 | 1.58 | 1.04 | 2.16 | 1251 | 10.5 |
| Budaka | 0.21 | 2.4 | 2.43 | 0.16 | 0.41 | 1359 | 6.9 |
| Budada | 0.16 | 46.3 | 5.26 | 2.38 | 0.09 | 1626 | 35.9 |
| Bugiri | 0.48 | 0.8 | 0.83 | 0.13 | 0.94 | 1431 | 8.2 |
| Buhweju | 0.38 | 2.4 | 3.36 | 0.29 | 0.38 | 1193 | 28.8 |
| Buikwe | 0.60 | 0.8 | 1.11 | 0.15 | 0.78 | 1364 | 10.2 |
| Bukedea | 0.51 | 1.7 | 1.77 | 0.27 | 0.75 | 1337 | 5.5 |
| Bukomansimbi | 0.29 | 1.3 | 1.31 | 0.12 | 0.60 | 1096 | 9.8 |
| Bukwo | 0.27 | 9.6 | 9.40 | 0.81 | 0.21 | 1465 | 26.1 |
| Bulambuli | 0.34 | 20.9 | 4.71 | 2.23 | 0.12 | 1478 | 14.3 |
| Buliisa | 0.50 | 0.7 | 0.74 | 0.11 | 0.29 | 1036 | 4.1 |
| Bundibugyo | 0.43 | 28.9 | 1.54 | 3.93 | 0.28 | 1362 | 26.7 |
| Bushenyi | 0.43 | 0.8 | 0.87 | 0.11 | 0.52 | 1204 | 17.3 |
| Busia | 0.36 | 0.9 | 0.87 | 0.10 | 0.72 | 1563 | 7.5 |
| Butaleja | 0.29 | 1.3 | 1.35 | 0.12 | 0.61 | 1365 | 6.1 |
| Butambala | 0.18 | 0.6 | 0.63 | 0.03 | 0.34 | 1269 | 10.8 |
| Buvuma | 0.13 | 2.1 | 2.30 | 0.09 | 0.25 | 1376 | 0.6 |
| Buyende | 0.62 | 0.3 | 0.29 | 0.05 | 1.11 | 1237 | 3.1 |
| Dokolo | 0.45 | 0.7 | 0.75 | 0.09 | 0.71 | 1358 | 3.6 |
| Gomba | 0.80 | 0.3 | 0.33 | 0.07 | 1.26 | 1154 | 9.1 |
| Gulu | 1.72 | 1.4 | 0.94 | 0.77 | 1.98 | 1448 | 9.7 |
| Hoima | 1.77 | 0.5 | 0.33 | 0.27 | 2.03 | 1071 | 7.0 |
| Ibanda | 0.49 | 0.6 | 0.52 | 0.10 | 0.92 | 1076 | 15.5 |
| Iganga | 0.48 | 0.6 | 0.57 | 0.08 | 0.91 | 1378 | 6.9 |
| Isingiro | 1.31 | 3.8 | 3.85 | 1.59 | 1.42 | 904 | 16.9 |
| Jinja | 0.32 | 1.6 | 1.64 | 0.16 | 0.57 | 1310 | 9.6 |
| Kaabong | 3.66 | 8.0 | 8.50 | 9.24 | 0.59 | 771 | 19.7 |
| Kabale | 0.85 | 5.4 | 5.46 | 1.46 | 1.49 | 1080 | 31.5 |
| Kabarole | 0.92 | 6.4 | 0.30 | 1.85 | 0.86 | 1326 | 18.6 |
| Kaberamaido | 0.63 | 0.4 | 0.47 | 0.08 | 0.90 | 1358 | 3.4 |
| Kalangala | 0.22 | 1.7 | 2.49 | 0.11 | 0.03 | 1698 | 1.3 |
| Kaliro | 0.35 | 0.7 | 0.74 | 0.08 | 0.67 | 1351 | 5.6 |
| Kalungu | 0.34 | 1.1 | 1.09 | 0.12 | 0.67 | 1168 | 8.3 |
| Kampala | 0.002 | 6.5 | 6.57 | 0.003 | 0.003 | 1262 | 9.7 |
| Kamuli | 0.74 | 0.3 | 0.32 | 0.07 | 1.39 | 1300 | 5.6 |
| Kamwenge | 1.19 | 0.3 | 0.31 | 0.11 | 1.63 | 1141 | 11.9 |
| Kanungu | 0.65 | 0.8 | 0.94 | 0.16 | 0.61 | 1138 | 20.7 |
| Kapchorwa | 0.18 | 6.1 | 3.02 | 0.35 | 0.16 | 1574 | 21.9 |
