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Spatial soil loss estimation using an integrated GIS-based revised universal soil loss equation (RUSLE) in selected watersheds in northern Ghana

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Abstract

This study used thespatially integrated RUSLE to estimate annual soil loss and spatial distribution of soil loss severity classes for nine (9) reservoir catchments in northern Ghana.This model is an empirical model with five (5)main input parameters: rainfall erosivity, soil erodibility, slope length/steepness, landcover management and erosion management practice factors. Estimated annual soil loss rate ranged from 0 – 96.30 t/ha/y. Estimated mean annual soil loss ranged from 3.71 – 8.17 %. The severity of annual soil loss rates ranged from very low class (0.0 – 1.0 t/ha/y) to very high class (> 60.0 t/ha/y). Across the nine (9) catchments, the very low soil loss severity class was noted to constitute a larger portion of between 36.70 to 67.50 %. The moderate soil severity class was noted as the highest contributor to total annual soil loss. Soil and water conservation measures are required in the watershed to reduce soil loss.

Keywords: Watershed, soil loss, Integrated GIS-based RUSLE model, surface water resources, lixisols

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1. Introduction

Soil loss in watersheds of surface water resources is a serious environmental problem (Gelagay and Minale, 2016) with the root cause being erosion (Bai *et al.*, 2008). Apart from causing accelerated on-site soil nutrient loss from farmlands in affected watersheds, it has resulted in accelerated off-site sediment accumulation in reservoirs, with implications for severe reduction in the designed life and water storage capacities of the affected reservoirs (Wang *et al.*, 2018). Though soil loss is a natural geological phenomenon and the result of the interplay between rainfall erosivity and soil erodibility factors, inappropriate human practices such as deforestation, cultivation in upslope areas without any support practices, bush burning, extension of urban areas, and uncontrolled and overgrazing have significantly aggravated soil loss in watersheds worldwide (Shiferaw, 2011;Mekonnen*et al.*, 2017).

In Ghana, Amegashie (2009) reported high soil loss rates of 18.28 – 157.55 t/ha/y in five (5) watersheds in the Upper East Region. Mean soil loss rates estimated in some watersheds of semi-arid areas of Africa include 22.80 t/ha/y at Tono, Ghana (Abubakari, 2014), and 47.4 t/ha/y at Koga, Ethiopia (Gelagay and Minale, 2016). Assessment of soil loss is useful in planning and soil conservation works in watersheds (Ganasri and Ramesh, 2015) with substantial efforts made on the development of soil loss assessment models (Nearing *et al.*, 2005) to quantitatively assess the extent and magnitude of soil loss (Kothyari*et al.*, 1994).

Soil loss information per unit land area in a watershed can be assessed using several models such as the old Universal Soil Loss Equation (USLE) - Empirical model (Wischmeier and Smith, 1978), Revised Universal Soil Loss Equation (RUSLE) - Empirical model (Renard*et al*. 1997), European Soil Erosion Model (EUROSEM) - Physically-based model (Morgan *et al.*, 1998), SystemeHydrologiqueEuropeen or European Hydrological System (MIKE-SHE) - Physically-based model (Abbott et al., 1986), Water Erosion Prediction Project (WEPP) - Physically-based model (Laflen*et al.*, 1991), Soil and Water Assessment Tool

(SWAT) - Conceptual model (Arnold et al., 1993) and Agricultural Catchment Research Unit (ACRU) - Conceptual model (Schulze, 1995).

Empirical models are a simulation of natural processes, mostly based on statistical observations and rely on developed regression relationships. The computational processes of empirical models are simple and their data requirements are less than those that are required for conceptual and physically-based models (Wheater*et al.*, 1993; Hajigholizadeh*et al.*, 2018). Physically-based models are generally based on the concept of the conservation of mass, momentum equations and energy as governing equations describing streamflow or overland flow, and conservation of mass equation for sediment (Bennett, 1974; Kandel*et al.*, 2004). Conceptual models are basically a combination of empirical and physically-based models and are more applicable to answering general questions (Beck, 1987; Hajigholizadeh*et al.*, 2018). These models were developed on the basis of spatially-lumped forms of water and the sediment continuity equation. The main focus of a conceptual model is to predict sediment yield, basically using the concept of the unit hydrograph (Lal, 1994).

Using conventional methods, physically-based models or conceptual models to assess soil loss is very expensive and time consuming so a RUSLE model integrated with remote sensing and GIS was used for the study whilst noting the non-existence of soil loss information (Wheater*et al.*, 1993; Hajigholizadeh*et al.*, 2018). The Integrated GIS-based RUSLE model was also selected for its minimal number of required data and for its ease as a tool for field application and its ability to analyze soil loss potential on a cell-bycell basis (Shinde*et al.*, 2010).Thisstudy assessed the annual soil loss per unit area of land innine (9) watersheds in northern Ghana and the estimated soil loss ratesfor some watersheds were within the tolerable limits as indicated by the FAO (1984) and USDA-NRCS (1999.

2. Materials and methods

2.1 Description of Study Areas

The study was carried out in nine (9) watersheds across the former three (3) administrative regions namely; Bontanga, Libga and Golingawatersheds in the Northern Region; Vea, Tono and Gambibgowatersheds in the Upper East Region and Sankana, Karni and Daffiamawatersheds in the Upper West Region of Ghana. A map showing the study watersheds is presented in Figure 1 whilst the description of the watersheds is presented in Table 1.

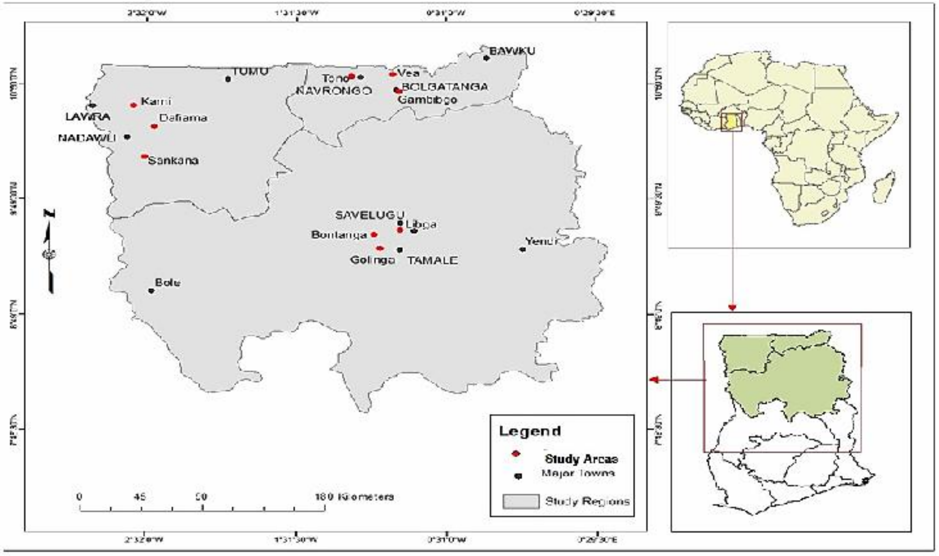


Figure 1: Map of the Former Three(3) Northern Regions Showing the Study Watersheds

Table 1: Description of Study Watersheds

Name of watershed		Bontanga	Golinga	Libga	Gambibgo	Tono	Vea	Daffiama	Karni	Sankana
Location	Region	Northern	Northern	Northern	Upper East	Upper East	Upper East	Upper West	Upper West	Upper West
	District/ Municipality	Kumbungu	Tolon	Savelugu	Bolgatanga	Kassena-Nankana	Bongo	Daffiama-Bussie-Issa	Lambussie-Karni	Nadowli-Kaleo
	Coordinates	9° 57'N 1° 02'W	9° 22'N 0° 57'W	9° 59'N 0° 85'W	10° 45'N 0° 50'W	10° 52'N 1° 08'W	10° 52'N 0° 51'W	10° 27'N 02° 34'W	10° 40'N 02° 38'W	10° 11'N 02° 36'W
Area of Watershed (km^2)		165	53	31	1.70	650	136	21	35	141

