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Soil loss estimation using the spatially integrated revised universal soil loss equation (RUSLE) in reservoir catchments 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 t/ha/y. 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 contributorto total annual soil loss. Soil and water conservation measures are requiredin the catchments to reduce soil loss.

*Keywords:*Reservoir catchment,soil loss, spatially integrated RUSLE, sediment accumulation, lixisols

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1. Introduction

Soil loss in reservoir catchments 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 reservoir catchments, 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 reservoir catchments 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) reservoir catchments in the Upper East Region. Mean soil loss rates estimated in some reservoir catchmentsof 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 reservoir catchments (Ganasri and Ramesh, 2016) 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-by-cell basis (Shinde*et al.*, 2010).This study assessed the annual soil loss per unit area of land innine (9) reservoir catchmentsin northern Ghana and the estimated soil loss ratesfor some reservoir catchmentswere 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) reservoir catchmentsacross the former three (3) administrative regions namely; Bontanga, Libga and Golinga catchmentsin the Northern Region; Vea, Tono and Gambibgo catchmentsin the Upper East Region and Sankana, Karni and Daffiama catchmentsin the Upper West Region of Ghana. A map showing the study reservoir catchments is presented in Figure 1 whilst the description of the reservoir catchmentsis presented in Table 1.

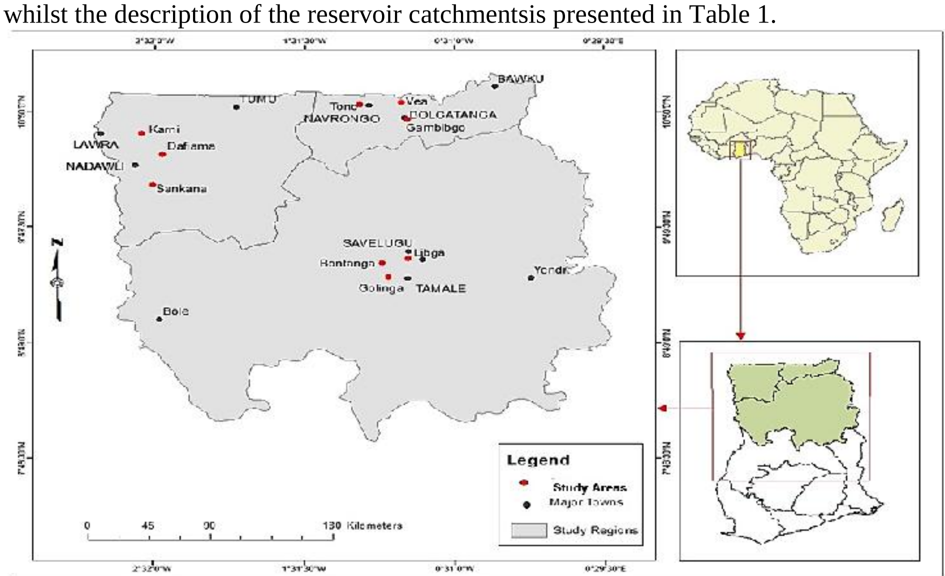


Figure 1: Map of the Former Three(3) Northern Regions Showing the Study Reservoir Catchments

Table 1: Description of Study Reservoir Catchments

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		

Table 1(cont'd)**:** Description of Study Reservoir Catchments

Name of watershed		Bontanga	Golinga	Libga	Gambibgo	Tono	Vea	Daffiama	Karni	Sankana
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 Spatially Integrated RUSLE

The spatially integrated RUSLE was used to estimate the annual soil loss rate at the nine (9) reservoir catchments. The model estimated annual soil loss rate by a cell-by-cell multiplication using raster maps of five (5) parameters as expressed in Equation 1 according 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 reservoir catchments.

$$A = RK(LS)CP \quad (1)$$

where A - Annual soil loss (t/ha/y), R - Rainfall erosivity factor (MJmm/h/ha/y), K - Soil erodibility factor (t/ha/hMJ/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).