| Kasese | 1.50 | 37.5 | 1.17 | 17.68 | 0.66 | 1150 | 19.9 |
| Katakwi | 1.10 | 4.1 | 3.95 | 1.41 | 1.07 | 1194 | 6.4 |
| Kayunga | 0.71 | 0.2 | 0.22 | 0.04 | 0.99 | 1241 | 4.7 |
| Kibaale | 2.16 | 0.1 | 0.13 | 0.09 | 3.28 | 1227 | 11.0 |
| Kiboga | 0.75 | 0.3 | 0.46 | 0.07 | 0.49 | 1223 | 9.6 |
| Kibuku | 0.21 | 1.6 | 1.69 | 0.11 | 0.42 | 1404 | 7.0 |
| Kiruhura | 2.31 | 0.8 | 0.59 | 0.55 | 1.46 | 968 | 11.6 |
| Kiryandongo | 1.82 | 0.3 | 0.21 | 0.19 | 0.99 | 1310 | 6.8 |
| Kisoro | 0.36 | 3.8 | 2.08 | 0.43 | 0.58 | 1314 | 27.5 |
| Kitgum | 2.10 | 3.6 | 3.08 | 2.40 | 1.54 | 1081 | 13.2 |
| Koboko | 0.38 | 1.4 | 1.30 | 0.17 | 0.58 | 1397 | 13.4 |
| Kole | 0.51 | 0.4 | 0.43 | 0.07 | 0.96 | 1385 | 6.7 |
| Kotido | 1.85 | 12.5 | 14.17 | 7.24 | 0.41 | 833 | 11.1 |
| Kumi | 0.48 | 2.3 | 2.45 | 0.34 | 0.89 | 1292 | 5.8 |
| Kween | 0.43 | 6.9 | 6.89 | 0.94 | 0.25 | 1283 | 16.7 |
| Kyankwanzi | 1.24 | 0.2 | 0.18 | 0.08 | 1.49 | 1179 | 7.4 |

**Table A1.** *Cont.*

| District Names | % of the Total Erosive Landcover | Overall Mean Soil Loss (t·ha$^{-1}$·y$^{-1}$) | Mean Soil Loss in Croplands (t·ha$^{-1}$·y$^{-1}$) | % of the Total Soil Loss in Erosive Landcover | % of the Cropland in Uganda | Mean Rainfall in the Erosive Lands (mm·y$^{-1}$) | Mean Slope % in the Erosive Lands |
|---|---|---|---|---|---|---|---|
| Kyegegwa | 0.88 | 0.1 | 0.14 | 0.04 | 1.30 | 1171 | 12.8 |
| Kyenjojo | 1.20 | 0.1 | 0.14 | 0.05 | 1.48 | 1238 | 13.3 |
| Lamwo | 2.78 | 3.1 | 2.79 | 2.75 | 0.83 | 1188 | 12.4 |
| Lira | 0.63 | 0.7 | 0.74 | 0.14 | 1.18 | 1404 | 6.5 |
| Luuka | 0.32 | 0.8 | 0.73 | 0.08 | 0.57 | 1336 | 7.6 |
| Luwero | 1.04 | 0.2 | 0.18 | 0.06 | 1.26 | 1262 | 8.2 |
| Lwengo | 0.51 | 1.9 | 1.94 | 0.30 | 0.74 | 1036 | 11.5 |
| Lyantonde | 0.44 | 0.7 | 0.69 | 0.10 | 0.29 | 958 | 12.2 |
| Manafwa | 0.27 | 3.1 | 2.62 | 0.26 | 0.48 | 1504 | 16.9 |
| Maracha | 0.22 | 2.2 | 2.26 | 0.15 | 0.48 | 1427 | 11.7 |
| Masaka | 0.46 | 1.4 | 1.52 | 0.20 | 0.78 | 1382 | 4.8 |
| Masindi | 1.97 | 0.3 | 0.37 | 0.16 | 0.84 | 1238 | 7.7 |
| Mayuge | 0.52 | 1.2 | 1.17 | 0.19 | 0.88 | 1250 | 3.4 |
| Mbale | 0.25 | 2.2 | 2.07 | 0.17 | 0.49 | 1416 | 14.0 |
| Mbarara | 0.89 | 2.3 | 2.08 | 0.65 | 1.05 | 982 | 16.4 |
| Mitooma | 0.28 | 0.8 | 0.69 | 0.07 | 0.49 | 1176 | 17.5 |