Rainfall System	Type	Uni-modal	Uni-modal	Uni-modal
	Annual Mean (mm)	1,000 – 1,300	700 – 1,010	800 – 1,100
	Duration (months)	5 – 6	5 – 6	5 – 6
Temperature (° C)	Day	33 – 39	20 – 22	29.0
	Night	35 – 45	23 – 28	32.2
	Mean	33 – 45	23 – 30	30.0
Relative Humidity (%)	Dry Season	50	10	20
	Wet Season	80	65	70
Agro-ecological Zone		Guinea Savannah	Guinea/Sudan Savannah	Guinea Savannah
Geology		Precambrian basement rocks and Palaeozoic rocks from the Voltaian sedimentary basin	Metamorphic and igneous rocks with gneisss, graodiorite and sandstone	Precambrian, granite and metamorphic rocks
Soil Classes		Acrisols, plinthosols, planosols, luvisols, gleysols and fluvisols	Plinthosols, luvisols, vertisols, leptosols, lixisols, and fluvisols	Lixisols, fluvisols, leptosols, vertisols, acrisols and plinthosols

2.2 Integrated GIS-based RUSLE Model

The Integrated GIS-based RUSLE model was used to estimate the annual soil loss rate at the nine (9) watersheds. The model estimated annual soil loss rate by a cell-by-cell multiplication using raster maps of five (5) parameters as expressed in Equation 1according to Renard*et al.* (1997). The model was simulated using ArcGIS with the detail process of the methodology illustrated in Figure 2. Input data included soil and rainfall, digital elevation model and landsat images of landuse/landcover of the watersheds.

$$A = RK(LS)CP \quad \text{……………………………………………} \quad (1)$$

Where: A - Annual soil loss (t/ha/y), R - Rainfall erosivity factor (MJmm/h/ha/y), K - Soil erodibility factor (t/ha/h/MJ/mm), LS - Slope length and steepness factor (dimensionless), C - Land cover management factor (dimensionless, ranges from 0 to 1), and P - Soil conservation support practice factor (dimensionless, ranges from 0 to 1).

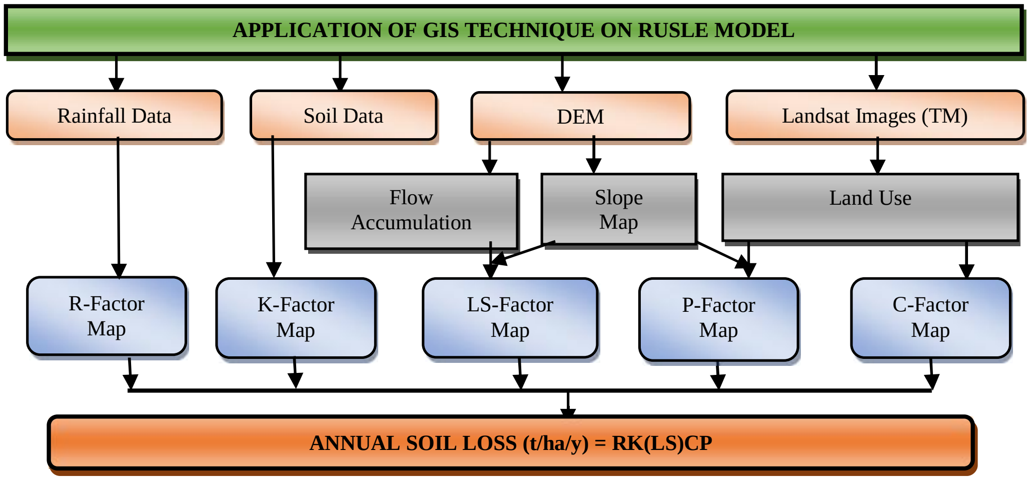


Figure 2: Methodological Framework of Soil Loss Estimation in Watersheds Using RUSLE Model
Adapted fromGelagay and Minale (2016)

2.2.1 Rainfall Erosivity Factor (R)

The R-factor quantifies the effect of rainfall intensity impact on soil erosion (Wischmeier and Smith, 1978) and it is estimated using Equation 2 (Hurni, 1985).

$$R = 0.562(Ar) - 8.12 \quad (2)$$

Where: R - Rainfall erosivity factor (MJmm/h/ha/y) andAr - Annual rainfall (mm).

Twenty (20) years annual rainfall data obtained from the Ghana Meteorological Agencies rain gauges was interpolated by inverse distance weighted method to generate uninterrupted rainfall data for each 30 m grid cell in ArcGIS 10.4 environment. From this continuous rainfall data, the R-factor value of each grid cell was computed using raster calculator geo-processing tool.

2.2.2 Soil Erodibility Factor (K)

The K factor represents soil type to erosion susceptibility, sediment transportability and amount and rate of runoff given a particular rainfall input (Ganasri and Ramesh, 2015). The soil maps of the watersheds were produced using Ghana soil shapefile (HWSD, 2017)with the region of interest extracted using each watershed area and the soil data layer clipped onto the watershed in ArcGIS environment10.4. The soil classes for each watershed were then determined from the soil maps and K-factor values obtained from literature for each soil class and then input into ArcGIS and processed to obtain K-factor maps for each watershed. The K-factor values (Table 2) for the corresponding soil classes were used in the study.

Table 2:Soil Erodibility (K) Factor Values for Different Soil Classes

FAO Soil Class	K-factor Value
Acrisols	0.25
Fluvisols	0.30
Leptosols	0.28
Lixisols	0.23
Planosols	0.34
Plinthosols	0.26
Vertisols	0.15

Adapted from Ashiagbor et al. (2014)

2.2.3 Slope Length and Steepness (LS) Factor

The slope length and steepness (LS) factor represents soil loss due to combinations of slope length and steepness relative to a standard unit plot (Ashiagbor*et al.,* 2014).The Spatial Analyst Extension Toolbox (Surface) in ArcGIS 10.4 was used to derive the slopes of the watersheds from the Digital Elevation Model (DEM) of the watershedsat 30 m resolution. All sinks in the DEM were identified and filled with the filled DEM for each watershed used as input to determine the flow direction (FD) and used as an input grid to derive the flow accumulation (FA). The LS-factor was calculated using raster calculator in ArcGIS and Equation 3 (Wischmeir and Smith, 1978).

$$LS = \left[\left(\frac{Q_a M}{22.13}\right)^{y} \text{X}\ (0.065 + 0.045\, S_g) + (0.0065\, S_g{}^{2})\right] \tag{3}$$

Where: LS - Slope length and steepness factor (dimensionless), Qa - Flow accumulation grid, M - Grid size, Sg - Grid slope (%), y – A dimensionless exponent (0.2 – 0.5) with varying values for different slopes depending on the slope steepness, being 0.5 for slopes exceeding 4.5 %, 0.4 for 3 - 4.5 % slopes, 0.3 for 1 – 3 %, and 0.2 for slopes less than 1 %.

2.2.4 Land Cover Management (C) Factor

The C factor quantifies the combined effect of plants, crop sequence and other soil cover surface on soil erosion (Molla and Sisheber, 2017). The C-factor is dimensionless with values ranging from 0 to 1. The C-factor maps were quantified from the landuse/landcover classes of the watersheds whilst the C-factor values (Table 3) by Hurni (1985) were used in this study.

Table 3: Land Cover Management (P) Factor

Landuse/Landcover Type	C-factor Value
Cropland	0.27
Built-up Areas	0.25
Water Body	0.00
Closed Savannah Woodland	0.05
Open Savannah Woodland	0.15

Adapted from Hurni (1985)

2.2.5 Erosion Management Practice (P) Factor

The study adopted a combination of general landuse and landcover types and slope. The P-factor values were assigned by categorizing the watersheds into major kinds of landuse and landcover types and assigned considering local management practices together with values in Table 4 (Sharma and Goyal, 2013) to produce the P-factor maps of the various watersheds.The P-factor is dimensionless with values ranging from 0 to 1.

Table 4: Erosion Management Practice (P) Factor

Landuse/Landcover Type	P-factor Value
Cropland	0.50
Built-up Areas	0.80
Water Body	0.00
Closed Savannah Woodland	1.00
Open Savannah Woodland	1.00

Adapted from Sharma and Goyal (2013)

3. Results and Discussion

3.1 The RUSLE Model Factors of the Watersheds

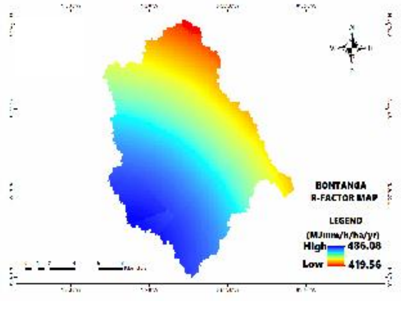
The estimated RUSLE model parameters which are R, K, LS and P factors of the nine (9) watersheds are presented in Table 5.