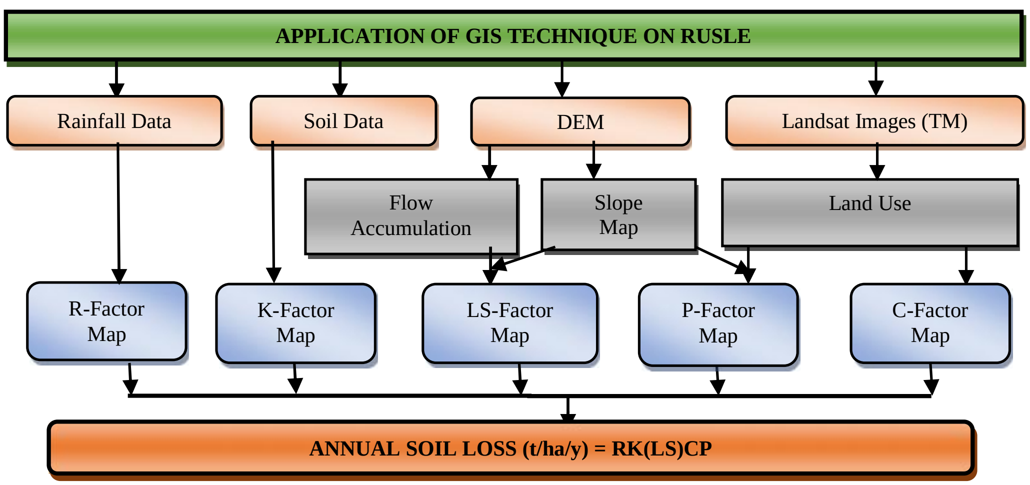


Figure 2: Methodological Framework of Soil Loss Estimation in Reservoir catchments Using the RUSLE Adapted fromGelagay and Minale (2016)

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, 2016). The soil maps of the reservoir catchments were produced using Ghana soil shapefile (HWSD, 2017)with the region of interest extracted using each catchment area and the soil data layer clipped onto the watershed in ArcGIS environment10.4. The soil classes for each catchment 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 catchment. 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 reservoir catchments from the Digital Elevation Model (DEM) of the reservoir catchmentsat 30 m resolution. All sinks in the DEM were identified and filled with the filled DEM for each catchment 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).

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

where LS - Slope length and steepness factor (dimensionless), Q_a - Flow accumulation grid, M - Grid size, S_g - 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 reservoir catchments 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 reservoir catchments 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 reservoir catchments.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 Factors of the Reservoir catchments

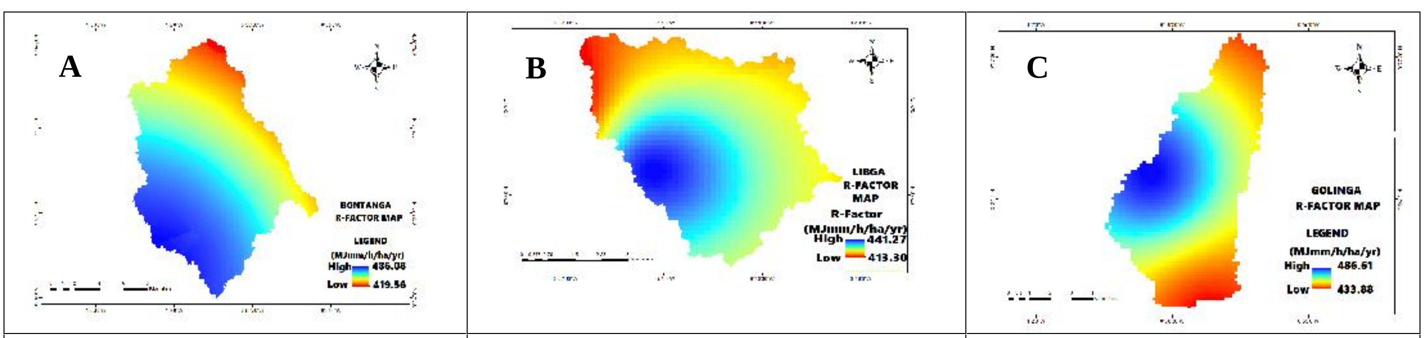
The estimated RUSLE parameters which are R, K, LS and P factors of the nine (9)reservoir catchments are presented in Table 5.

Table 5: Estimated RUSLE Factors of the Study Reservoir catchments.

Watershed	Mean Annual Rainfall (mm)	R-Factor Value (MJmm/h/ha/y)	K-Factor Value (t/ha/hMJ/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 reservoir catchments ranged from 934 mm to 1074 mm.Dabral*et al.* (2008) and Ganasri and Ramesh (2016) noted that soil loss rate in the reservoir catchments 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 reservoir catchments 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 reservoir catchments decreases from the deep blue area to the deep red area.