| Mityana | 0.71 | 0.3 | 0.28 | 0.06 | 1.27 | 1242 | 11.0 |
| Moroto | 1.81 | 6.7 | 12.65 | 3.78 | 0.06 | 654 | 14.4 |
| Moyo | 0.86 | 1.7 | 1.55 | 0.46 | 0.65 | 1237 | 14.0 |
| Mpigi | 0.48 | 0.7 | 0.78 | 0.11 | 0.93 | 1317 | 8.3 |
| Mubende | 2.26 | 0.3 | 0.25 | 0.18 | 3.70 | 1152 | 11.7 |
| Mukono | 0.78 | 0.3 | 0.34 | 0.08 | 1.07 | 1497 | 4.6 |
| Nakapiripirit | 2.13 | 3.9 | 3.00 | 2.62 | 0.11 | 1012 | 8.8 |
| Nakaseke | 1.69 | 0.4 | 0.21 | 0.21 | 0.60 | 1221 | 7.2 |
| Nakasongola | 1.55 | 0.6 | 0.73 | 0.28 | 0.65 | 1132 | 6.0 |
| Namayingo | 0.26 | 2.0 | 1.75 | 0.16 | 0.46 | 1172 | 1.2 |
| Namutumba | 0.35 | 1.4 | 1.42 | 0.15 | 0.74 | 1404 | 7.3 |
| Napak | 2.27 | 6.4 | 7.10 | 4.56 | 0.23 | 898 | 8.8 |
| Nebbi | 0.95 | 1.6 | 1.35 | 0.47 | 1.05 | 1018 | 9.0 |
| Ngora | 0.25 | 3.1 | 3.29 | 0.24 | 0.51 | 1317 | 6.1 |
| Ntoroka | 0.60 | 1.2 | 1.29 | 0.22 | 0.06 | 1019 | 7.1 |
| Ntungamo | 1.01 | 2.6 | 2.20 | 0.84 | 1.25 | 965 | 16.8 |
| Nwoya | 2.36 | 2.1 | 2.09 | 1.55 | 1.60 | 1328 | 8.7 |
| Otuke | 0.81 | 4.0 | 3.68 | 1.01 | 0.66 | 1360 | 8.2 |
| Oyam | 1.08 | 0.3 | 0.32 | 0.10 | 1.90 | 1392 | 5.8 |
| Pader | 1.70 | 3.0 | 2.97 | 1.61 | 1.60 | 1358 | 10.4 |
| Pallisa | 0.42 | 1.9 | 1.96 | 0.25 | 0.83 | 1392 | 6.2 |
| Rakai | 1.53 | 2.5 | 2.54 | 1.21 | 2.52 | 1197 | 9.0 |
| Rubirizi | 0.56 | 0.3 | 0.37 | 0.05 | 0.21 | 1054 | 9.2 |
| Rukungiri | 0.73 | 1.1 | 1.36 | 0.26 | 0.95 | 1081 | 15.6 |
| Serere | 0.62 | 0.8 | 0.82 | 0.16 | 1.05 | 1327 | 3.7 |
| Sheema | 0.35 | 1.4 | 1.09 | 0.15 | 0.62 | 1086 | 14.5 |
| Sironko | 0.21 | 14.6 | 1.43 | 0.95 | 0.21 | 1586 | 21.0 |
| Soroti | 0.61 | 2.8 | 3.01 | 0.54 | 1.19 | 1387 | 5.9 |
| Ssembabule | 1.18 | 0.5 | 0.59 | 0.20 | 1.16 | 1023 | 10.0 |
| Tororo | 0.58 | 1.8 | 1.77 | 0.32 | 1.26 | 1466 | 6.3 |
| Wakiso | 0.56 | 0.6 | 0.69 | 0.11 | 1.05 | 1379 | 7.5 |
| Yumbe | 1.18 | 1.5 | 1.18 | 0.56 | 0.95 | 1293 | 10.8 |
| Zombo | 0.45 | 0.8 | 0.81 | 0.12 | 0.36 | 1340 | 14.9 |
| Total erosive lands | 100 | 3.2 | 1.49 | 100 | 100 | 1182 | 11.4 |

**Table A2.** Mean estimated soil loss rates in the 50 largest erosion-prone protected areas of Uganda, share of soil loss in the 50 total erosion-prone protected areas, mean annual rainfall intensity and mean slope.