Table 5: Estimated RUSLE Factors of the Study Watersheds.

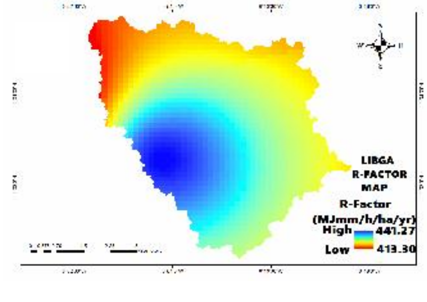
Watershed	Mean Annual Rainfall (mm)	R-Factor Value (MJmm/h/ha/y)	K-Factor Value (t/ha/h/MJ/mm)	LS-Factor Value	C-Factor Value	P-Factor Value
Bontanga	1074	419.56 - 486.08	0.25 - 0.34	0 - 2.16	0 - 0.27	0 - 1.0
Golinga	1030	433.88 - 486.61	0.25 - 0.34	0 - 1.50	0 - 0.27	0 - 1.0
Libga	1065	413.97 - 441.27	0.25 - 0.34	0 - 1.75	0 - 0.27	0 - 1.0
Gambibgo	969	403.16 - 404.25	0.23 - 0.30	0 - 1.24	0 - 0.27	0 - 1.0
Tono	970	374.92 - 401.77	0.15 - 0.30	0 - 6.36	0 - 0.27	0 - 1.0
Vea	934	390.86 - 430.31	0.15 - 0.30	0 - 2.57	0 - 0.27	0 - 1.0
Daffiama	1046	374.14 - 417.46	0.15 - 0.28	0 - 0.84	0 - 0.27	0 - 1.0
Karni	1042	379.28 - 428.93	0.15 - 0.28	0 - 2.07	0 - 0.27	0 - 1.0
Sankana	1009	373.61 - 447.05	0.15 - 0.28	0 - 1.73	0 - 0.27	0 - 1.0

3.2 Rainfall Erosivity (R) Factor

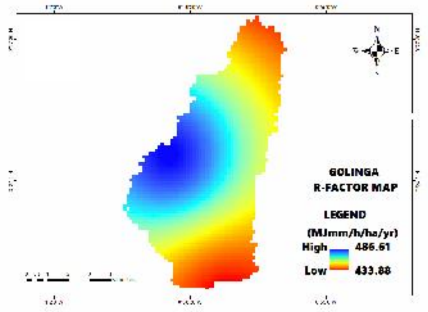
The mean annual rainfall amounts in the 9 watersheds ranged from 934 mm to 1074 mm.Dabral*et al.* (2008) andGanasri and Ramesh (2015) noted that soil loss rate in the watersheds is more sensitive to rainfall. An estimated low R-factor value of 373.61 MJmm/h/ha/y at Sankana watershed and 486.61 MJmm/h/ha/y was estimated at the Golinga watershed as the highest. Details of the R-factor values are as presented in Table 5. Farhan *et al.* (2013) reported the distribution of R-factor values to vary and consistent with annual rainfall, and classified R-factor values of 300 – 600 MJmm/h/ha/y as moderately erosive. Rainfall in the watersheds is moderately erosive and might cause moderate soil loss. As shown in Figure 3, the influence of rainfall erosivity factor on soil loss in the watersheds decreases from the deep blue area to the deep red area.



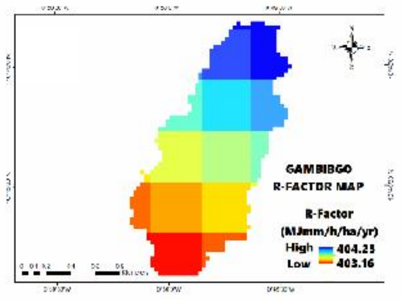
Bontanga



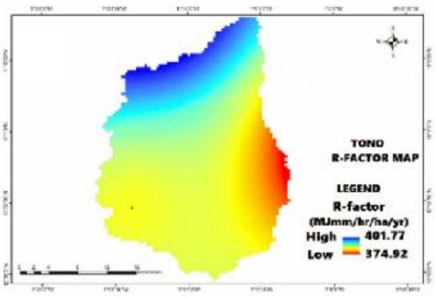
Golinga



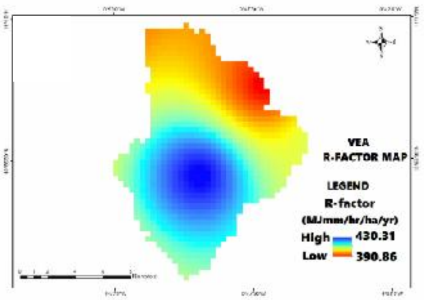
Libga



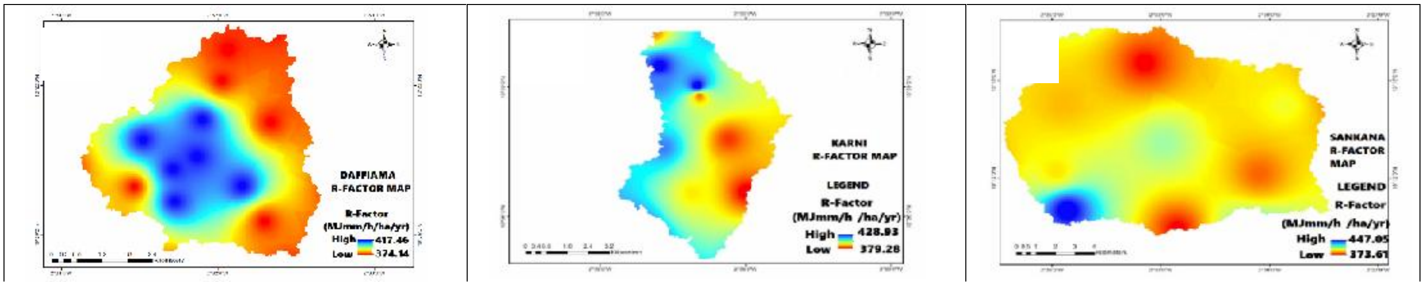
Gambibgo



Tono



Vea



Daffiama | **Karni** | **Sankana**

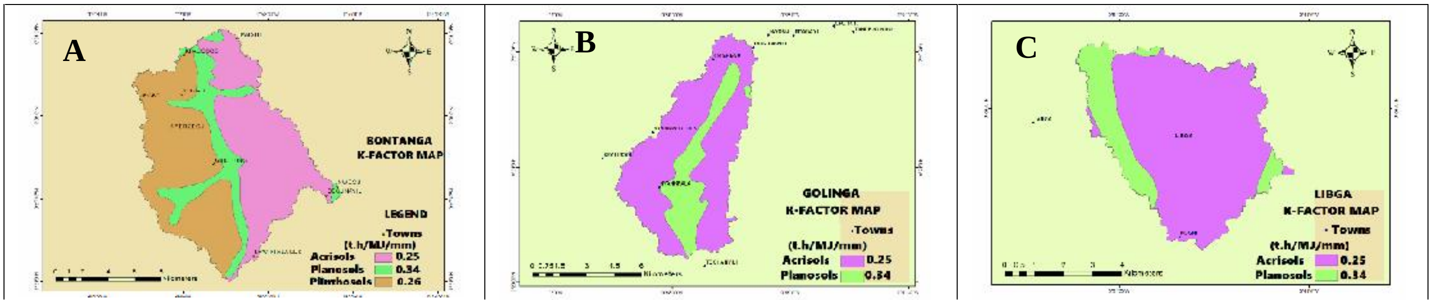
Figure 3: Rainfall Erosivity (R) Factor in the Study Watersheds (A – I)