Bontanga	Golinga	Libga

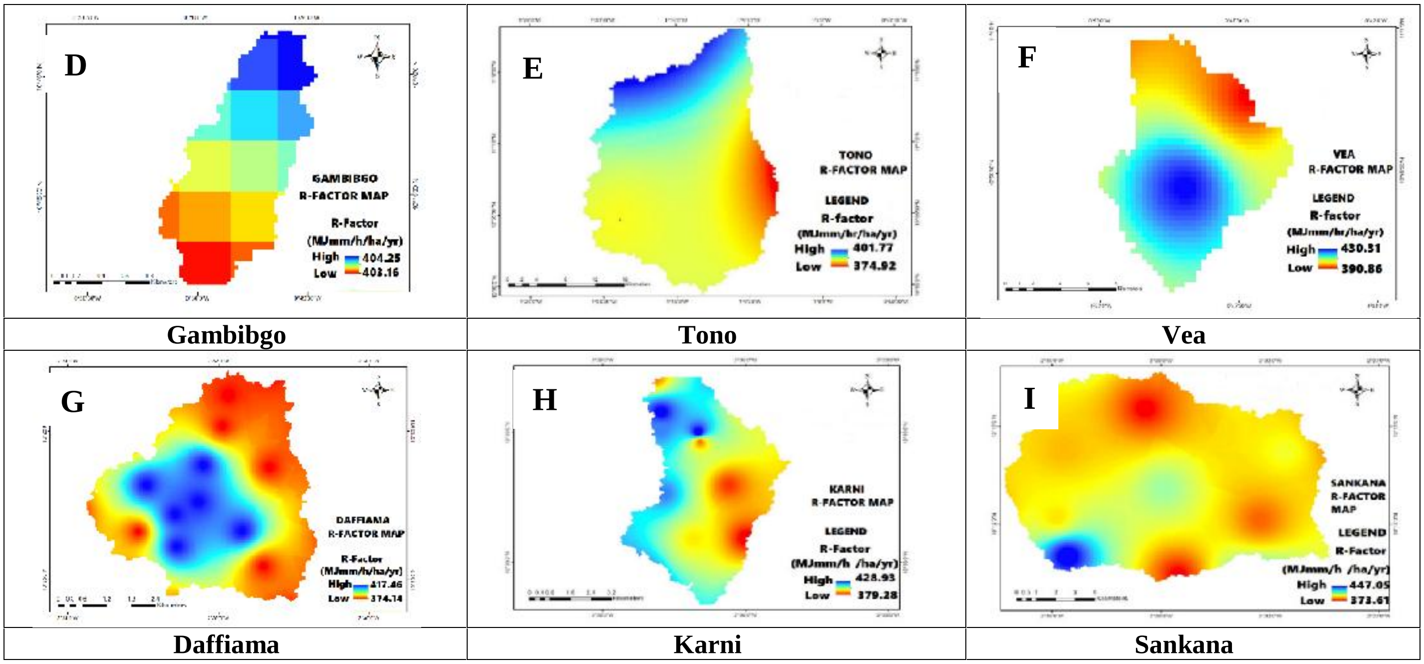


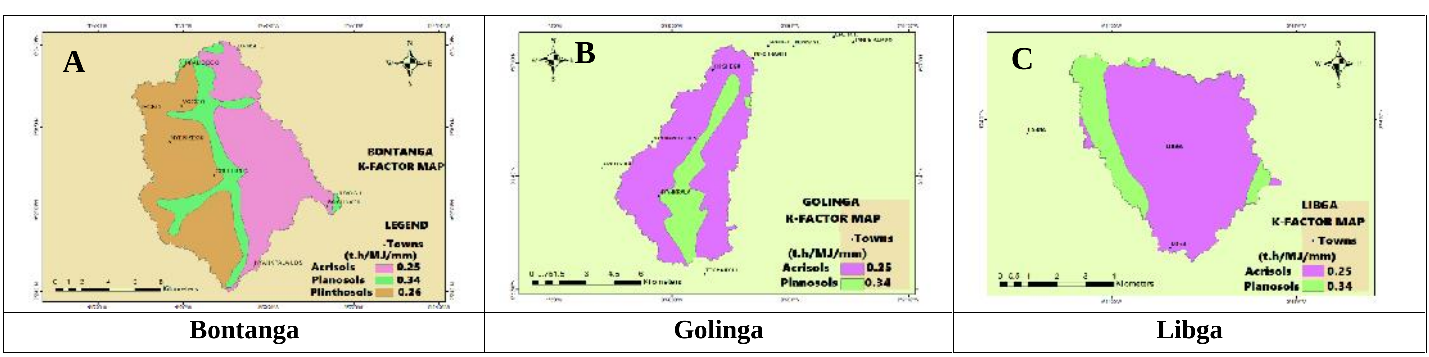
Figure 3: RainfallErosivity (R) Factor in the Study Reservoir catchments (A – I)