| Names of 50 Largest Protected Areas | % of 50 Protected Areas | Mean Soil Loss in the Class (t·ha$^{-1}$·y$^{-1}$) | % of Contribution to Total Soil Loss | Mean Rainfall in the Class (mm·y$^{-1}$) | Mean Slope in the Class (% Rise) |
|---|---|---|---|---|---|
| Agoro—Agu | 0.80 | 3.53 | 0.326 | 1264 | 36.5 |
| Ajai | 0.38 | 1.46 | 0.064 | 1166 | 9.0 |
| Amudat | 6.08 | 4.03 | 2.827 | 851 | 6.7 |
| Atiya | 0.57 | 2.79 | 0.184 | 1250 | 33.1 |
| Bokora Corridor | 5.55 | 12.13 | 7.767 | 879 | 11.1 |
| Budongo | 2.50 | 0.23 | 0.067 | 1246 | 10.5 |
| Bugoma | 1.22 | 0.02 | 0.003 | 1127 | 10.3 |
| Bugungu | 1.40 | 0.59 | 0.094 | 1090 | 7.6 |
| Buyaga Dam | 0.49 | 0.64 | 0.036 | 987 | 11.0 |
| Bwindi Impenetrable | 1.00 | 1.65 | 0.190 | 1335 | 36.3 |

**Table A2.** *Cont.*

| Names of 50 Largest Protected Areas | % of 50 Protected Areas | Mean Soil Loss in the Class ($t \cdot ha^{-1} \cdot y^{-1}$) | % of Contribution to Total Soil Loss | Mean Rainfall in the Class ($mm \cdot y^{-1}$) | Mean Slope in the Class (% Rise) |
|---|---|---|---|---|---|
| Iriri | 3.20 | 3.54 | 1.308 | 1017 | 6.8 |
| Kadam | 1.25 | 5.21 | 0.752 | 1124 | 39.3 |
| Kagombe | 0.92 | 0.02 | 0.002 | 1252 | 11.5 |
| Kalinzu | 0.43 | 0.23 | 0.011 | 1243 | 19.7 |
| Karenga | 2.92 | 6.39 | 2.156 | 932 | 10.8 |
| Karuma | 2.05 | 0.07 | 0.016 | 1375 | 7.6 |
| Kasagala | 0.30 | 0.27 | 0.009 | 1151 | 10.2 |
| Kasyoha - Kitomi | 1.18 | 0.27 | 0.036 | 1223 | 26.7 |
| Katonga | 0.63 | 0.04 | 0.003 | 1091 | 10.2 |
| Kibale | 2.41 | 0.11 | 0.032 | 1250 | 13.5 |
| Kidepo Valley | 4.30 | 7.57 | 3.761 | 794 | 15.0 |
| Kigezi | 0.81 | 0.43 | 0.041 | 1011 | 8.2 |
| Kikonda | 0.40 | 0.58 | 0.027 | 1177 | 6.8 |
| Kilak | 0.32 | 1.39 | 0.051 | 1418 | 18.7 |
| Kyambura | 0.43 | 0.63 | 0.031 | 1020 | 5.6 |
| Lomunga | 0.46 | 0.66 | 0.035 | 1221 | 7.7 |
| Lopeichubei | 0.51 | 4.26 | 0.250 | 761 | 43.9 |
| Mabira | 0.93 | 0.02 | 0.003 | 1399 | 11.8 |
| Malabigambo | 0.34 | 0.17 | 0.007 | 1261 | 5.5 |
| Matheniko | 5.28 | 10.39 | 6.328 | 610 | 14.1 |
| Moroto | 1.46 | 5.67 | 0.957 | 753 | 35.8 |
| Mount Elgon | 3.40 | 33.81 | 13.256 | 1675 | 30.2 |
| Mount Kei | 1.24 | 1.91 | 0.273 | 1351 | 13.4 |
| Murchison Falls | 11.53 | 1.06 | 1.408 | 1290 | 8.2 |
| Nangolibwel | 0.61 | 10.33 | 0.722 | 1168 | 29.1 |
| Napak | 0.67 | 5.65 | 0.438 | 1113 | 26.1 |
| North Maramagambo | 0.90 | 0.03 | 0.003 | 1131 | 11.7 |
| Nyangea - Napore | 1.29 | 4.55 | 0.679 | 983 | 30.5 |
| Otze Forest White Rhino | 0.55 | 5.03 | 0.321 | 1251 | 29.4 |
| Pian Upe | 6.56 | 3.49 | 2.640 | 1114 | 5.6 |
| Queen Elizabeth | 6.01 | 0.62 | 0.432 | 972 | 5.6 |
| Queen Elizabeth National Park | 7.26 | 0.56 | 0.467 | 986 | 7.1 |
| Rom | 0.33 | 2.94 | 0.113 | 1062 | 38.8 |
| Rwenzori Mountains | 3.02 | 142.94 | 49.852 | 1591 | 49.6 |
| Semuliki | 0.64 | 0.03 | 0.002 | 1262 | 6.3 |
| South Busoga | 0.46 | 1.52 | 0.081 | 1290 | 9.2 |
| South Maramagambo | 0.45 | 0.05 | 0.003 | 1115 | 14.3 |
| Timu | 0.37 | 2.80 | 0.121 | 751 | 18.0 |
| Toro-Semuliki | 1.60 | 0.89 | 0.165 | 1066 | 10.6 |
| Zulia | 2.55 | 5.59 | 1.650 | 713 | 22.2 |
| Total 50 largest protected areas | 100 | 8.66 | 100 | 1091 | 14.7 |

## References