3.3 Soil Erodibility (K) Factor

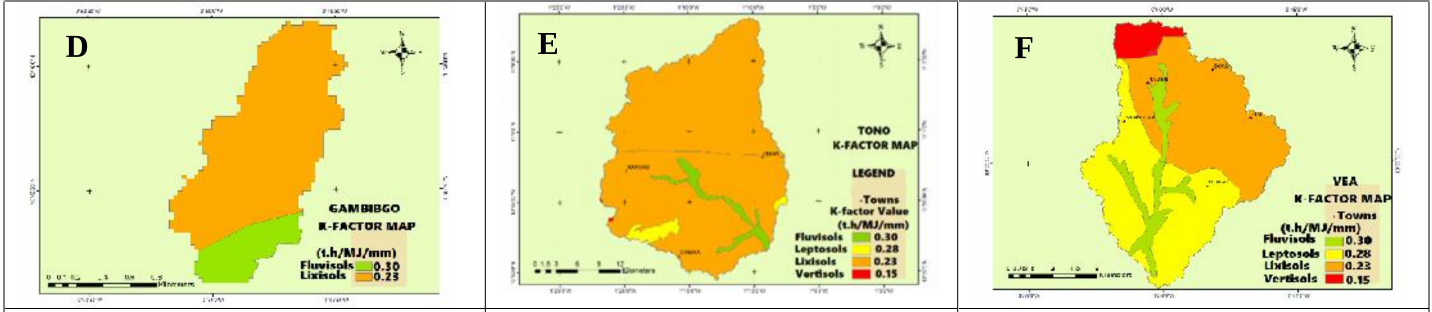
The number of soil classes identified in the study watersheds varied from 2 to 4 with the details presented in Table 6 and Figure4. The K-factor values for the various soils ranged from 0.15 – 0.34 t/ha/h/MJ/mm with the lowest being vertisols and the highest being planosols. Based on the classification of NRCS-USDA (2002), the K-factor values obtained indicate that the watersheds have low to moderate erodible soils. The areal coverage statistics presented in Table 6 indicated that low erodible soils constituted the largest area of the Tono, Vea, Gambibgo, Libga and Golinga watersheds whereas the moderately erodible soils constituted the largest area of the Bontanga, Sankana, Karni and Daffiama watersheds This suggests that the contribution of K-factor to soil loss in the watersheds ranged from low to moderate.

Table 6: Soil Classes, K-factor Values, Erodility Class and Areal Coverage in the Study Watersheds

FAO Soil Class	K-factor (t/ha/h/MJ/mm)	Erodibility Class	Name of Watershed/FAO Soil Class Areal Coverage (km^2)								
			Bontanga	**Golinga**	**Libga**	**Gambibgo**	**Tono**	**Vea**	**Daffiama**	**Karni**	**Sankana**
Lixisols	0.23	Low	-	-	-	1.40	610.30	60.60	-	0.14	47.30
Fluvisols	0.30	Moderate	-	-	-	0.30	23.20	13.10	-	-	-
Leptosols	0.28	Moderate	-	-	-	-	16.00	53.50	16.00	27.68	73.47
Vertisols	0.15	Low	-	-	-	-	0.50	8.80	5.00	7.44	20.23
Acrisols	0.25	Low	68.00	40.60	25.00	-	-	-	-	-	-
Plinthosols	0.26	Moderate	69.50	-	-	-	-	-	-	-	-
Planonosls	0.34	Moderate	27.50	12.40	6.00	-	-	-	-	-	-
TOTAL	-	-	**165.0**	**53.0**	**31.0**	**1.70**	**650.0**	**136.0**	**21.0**	**35.0**	**141.0**



Bontanga | **Golinga** | **Libga**



Gambibgo | **Tono** | **Vea**

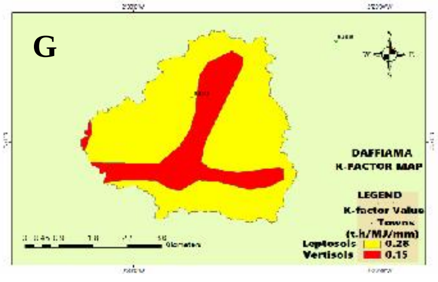
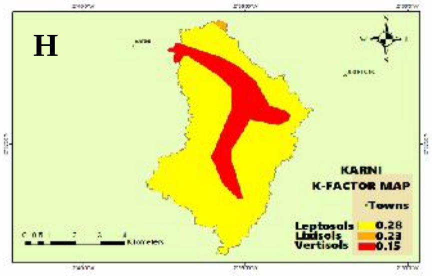
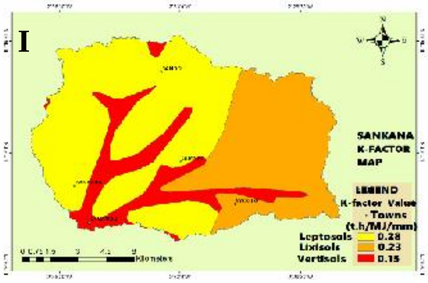
		
Daffiama	**Karni**	**Sankana**

Figure 4: Soil Erodibility (K) Factor in the Study Watersheds (A – I)

3.4 Slope Length and Steepness (LS) Factor

As presented in Table 5 and Figure 5, the combined LS-factor value of the watersheds varies from 0 to 6.36 (dimensionless) with the highest value estimated at the Tono watershed due to high terrains in some parts of the watershed. The estimated LS-factor values in all the watersheds indicate that the topography of the watersheds is relatively flat to gentle. According to Molla and Sisheber (2017), relatively flat to gentle topography has low LS-factor values ranging from 0 – 10.0 and does not contribute significantly to soil loss.This suggests that the influence of the combined slope length–steepness to soil loss might be low across all the study watersheds.

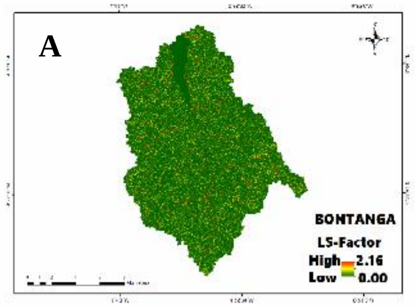
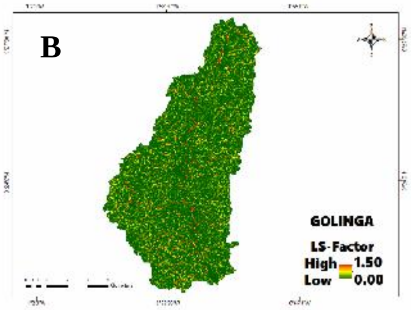
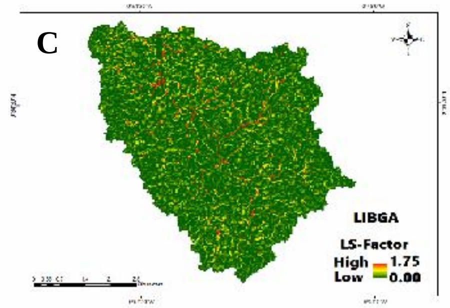
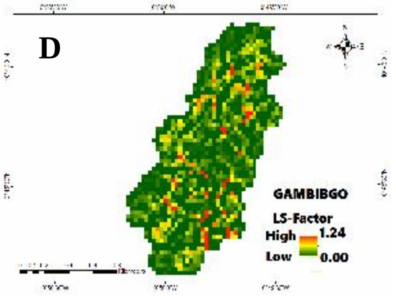
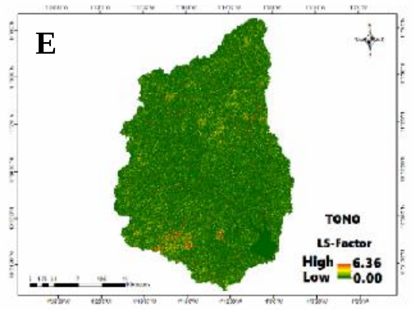
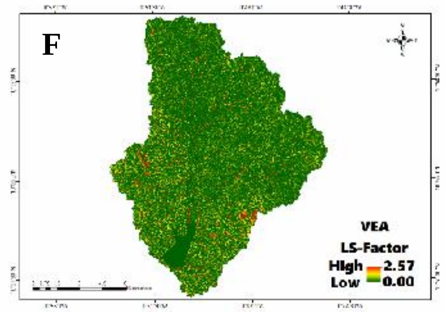
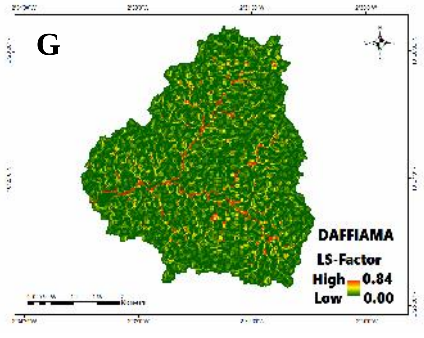
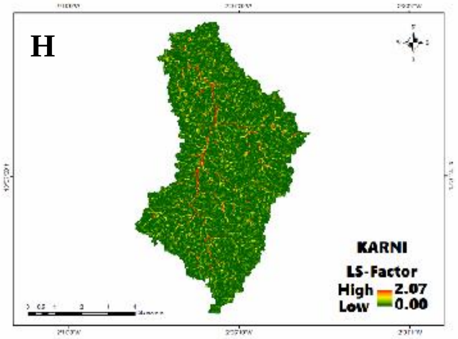
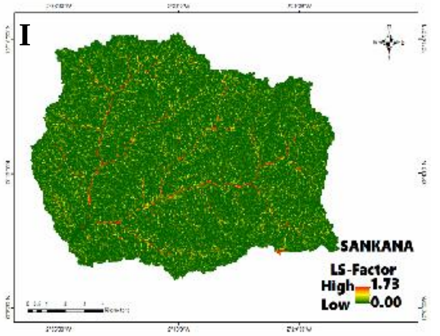
		