3.3 Soil Erodibility (K) Factor

The number of soil classes identified in the study reservoir catchments 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/hMJ/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 reservoir catchments 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 reservoir catchments whereas the moderately erodible soils constituted the largest area of the Bontanga, Sankana, Karni and Daffiama reservoir catchments. This suggests that the contribution of K-factor to soil loss in the reservoir catchments ranged from low to moderate.

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

FAO Soil Class	**K-factor (t/ha/hMJ/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**



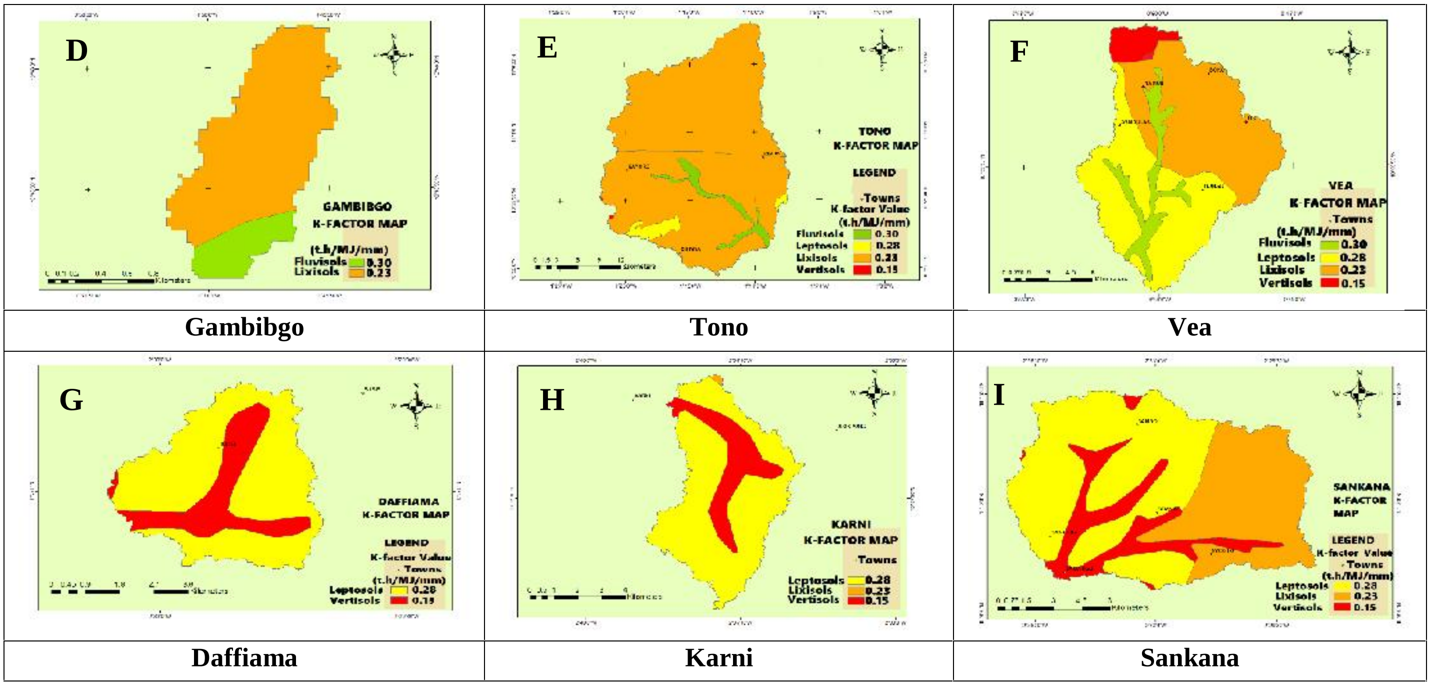
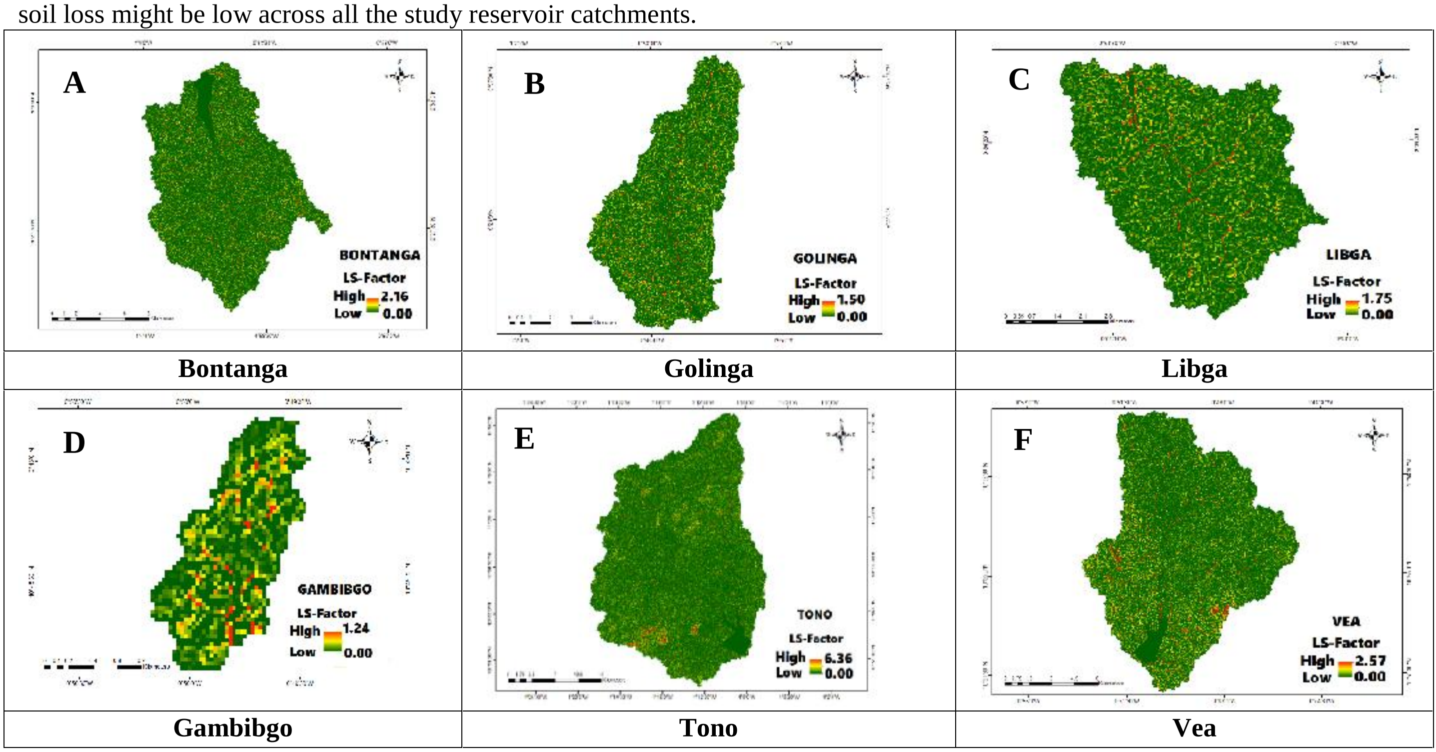
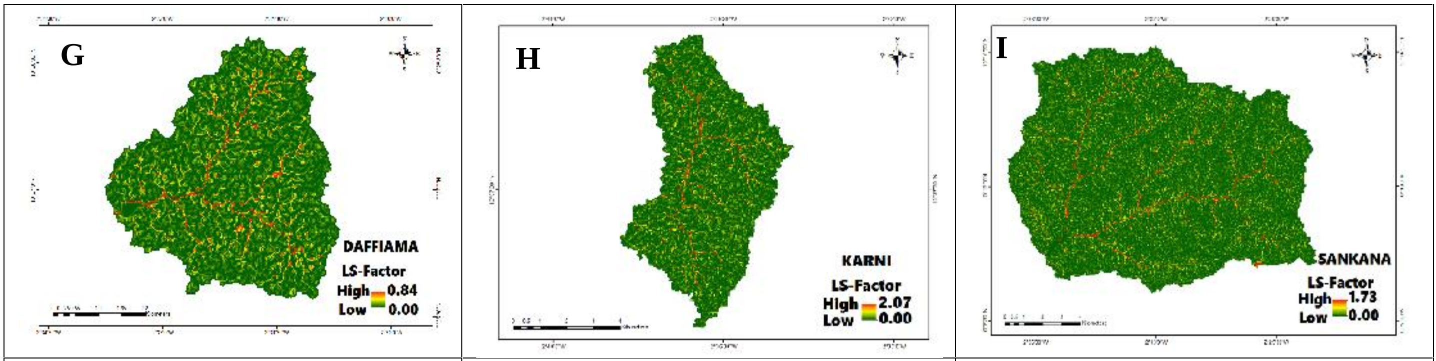