1. Bell, M.; Boardman, J. Past and present soil erosion. *Oxbow Monogr.* **1992**, *22*, 250.
2. Lufafa, A.; Tenywa, M.; Isabirye, M.; Majaliwa, M.; Woomer, P. Prediction of soil erosion in a lake victoria basin catchment using a gis-based universal soil loss model. *Agric. Syst.* **2003**, *76*, 883–894. [CrossRef]
3. Nachtergaele, F.; Petri, M.; Biancalani, R.; Van Lynden, G.; Van Velthuizen, H.; Bloise, M. Global land degradation information system (gladis). *Beta version. An information database for land degradation assessment at global level. Land degradation assessment in drylands technical report September*. 2011. Available online: http://www.fao.org/nr/lada/index.php?option=com_docman&task=doc_download&gid=773&Itemid=165&lang=en (accesed on 20 July 2016).
4. Van Straaten, P. *Rocks for Crops: Agrominerals of Sub-Saharan Africa*; ICRAF: Nairobi, Kenya, 2002.
5. Tilman, D.; Fargione, J.; Wolff, B.; D'Antonio, C.; Dobson, A.; Howarth, R.; Schindler, D.; Schlesinger, W.H.; Simberloff, D.; Swackhamer, D. Forecasting agriculturally driven global environmental change. *Science* **2001**, *292*, 281–284. [CrossRef] [PubMed]
6. Matson, P.A.; Parton, W.J.; Power, A.; Swift, M. Agricultural intensification and ecosystem properties. *Science* **1997**, *277*, 504–509. [CrossRef] [PubMed]
7. Nahayo, L.; Li, L.; Kayiranga, A.; Karamage, F.; Mupenzi, C.; Ndayisaba, F.; Nyesheja, E.M. Agricultural impact on environment and counter measures in rwanda. *Afr. J. Agric. Res.* **2016**, *11*, 2205–2212.
8. Cerdà, A.; Lavee, H.; Romero-Díaz, A.; Hooke, J.; Montanarella, L. Preface. *Land Degrad. Dev.* **2010**, *21*, 71–74. [CrossRef]

9. Borrelli, P.; Paustian, K.; Panagos, P.; Jones, A.; Schütt, B.; Lugato, E. Effect of good agricultural and environmental conditions on erosion and soil organic carbon balance: A national case study. *Land Use Policy* **2016**, *50*, 408–421. [CrossRef]
10. Grinning Planet. Polluted Seas: Major Bodies of Water/Areas with Serious Water Pollution Problems. Available online: http://grinningplanet.com/2005/07-26/polluted-seas.htm (accessed on 20 January 2016).
11. Karamage, F.; Zhang, C.; Kayiranga, A.; Shao, H.; Fang, X.; Ndayisaba, F.; Nahayo, L.; Mupenzi, C.; Tian, G. Usle-based assessment of soil erosion by water in the nyabarongo river catchment, rwanda. *Int. J. Environ. Res. Public Health* **2016**, *13*, 835. [CrossRef] [PubMed]
12. Albright, T.; Moorhouse, T.; McNabb, T. The abundance and distribution of water hyacinth in lake victoria and the kagera river basin, 1989–2001. Usgs/eros data center and clean lakes. Available online: http://nilerak.hatfieldgroup.com/english/nrak/EO/USGS_CLI_WH_LakeVictoria.pdf (accessed on 16 August 2016).
13. Albright, T.P.; Moorhouse, T.; McNabb, T. The rise and fall of water hyacinth in lake victoria and the kagera river basin, 1989–2001. *J. Aquat. Plant Manag.* **2004**, *42*, 73–84.
14. Bai, Z.G.; Dent, D.L.; Olsson, L.; Schaepman, M.E. Proxy global assessment of land degradation. *Soil Use Manag.* **2008**, *24*, 223–234. [CrossRef]
15. Banana, A.Y.; Gombya-Ssembajjwe, W. Successful rorest management: Ine importance of security of tenure and rule enforcement in ugandan forests. *People For. Commun. Inst. Gov.* **2000**, *87*, 46.
16. Majaliwa, J.; Twongyirwe, R.; Nyenje, R.; Oluka, M.; Ongom, B.; Sirike, J.; Mfitumukiza, D.; Azanga, E.; Natumanya, R.; Mwerera, R. The effect of land cover change on soil properties around kibale national park in south western uganda. Available online: https://www.hindawi.com/journals/aess/2010/185689/ (accessed on 17 September 2016).
17. Regional Centre For Mapping Resource For Development. Land Cover Viewer: Eastern & Southern Africa. Available online: http://apps.rcmrd.org/landcoverviewer/ (accessed on 20 October 2016).