Bontanga	**Golinga**	**Libga**
		
Gambibgo	**Tono**	**Vea**
		
Daffiama	**Karni**	**Sankana**

Figure 5: Slope Length and Steepness (LS) Factor in the Study Watersheds (A – I)

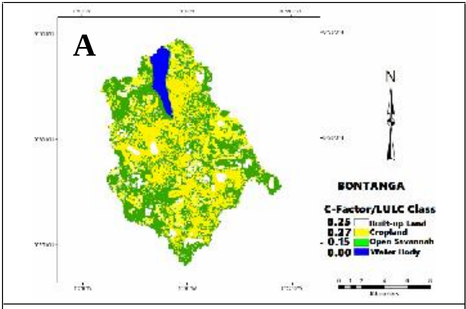
3.5 Landcover Management (C) Factor

Four (4) major landuse/landcover (LULC) classes thus; cropland, water body, built-up land and open savannah woodland were identified (Table7) in the study watersheds except Tono which had closed savannah woodland as the fifth major LULC class. The C-factor values of the LULC classes ranged for 0.0 – 0.27 and according to Renard*et al.* (1997), LULC classes with C-factor values above 0.20 significantly contributes to soil loss if conservation measures are not installed. Across all the watersheds, the predominant LULC was cropland with the highest C-factor value (0.27) and constituted over 40 % of the area of each watersheds (Table 7 and Figure 6). Cropland can significantly influence high soil loss in watersheds as tilling of the land for crop production destroys the vegetative cover as well as disturbs the soil and renders it susceptible to erosion and subsequent loss. Open and closed savannah woodlands with high potentials of controlling soil erosion and loss are noted to be depleted annually by crop production and built-up areas. Molla and Sisheber (2017) noted the contribution of C-factor to soil loss in watersheds to be higher in cultivated lands followed by built-up/bare lands and grasslands that are heavily grazed.

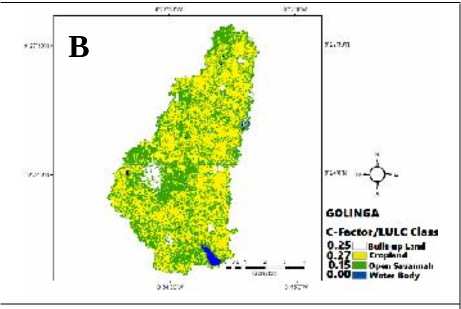
Table 7: Different Landuse/Landcover Classes and their C-Factor and Areal Coverage

LULC	**C-Factor**	**Name of Watershed/LULC Areal Extent (km^2)**								
		Bontanga	**Golinga**	**Libga**	**Gambibgo**	**Tono**	**Vea**	**Daffiama**	**Karni**	**Sankana**
CL	0.27	111.00	39.46	17.95	0.70	245.86	74.86	10.58	22.25	91.26
BL	0.25	8.23	3.77	4.04	0.63	79.43	10.38	3.23	3.01	4.40
WB	0.00	7.41	0.40	0.23	0.11	16.19	5.59	0.11	0.20	0.38
OSW	0.15	38.36	9.37	8.78	0.26	198.60	45.17	7.08	9.54	44.20
CSW	0.05	-	-	-	-	109.92	-	-	-	-
Total	-	**165.0**	**53.0**	**31.0**	**1.70**	**650.0**	**136.0**	**21.0**	**35.0**	**141.0**

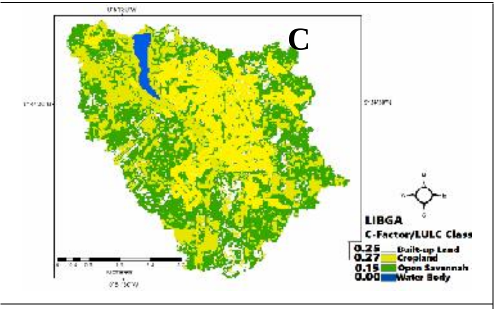
LULC – Landuse/landcover; CL – Cropland; BL – Built-up lan;, WB – Water bodies; OSW – Open savannah woodland; CSW – Closed savannah woodlan;, C-Factor – Landcover management factor



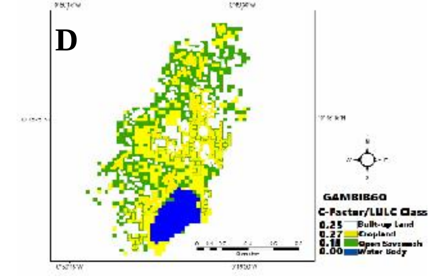
Bontanga



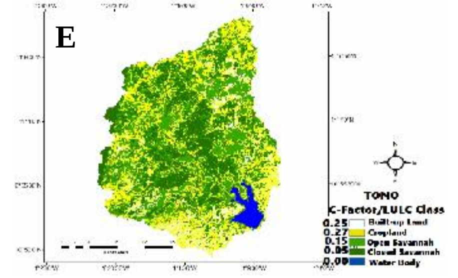
Golinga



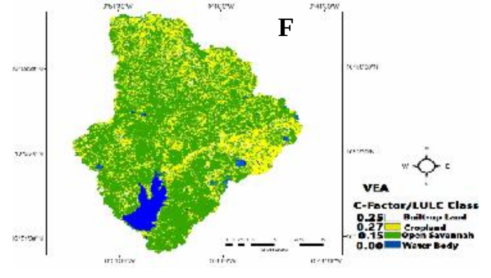
Libga



Gambibgo



Tono



Vea

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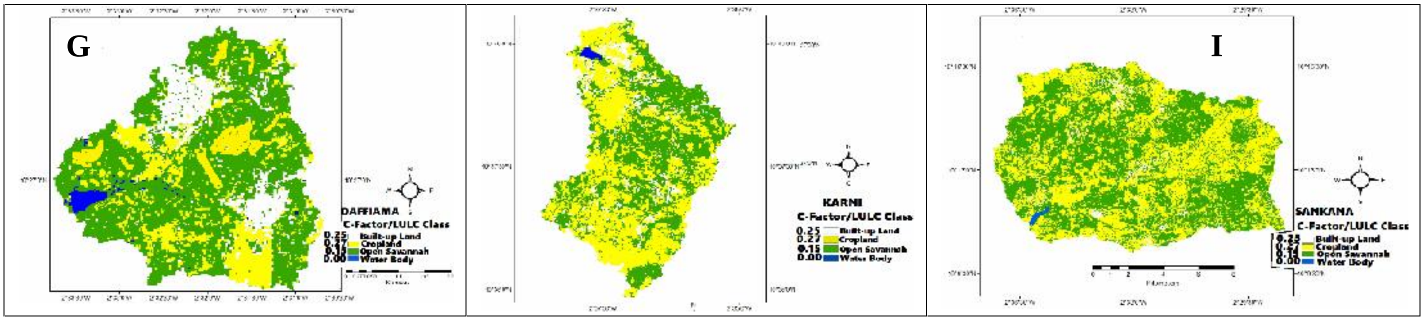