Figure 4: Soil Erodibility (K) Factor in the Study Reservoir catchments (A – I)

3.4 Slope Length and Steepness (LS) Factor

As presented in Table 5 and Figure 5, the combined LS-factor value of the reservoir catchments 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 catchment. The estimated LS-factor values in all the reservoir catchments indicate that the topography of the reservoir catchments 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 reservoir catchments.





Daffiama	Karni	Sankana

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

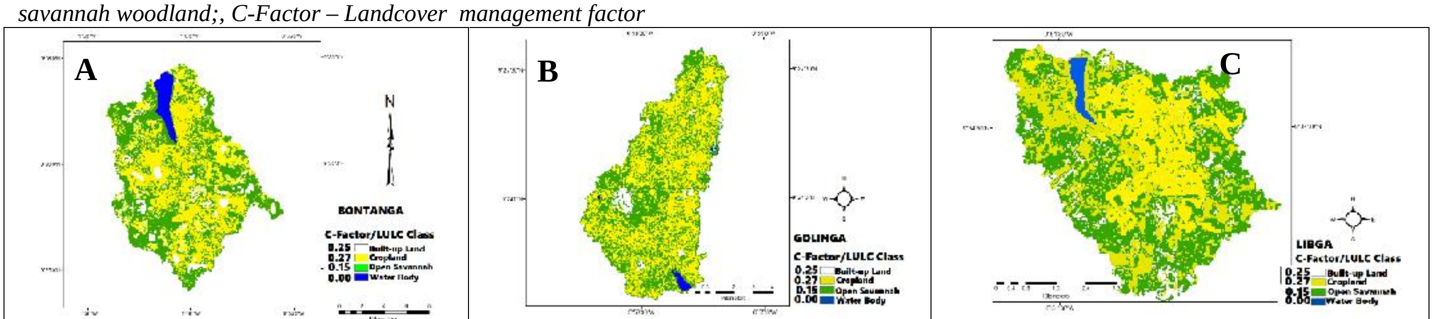
3.5 Landcover Management (C) Factor

Four (4) major landuse/landcover (LULC) classes thus; cropland, water body, built-up land and open savannah woodland were identified (Table7) in the study reservoir catchments 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 contribute to soil loss if conservation measures are not installed. Across all the reservoir catchments, the predominant LULC was cropland with the highest C-factor value (0.27) and constituted over 40 % of the area of each reservoir catchments (Table 7 and Figure 6). Cropland can significantly influence high soil loss in reservoir catchments 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 reservoir catchments to be higher in cultivated lands followed by built-up/bare lands and grasslands that are heavily grazed.