18. Hartter, J.; Ryan, S.J.; MacKenzie, C.A.; Goldman, A.; Dowhaniuk, N.; Palace, M.; Diem, J.E.; Chapman, C.A. Now there is no land: A story of ethnic migration in a protected area landscape in western uganda. *Popul. Environ.* **2015**, *36*, 452–479. [CrossRef]
19. United Nations. World Urbanization Prospects: The 2014 Revision, cd-Rom Edition. Available online: http://esa.un.org/unpd/wpp/ (accessed on 4 September 2016).
20. Bagoora, F.D. Soil erosion and mass wasting risk in the highland area of uganda. *Mount. Res. Dev.* **1988**, 173–182. [CrossRef]
21. Claessens, L.; Van Breugel, P.; Notenbaert, A.; Herrero, M.; Van De Steeg, J. Mapping potential soil erosion in east africa using the universal soil loss equation and secondary data. *IAHS Publ.* **2008**, *325*, 398.
22. Renard, K.G.; Foster, G.; Weesies, G.; McCool, D.; Yoder, D. *Predicting Soil Erosion by Water: A Guide to Conservation Planning with the Revised Universal Soil Loss Equation (Rusle)*; United States Department of Agriculture: Washington, DC, USA, 1997.
23. Mwebaze, S.; Suttie, J.; Reynolds, S. *Country Pasture/Forage Resource Profiles: Uganda*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2011.
24. Energy-Sector-GIS-Working-Group-Uganda. Open Data. Available online: http://data.energy-gis.opendata.arcgis.com/datasets/f0d63758fb8f4ded85394b51594d294a_0 (accessed on 20 May 2016).
25. Maetens, W.; Vanmaercke, M.; Poesen, J.; Jankauskas, B.; Jankauskien, G.; Ionita, I. Effects of land use on annual runoff and soil loss in europe and the mediterranean: A meta-analysis of plot data. *Prog. Phys. Geogr.* **2012**, *36*, 599–653. [CrossRef]
26. Maetens, W.; Poesen, J.; Vanmaercke, M. How effective are soil conservation techniques in reducing plot runoff and soil loss in europe and the mediterranean? *Earth-Sci. Rev.* **2012**, *115*, 21–36. [CrossRef]
27. Wischmeier, W.H.; Smith, D.D. *Predicting Rainfall Erosion Losses-A Guide to Conservation Planning*; USDA: Washington, DC, USA, 1978.
28. Panagos, P.; Borrelli, P.; Meusburger, K.; Alewell, C.; Lugato, E.; Montanarella, L. Estimating the soil erosion cover-management factor at the european scale. *Land Use Policy* **2015**, *48*, 38–50. [CrossRef]
29. Panagos, P.; Borrelli, P.; Meusburger, K. A new european slope length and steepness factor (LS-factor) for modeling soil erosion by water. *Geosciences* **2015**, *5*, 117–126. [CrossRef]
30. Fantappiè, M.; Priori, S.; Costantini, E. Soil erosion risk, sicilian region (1:250,000 scale). *J. Maps* **2015**, *11*, 323–341. [CrossRef]

31. Angima, S.; Stott, D.; O'neill, M.; Ong, C.; Weesies, G. Soil erosion prediction using rusle for central kenyan highland conditions. *Agric. Ecosyst. Environ.* **2003**, *97*, 295–308. [CrossRef]
32. Farhan, Y.; Nawaiseh, S. Spatial assessment of soil erosion risk using rusle and gis techniques. *Environ. Earth Sci.* **2015**, *74*, 4649–4669. [CrossRef]
33. Renard, K.G.; Freimund, J.R. Using monthly precipitation data to estimate the r-factor in the revised usle. *J. Hydrol.* **1994**, *157*, 287–306. [CrossRef]
34. Funk, C.; Nicholson, S.E.; Landsfeld, M.; Klotter, D.; Peterson, P.; Harrison, L. The centennial trends greater horn of Africa precipitation dataset. *Sci. Data* **2015**, *2*, 150050. [CrossRef] [PubMed]
35. Lo, A.; El-Swaify, S.A.; Dangler, E.W.; Shinshiro, L. Effectiveness of EI30 as an erosivity index in Hawaii. In *Soil Erosion and Conservation*; E1-Swaify, S.A., Moldenhauer, W.C., Lo, A., Eds.; Soil Conservation Society of America: Ankeny, IA, USA, 1985; pp. 384–392.