Daffiama **Karni** **Sankana**

Figure 6: Landcover Management (C) Factor in the Study Watersheds (A – I)

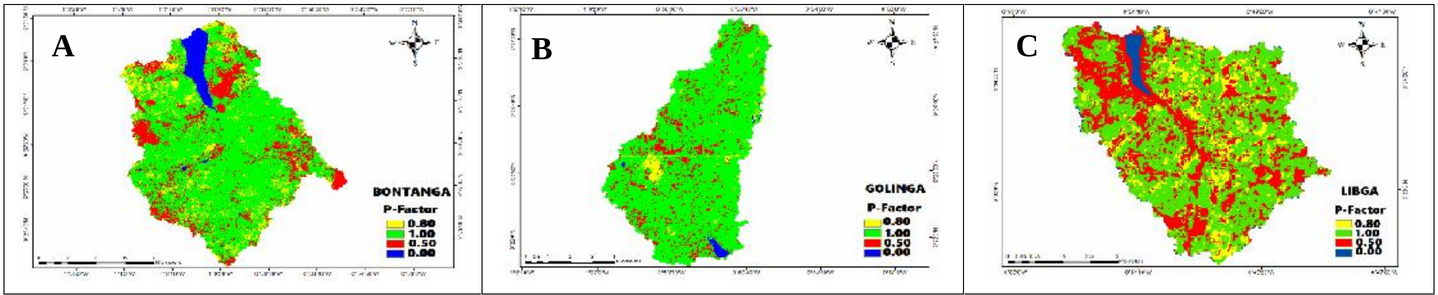
3.6 Erosion Management Practice (P) Factor

The P-factor values of the study watersheds ranged from 0 – 1.0 with water body recording the lowest value while the closed and open savannah woodlands recorded the highest value (Table 8 and Figure 7). According to Ganasri and Ramesh (2015), a P-factor value approaching zero indicates good soil conservation practice whereas the value approaching 1.0 indicates poor soil conservation practice in reducing or controlling soil loss due to erosion. The P-factor values obtained showed that no conservation practices are carried out to control soil loss in the closed and open savannah woodlands. However, some few soil conservation management practices like ploughing across the slope and earthen/stone bunding were being carried out in some croplands and built-up areas to check soil erosion and loss. Onori*et al.* (2006) indicated that cultivated and built-up lands with some soil conservation practices have P-factor values less than 1.0, while those without soil conservation management practices equals to 1.0.

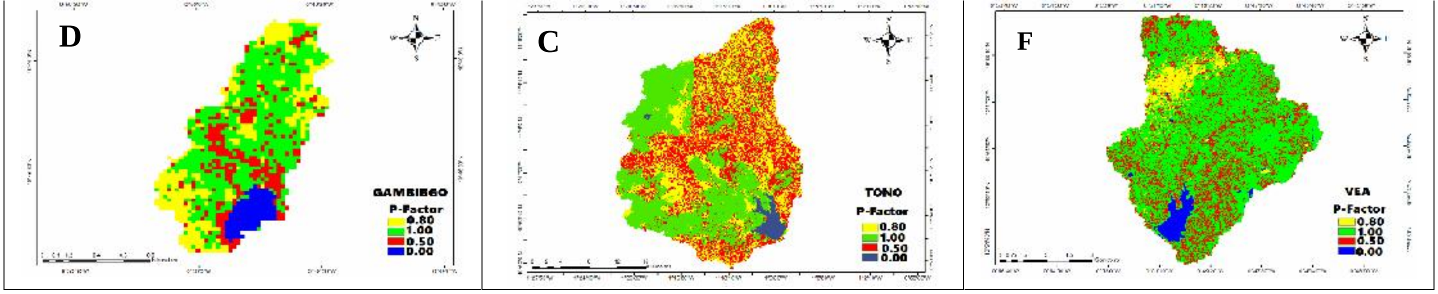
Table 8: Different Landuse/Landcover Classes and their P-Factor and Areal Coverage

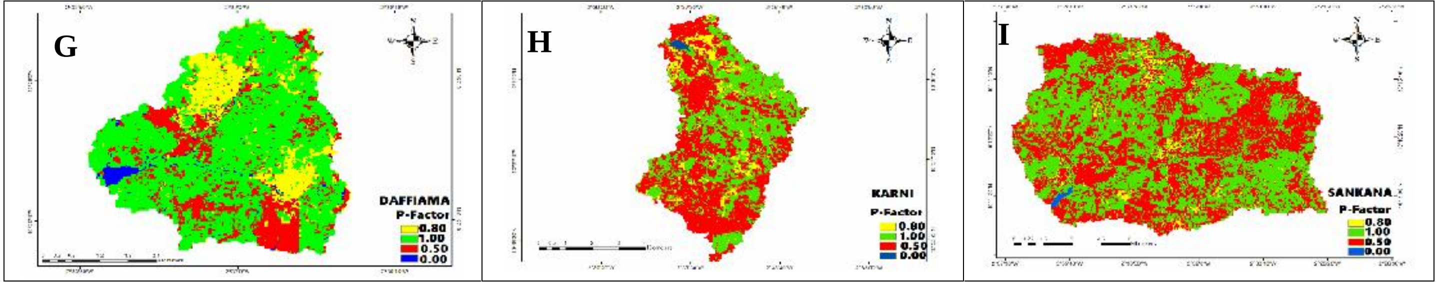
LULC	P-Factor	Name of Watershed/LULC Areal Extent (km^2)								
		Bontanga	Golinga	Libga	Gambibgo	Tono	Vea	Daffiama	Karni	Sankana
CL	0.50	111.00	39.46	17.95	0.70	245.86	74.86	10.58	22.25	91.26
BL	0.80	8.23	3.77	4.04	0.63	79.43	10.38	3.23	3.01	4.40
WB	0.00	7.41	0.40	0.23	0.11	16.19	5.59	0.11	0.20	0.38
OSW/ CSW	1.00	38.36	9.37	8.78	0.26	308.52	45.17	7.08	9.54	44.20
Total	-	165.0	53.0	31.0	1.70	650.0	136.0	21.0	35.0	141.0

LULC – Landuse/landcover; CL – Cropland; BL – Built-up land; WB – Water bodies; OSW – Open savannah woodland; CSW – Closed savannah woodland; C-Factor – Landcover management factor



Bontanga **Golinga** **Libga**





Gambibgo — **Daffiama**

Tono — **Karni**

Vea — **Sankana**

Figure 7: Erosion Management Practice (P) Factors in the Study Watersheds (A – I)

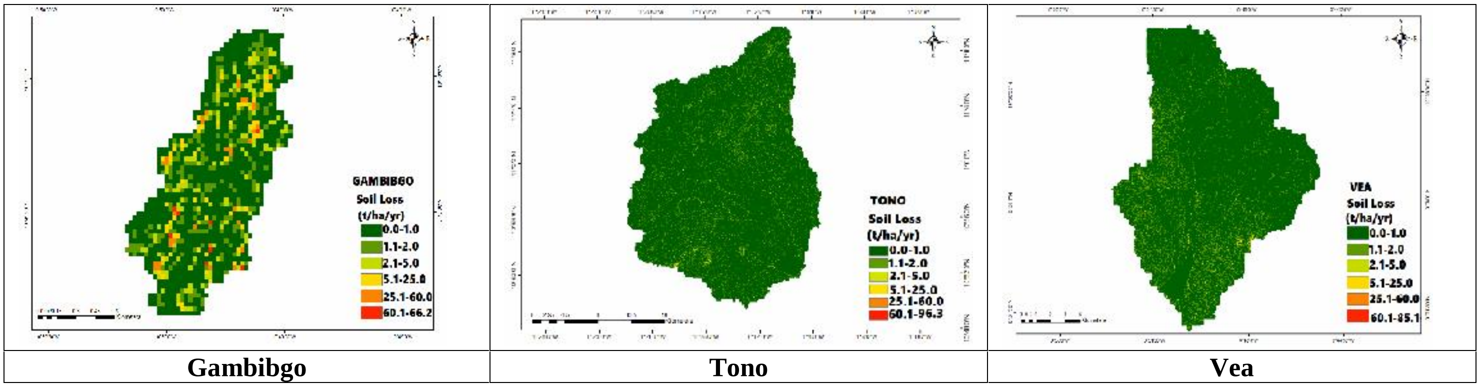
3.7 Annual Soil Loss in Watersheds of Upper East Region