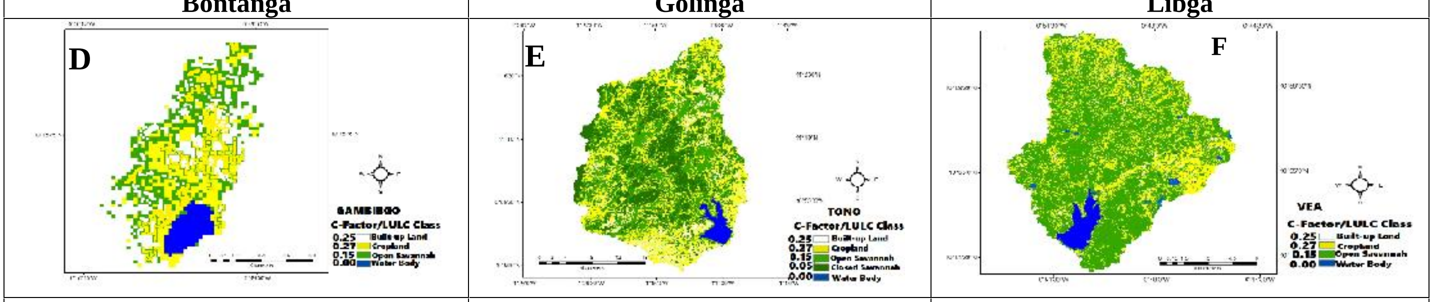
Table 7. Areal Extent of C-Factor for Different Landuse/Landcover Classes at the Various Catchments

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	16.95	0.70	245.86	74.86	10.58	23.25	96.52
BLU	0.25	8.23	3.77	7.04	0.63	79.43	10.38	3.91	3.01	8.80
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	6.78	0.26	218.60	45.17	6.40	8.54	35.30
CSW	0.05	-	-	-	-	89.92	-	-	-	-
Total	-	**165.0**	**53.0**	**31.0**	**1.70**	**650.0**	**136.0**	**21.0**	**35.0**	**141.0**

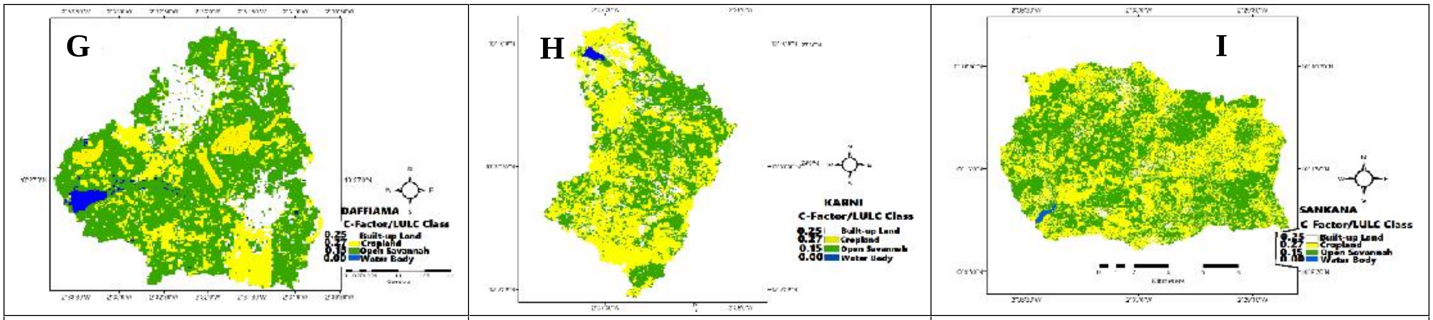
LULC – Landuse/landcover; CL – Cropland; BLU – Built-up land;, WB – Water bodies; OSW – Open savannah woodland; CSW – Closed savannah woodland;, C-Factor – Landcover management factor



Bontanga	Golinga	Libga



Gambibgo	Tono	Vea



Daffiama	Karni	Sankana

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

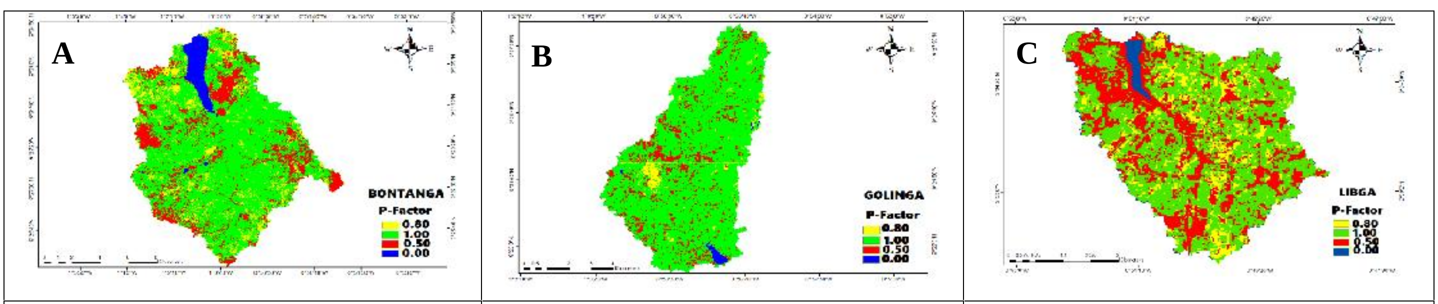
3.6 Erosion Management Practice (P) Factor

The P-factor values of the study reservoir catchments 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 (2016), 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.