36. Chris Funk, P.P.; Landsfeld, M.; Pedreros, D.; Verdin, J.; Shukla, S.; Husak, G.; Rowland, J.; Harrison, L.; Hoell, A.; Michaelsen, J. The climate hazards infrared precipitation with stations-a new environmental record for monitoring extremes. *Sci. Data* **2015**, *2*, 150066. [CrossRef] [PubMed]
37. Panagos, P.; Meusburger, K.; Ballabio, C.; Borrelli, P.; Alewell, C. Soil erodibility in Europe: A high-resolution dataset based on lucas. *Sci. Total Environ.* **2014**, *479*, 189–200. [CrossRef] [PubMed]
38. Anache, J.A.A.; Bacchi, C.G.V.; Panachuki, E.; Sobrinho, T.A. Assessment of methods for predicting soil erodibility in soil loss modeling. *Geociências* **2015**, *34*, 32–40.
39. Hengl, T.; Heuvelink, G.B.; Kempen, B.; Leenaars, J.G.; Walsh, M.G.; Shepherd, K.D.; Sila, A.; MacMillan, R.A.; de Jesus, J.M.; Tamene, L. Mapping soil properties of Africa at 250 m resolution: Random forests significantly improve current predictions. *PLoS ONE* **2015**, *10*, e0125814. [CrossRef] [PubMed]
40. Williams, J.R. The EPIC model. In *Computer Models of Watershed Hydrology*; Water Resources Publications: Highlands Ranch, CO, USA, 1995; pp. 909–1000.
41. Nam, P.T.; Yang, D.; Kanae, S.; Oki, T.; Musiake, K. Global soil loss estimate using rusle model: The use of global spatial datasets on estimating erosive parameters. *Geol. Data Process.* **2003**, *14*, 49–53. [CrossRef]
42. Kim, J.B.; Saunders, P.; Finn, J.T. Rapid assessment of soil erosion in the rio lempa basin, central America, using the universal soil loss equation and geographic information systems. *Environ. Manag.* **2005**, *36*, 872–885. [CrossRef] [PubMed]
43. Desmet, P.; Govers, G. A gis procedure for automatically calculating the usle ls factor on topographically complex landscape units. *J. Soil Water Conserv.* **1996**, *51*, 427–433.
44. Foster, G.; Meyer, L.; Onstad, C. A runoff erosivity factor and variable slope length exponents for soil loss estimates. *Trans. ASAE* **1977**, *20*, 683–0687. [CrossRef]
45. Millward, A.A.; Mersey, J.E. Adapting the rusle to model soil erosion potential in a mountainous tropical watershed. *Catena* **1999**, *38*, 109–129. [CrossRef]
46. United States Geological Survey. U.S. Geological Survey Earthexplorer (ee) Tool. Available online: http://earthexplorer.usgs.gov/ (accessed on 20 September 2016).
47. McCool, D.; Brown, L.; Foster, G.; Mutchler, C.; Meyer, L. Revised slope steepness factor for the universal soil loss equation. *Trans. ASAE* **1987**, *30*, 1387–1396. [CrossRef]
48. McCool, D.K.; Foster, G.R.; Mutchler, C.; Meyer, L. Revised slope length factor for the universal soil loss equation. *Trans. ASAE* **1989**, *32*, 1571–1576. [CrossRef]
49. Barrios, A.G.; Quiñónez, E. Evaluación de la erosión utilizando el modelo (r) usle, con apoyo de sig. Aplicación en una microcuenca de los andes venezolanos. *Rev. For. Venez.* **2000**, *44*, 2000.
50. NASA Goddard Space Flight Center. Mod13q1-Modis/Terra Vegetation Indices 16-Day l3 Global 250 m Sin Grid. Available online: http://ladsweb.nascom.nasa.gov/data/html (accessed on 18 May 2016).
51. Van der Knijff, J.; Jones, R.; Montanarella, L. Soil Erosion Risk Assessment in Europe. Available online: https://www.researchgate.net/profile/Luca_Montanarella/publication/237727657_Soil_erosion_risk_assessment_in_Europe_EUR_19044_EN/links/55d1c0f208ae2496ee6580ca.pdf (accessed on 10 September 2016).
52. Kim, H.S. *Soil Erosion Modeling Using Rusle and Gis on the Imha Watershed, South Korea*; Colorado State University: Fort Collins, CO, USA, 2006.
53. Shin, G. The Analysis of Soil Erosion Analysis in Watershed Using Gis. Ph.D. Dissertation, Department of Civil Engineering, Gang-Won National University, Chuncheon, Korea, 1999.
54. Morgan, R.P.C. *Soil Erosion and Conservation*; John Wiley & Sons: Hoboken, NJ, USA, 2009.

55. Bamutaze, Y. Revisiting socio-ecological resilience and sustainability in the coupled mountain landscapes in eastern Africa. *Curr. Opin. Environ. Sustain.* **2015**, *14*, 257–265. [CrossRef]
56. Verheijen, F.G.; Jones, R.J.; Rickson, R.; Smith, C. Tolerable versus actual soil erosion rates in Europe. *Earth-Sci. Rev.* **2009**, *94*, 23–38. [CrossRef]
57. Stocking, M.; Pain, A. *Soil Life and the Minimum Soil Depth for Productive Yields*; Discussion paper 150; University of East Anglia, School of Development Studies: Norwich, UK, 1983.