The soil loss maps of the watersheds are shown in Figure 8 while the statistical details of the annual soil loss and their associated severity classes are presented in Table 9. The study estimated the annual soil loss at the Tono watershed to range from 0.0 – 96.30 t/ha/y with the mean loss as 6.91 t/ha/y. The annual soil loss at Vea watershed was estimated to range from 0.0 – 85.10 t/ha/y withmean 8.17 t/ha/y while the loss at the Gambibgo watershed ranged from 0.0 – 66.20 t/ha/y with mean of 5.37 t/ha/y. The estimated mean annual soil loss at the Vea watershed exceeded the FAO tolerable soil loss limits of 4.20 – 7.20 t/ha/y for soils with deep depth (FAO, 1984), but lower than the global tolerable soil loss limit of 11.20 t/ha/y (USDA-NRCS, 1999). However, the mean annual soil loss estimated at the Tono and Gambibgo watersheds were within the FAO and global tolerable soil loss limits. Abubakari (2014) estimated a very high mean annual soil loss of 22.83 t/ha/y at the Tono watershed using GeoWEPP model. Atakora*et al.* (2013) estimated mean annual soil loss of 6.8 – 10.2 t/ha/y at the watershed of Biemso valley in Ghana and this relatively conforms to the findings of this study. In a similar study in the Densu Basin located in the south-eastern part of Ghana, Owusu (2012) estimated mean annual soil loss of 2.20 t/ha/y, which is quite lower than the values in this study. This could be attributed to differences in agro-climatic zones.

As presented in Table 8, the severity of annual soil loss in the watersheds ranged from very low (0.0 – 1.0 t/ha/y) to very high (> 60.0 t/ha/y) with the dominant one being the very low class with a coverage area of 50.6 – 67.5 %. It, however, was noted to contribute the least of about 7.80 – 9.40 % of the total annual soil loss. The moderate severity soil loss class with a coverage area between 1.70 – 18.80 % was noted as the highest contributor of about 25.2 – 51.2 % of the total annual soil loss at the Tono and Gambibgo watersheds. At Vea watershed, the very high severity soil loss class contributed the highest of 29.1 % to its total annual soil loss (Table 9), and this could be due to the presence of leptosols and fluvisols which are less resistant to erosion. It was also observed from the study that the hot spot areas which contribute high to very high soil losses in the watersheds were spatially found in the steep slope parts of the watersheds and along the banks of water courses such as rivers and streams. Farhan *et al.* (2013) for example reported a strong correlation between the highest soil loss values and slope steepness in Kufranja watershed in Northern Jordan.

Table 9: Severity and Coverage of Annual Soil Loss in Watersheds of Upper East Region

Watershed		**Gambibgo**				**Tono**				**Vea**			
Soil Loss (t/ha/y)	**Soil Loss Severity Class**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**
0.0 - 1.0	Very Low	86.0	50.6	77.4	9.4	39,913.3	61.4	37,917.6	8.5	9,173.9	67.5	8,715.2	7.8
1.1 - 2.0	Low	35.2	20.7	104.0	10.4	3,124.1	4.8	24,635.3	5.5	1,471.5	10.8	17,828.4	16.1
2.1 - 5.0	Moderate Low	26.8	15.8	208.6	22.9	6,720.6	10.4	72,419.3	16.2	868.6	6.4	20,208.6	18.2
5.1 - 25.0	Moderate	13.1	7.7	229.8	25.2	12,232.3	18.8	229,359.6	51.2	234.1	1.7	17,693.5	15.9
25.1 - 60.	High	7.3	4.3	196.8	21.6	2,238.9	3.4	40,818.3	9.1	1,788.3	13.1	32,343.5	29.1
> 60.0	Very High	1.7	1.0	95.9	10.5	770.8	1.2	43,043.6	9.6	63.6	0.5	14,246.3	12.8
Total	**-**	**170**	**100**	**912.5**	**100**	**65,000**	**100**	**448,193.8**	**100**	**13,600**	**100**	**111,053.5**	**100**
Mean	**-**	**-**	**-**	**5.37**	**-**	**-**	**-**	**6.91**	**-**	**-**	**-**	**8.17**	**-**



Gambibgo **Tono** **Vea**

Figure 8: Spatial Distribution of Soil Loss in Watersheds of Upper East Region

3.8 Annual Soil Loss in Watersheds of Upper West Region

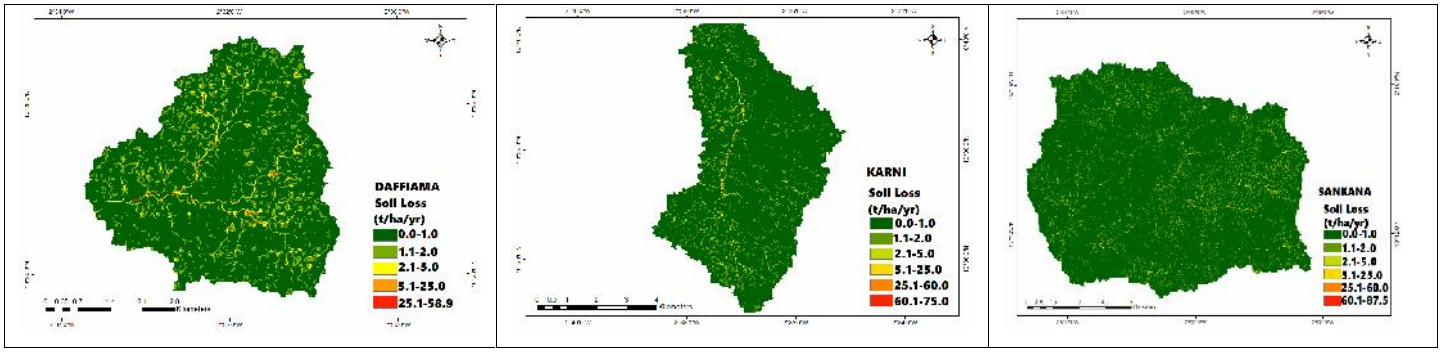
The annual soil loss rates at the Sankana, Karni and Daffiama watersheds which are situated in the Upper West Region of Ghana were estimated to range from 0.0 – 87.50 t/ha/y with mean loss ranging from 5.94 – 7.78 t/ha/y as presented in Figure 9. The estimated mean annual soil loss at Sankana and Daffiama watersheds were within the FAO (1984) soil loss tolerable limits of 4.20 – 7.20 t/ha/y and also lower than the global soil loss tolerable limit of 11.20 t/ha/y as reported by USDA-NRCS (1999). The mean annual soil loss at the Karni watershed was observed to have exceeded the FAO soil loss tolerable limits but lower than that of the global tolerable limit.

In a similar study in the Densu Basin in Ghana, Owusu (2012) estimated mean annual soil loss of 2.20 t/ha/y, which is quite lower than the estimated means in this study. Also, Mesele (2015) estimated lower mean annual soil loss of 1.42 t/ha/y at Kumasi-Anwomaso in Ghana. The very wide differences in means could be attributed to different geographical locations as the Densu Basin and Kumasi-Anwomaso are respectively located in the south-eastern and southern parts of Ghana whilst Daffiama, Karni and Sankana watersheds are located in the Guinea agro-ecological zone in northern Ghana.

The study also found very low to very high severity soil losses in all the watersheds except Daffiama. Across all the watersheds, the very low soil loss severity class constituted the largest area of about 36.70 – 48.30 % but contributes the least of about 5.9 – 7.9 % of the total annual soil loss in the watersheds (Table 10). Again, the moderate soil loss severity class was found contributing the highest between 31.2 – 38.6 % of the total annual soil loss of the watersheds.