58. Jones, R.J.; Le Bissonnais, Y.; Bazzoffi, P.; Sanchez Diaz, J.; Düwel, O.; Loj, G.; Øygarden, L.; Prasuhn, V.; Rydell, B.; Strauss, P. Nature and extent of soil erosion in Europe. *Reports of the Technical Working Groups Established under the Thematic Strategy for Soil Protection*. Available online: https://www.researchgate.net/publication/242136385_nature_and_extent_of_soil_erosion_in_europe (accessed on 13 August 2016).
59. UNEP-WCMC. Protected Areas Delimited by the United Nations Environment Programme (UNEP) and the World Conservation Monitoring Centre (WCMC). Available online: https://www.protectedplanet.net/ (accessed on 15 May 2015).
60. Panagos, P.; Borrelli, P.; Poesen, J.; Ballabio, C.; Lugato, E.; Meusburger, K.; Montanarella, L.; Alewell, C. The new assessment of soil loss by water erosion in Europe. *Environ. Sci. Policy* **2015**, *54*, 438–447. [CrossRef]
61. Alewell, C.; Egli, M.; Meusburger, K. An attempt to estimate tolerable soil erosion rates by matching soil formation with denudation in alpine grasslands. *J. Soils Sediments* **2015**, *15*, 1383–1399. [CrossRef]
62. Bewket, W.; Teferi, E. Assessment of soil erosion hazard and prioritization for treatment at the watershed level: Case study in the chemoga watershed, blue nile basin, Ethiopia. *Land Degrad. Dev.* **2009**, *20*, 609–622. [CrossRef]
63. Pimentel, D.; Burgess, M. Soil erosion threatens food production. *Agriculture* **2013**, *3*, 443–463. [CrossRef]
64. Blanco-Canqui, H.; Lal, R. Soil and water conservation. In *Principles of Soil Conservation and Management*; Springer: Heidelberg, Germany, 2010; pp. 1–19.
65. Bachou, H. Malnutrition in Uganda. We've Already Paid Too High a Price: Economic Development and Nutrition Fact Sheet. Available online: https://pdfs.semanticscholar.org/1b2d/b7485379e8b948e157eca74edfa27fd2fad1.pdf (accessed on 20 December 2016).
66. Elliot, W.J.; Page-Dumroese, D.; Robichaud, P.R. 12 the effects of forest management on erosion and soil productivity. Available online: https://books.google.de/books?hl=de&lr=&id=hebmq2q1dZkC&oi=fnd&pg=PA195&dq=the+effects+of+forest+management+on+erosion+and+soil+productivity.&ots=Bb4gyL7eJw&sig=oQKJsNcda8v_osteLl4YjTt3EFo#v=onepage&q=the%20effects%20of%20forest%20management%20on%20erosion%20and%20soil%20productivity.&f=false (accessed on 20 September 2016).
67. Karamage, F.; Shao, H.; Chen, X.; Ndayisaba, F.; Nahayo, L.; Kayiranga, A.; Omifolaji, J.K.; Liu, T.; Zhang, C. Deforestation effects on soil erosion in the lake kivu basin, dr congo-rwanda. *Forests* **2016**, *7*, 281. [CrossRef]
68. Ferro, V.; Giordano, G.; Iovino, M. Isoerosivity and erosion risk map for sicily. *Hydrol. Sci. J.* **1991**, *36*, 549–564. [CrossRef]
69. Kheir, R.B.; Cerdan, O.; Abdallah, C. Regional soil erosion risk mapping in Lebanon. *Geomorphology* **2006**, *82*, 347–359. [CrossRef]
70. Lu, D.; Li, G.; Valladares, G.; Batistella, M. Mapping soil erosion risk in rondonia, brazilian amazonia: Using rusle, remote sensing and gis. *Land Degrad. Dev.* **2004**, *15*, 499–512. [CrossRef]
71. Fathizad, H.; Karimi, H.; Alibakhshi, S.M. The estimation of erosion and sediment by using the rusle model and rs and gis techniques (case study: Arid and semi-arid regions of Doviraj, Ilam province, Iran). *Int. J. Agric. Crop Sci.* **2014**, *7*, 303.
72. Grimm, M.; Jones, R.; Montanarella, L. Soil Erosion Risk in Europe. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.397.2450&rep=rep1&type=pdf (accessed on 30 August 2016).
73. Van der Knijff, J.; Jones, R.; Montanarella, L. Soil Erosion Risk Assessment in Italy. Available online: http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.397.2309&rep=rep1&type=pdf (accessed on 27 August 2016).