Table 10: Severity and Coverage of Annual Soil Loss in Watersheds of Upper West Region

Watershed		**Daffiama**				**Karni**				**Sankana**			
Soil Loss (t/ha/y)	**Soil Loss Severity Class**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**
0.0 - 1.0	Very Low	770.7	36.7	732.2	5.9	1,690.5	48.3	1,605.9	7.9	6,105.3	43.3	5,800.0	6.5
1.1 - 2.0	Low	606.9	28.9	2,421.5	19.4	857.5	24.5	4,661.8	17.1	4,173.6	29.6	15,297.1	17.3
2.1 - 5.0	Moderate Low	212.1	10.1	2,227.1	17.9	381.1	10.9	5,340.8	19.6	1,762.5	12.5	17,799.3	20.1
5.1 - 25.0	Moderate	310.8	14.8	4,817.4	38.6	430.5	12.3	9,631.8	35.4	1,015.2	7.2	27,690.4	31.2
25.1 - 60.0	High	199.5	9.5	2,274.3	18.2	133.0	3.8	3,614.3	13.3	860.1	6.1	12,623.2	14.3
> 60.0	Very High	-	-	-	-	7.0	0.2	2,350.1	8.6	183.3	1.3	9,416.8	10.6
Total	**-**	**2,100**	**100**	**12,472.5**	**100**	**3,500**	**100**	**16,714.6**	**100**	**14,100**	**100**	**88,626.8**	**100**
Mean	**-**	-	-	**5.94**	-	-	-	**7.78**	-	-	-	**6.29**	-



Daffiama	Karni	Sankana

Figure 9: Spatial Distribution of Soil Loss in Watersheds of Upper West Region

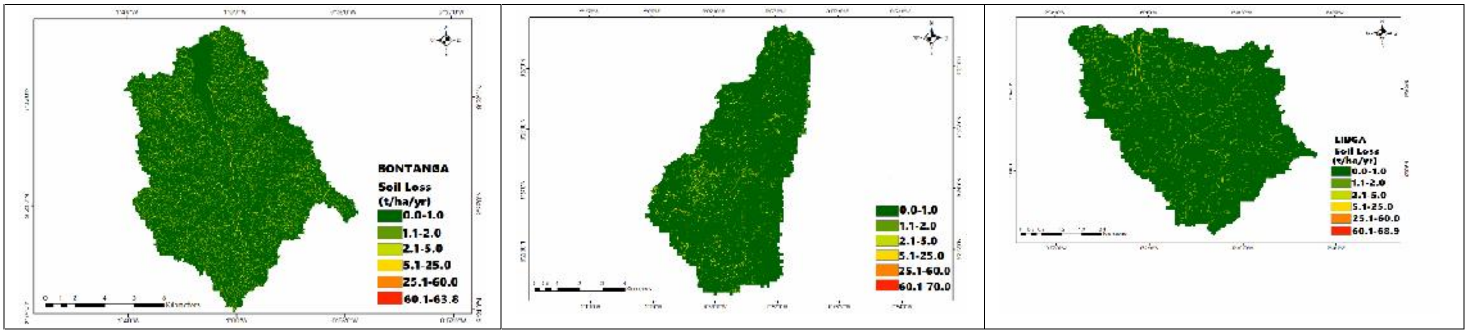
3.9 Annual Soil Loss in Watersheds of Northern Region

As presented in Figure 10, the estimated annual soil loss rate ranged from 0.0 – 70.0 t/ha/y in the Bontanga, Golinga and Libga watersheds which are located in the Northern Region. The estimated mean annual soil loss at the watersheds of 3.71 – 4.96 t/ha/y presented in Table 11 were within the tolerable soil loss limits of 4.20 – 7.20 t/ha/y for soils with deep depth reported by FAO (1984) and also within the global tolerable soil loss limit of 11.2 t/ha/y indicated by USDA-NRCS (1999). However, it was observed that the estimated mean annual soil loss rates at the study watersheds were quite higher than the mean soil loss of 2.20 t/ha/y estimated by Owusu (2013) at the Densu Basin in located the south-eastern part of Ghana.

The severity of soil loss in the watersheds ranges from very low (0.0 – 1.0 t/ha/y) to very high (> 60.0 t/ha/y). The very low severity class was predominant with a coverage area ranging from 42.40 – 60.20 % and contributing about 7.70 – 15.4 % of the total annual soil loss (Table 11). The moderate severity class which constituted an area ranging from 3.50 – 15.20 % was noted as the highest contributor (25.0 – 42.80 %) of the total annual soil loss. As seen in Table 11, the watersheds were not much affected by very high soil loss as only a small area ranging from 0.10 – 1.10 % was affected by this soil loss severity class, contributing averagely 5.41 % of the total annual soil loss. This could be attributed to the relatively flat topography of the watersheds as well as the dominance of acrisols and plinthosols which are group ‘A’ soils and intrinsically less susceptible to severe erosion (USDA-NRCS, 1985). Farhan *et al.* (2013) stated that soil loss in watersheds varies spatially with changes in topography, soil characteristics and landuse/landcover.

Table 11: Severity and Coverage of Annual Soil Loss in Watersheds of Northern Region

Watershed		**Bontanga**				**Golinga**				**Libga**			
Soil Loss (t/ha/y)	**Soil Loss Severity Class**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**	**Coverage Area (ha)**	**% Total Area**	**Annual Soil Loss (t)**	**% Total Annual Soil Loss**
0.0 - 1.0	Very Low	6,996	42.4	6,296.4	9.7	2,899.1	54.7	2,724.2	11.0	1866.2	60.2	7,747.5	15.4
1.1 - 2.0	Low	3,646.5	22.1	10,903.0	13.3	1,245.5	23.5	2,478.5	13.8	911.4	29.4	2,588.7	22.8
2.1 - 5.0	Moderate Low	2,970.0	18.0	17,285.4	21.1	535.3	10.1	4,073.6	16.4	173.6	5.6	2,233.3	19.7
5.1 - 25.0	Moderate	2,508.0	15.2	35,011.7	42.8	455.8	8.6	10,241.8	37.4	108.5	3.5	2,832.2	25.0
25.1 - 60.0	High	264.0	1.6	6,937.9	8.5	106	2.0	3,209.7	12.9	37.2	1.2	1,827.1	16.1
> 60.0	Very High	115.5	0.7	5,325.7	6.5	58.3	1.1	2,157.1	8.7	3.2	0.1	117.8	1.04
Total	**-**	**16,500**	**100**	**81,760.1**	**100**	**5,300**	**100**	**24,885.9**	**100**	**3,100**	**100**	**11,346.6**	**100**
Mean	**-**	**-**	**-**	**4.96**	**-**	**-**	**-**	**4.70**	**-**	**-**	**-**	**3.71**	**-**



Bontanga	Golinga	Libga

Figure 10: Spatial Distribution of Soil Loss in Watersheds of Northern Region

4. Conclusions

The study used the RUSLE model integrated with remote sensing and GIS tools to estimate the magnitude of annual soil loss and the spatial distribution of soil loss severity classes in nine (9) watersheds in northern Ghana. The estimated annual soil loss in the various watersheds ranged from 0 – 96.30 t/ha/y. Estimated mean annual soil loss of 7 watersheds were within tolerable soil loss limits according to FAO (1984) and USDA-NRCS (1999) classification. Mean annual soil loss estimated for 2 watersheds i.e. Vea and Karni exceeded the tolerable soil loss limit set by the USDA-NRCS (1999).

The severity of annual soil loss rates in the watersheds ranged from very low class (0.0 – 1.0 t/ha/y) to very high class (> 60.0 t/ha/y). Across all the watersheds, the very low severity class constituted the largest area of 36.70 – 67.50 % but was noted as the least contributor of 5.90 – 15.40 % to the total annual soil loss. At Tono and Vea watersheds, which have leptosols and fluvisols noted to be less resistant to soil erosion as well as the high terrain in some parts watersheds presented high and very high severity soil loss classes and contributed significantly to the total annual soil loss in the watersheds.

Farming practices such as ploughing along the slope, slashing and burning, and farming very close to the banks of water courses in the watersheds were some of the main causes of soil loss in the watersheds. High terrain and slope steepness in some parts of Tono, Vea watersheds also contributed to high soil loss. Soil and water conservation measures such as contour ploughing, stone/earth bunding and upstream afforestation of the watersheds are best practices to reduce soil loss. Education on riparian area protection and avoidance of farming in buffer zones of the reservoirs which has a multiplier negative effect on soil loss and reservoir sedimentation is very necessary in all watersheds.Analysis of the temporal distribution of the soil loss in the watersheds is necessary and therefore recommended for future studies.

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