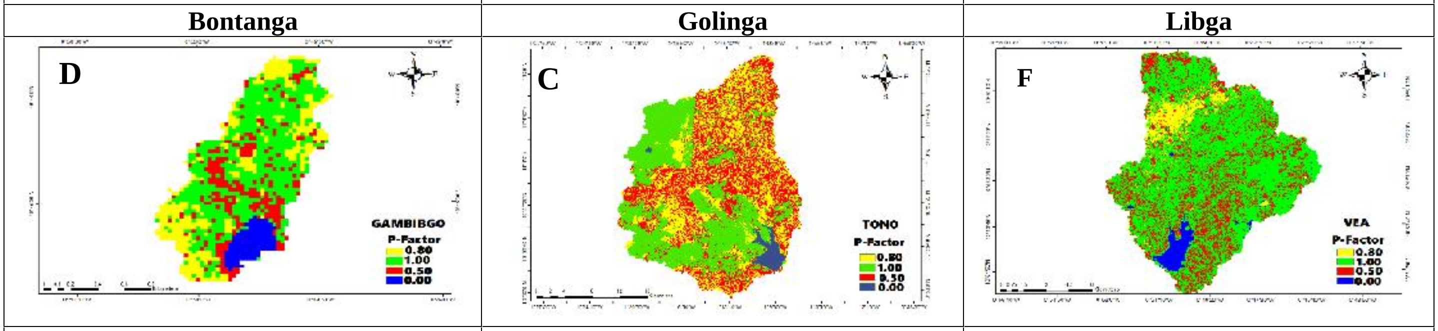
Table 8: Areal Extent of P-Factor for Different Landuse/Landcover Classes at the Various Catchments

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
BLU	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

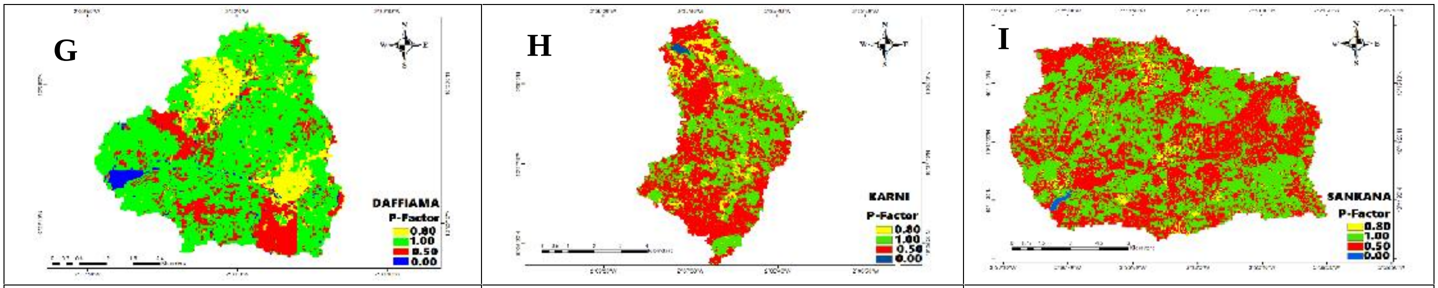
LULC – Landuse/landcover; CL – Cropland; BLU – Built-up land; WB – Water bodies; OSW – Open savannah woodland; CSW – Closed savannah woodland; C-Factor – Landcover management factor



Bontanga	Golinga	Libga



Gambibgo	Tono	Vea



Daffiama	Karni	Sankana

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

3.7 Annual Soil Loss ofReservoir Catchmentsin the Study Area

The soil loss maps of the study reservoir catchments are shown in Figure 8 whilst 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 reservoir catchments to range from 0.0–96.30 t/ha/y with the mean annual loss found to range from 3.71–8.17 t/ha/y as presented in Table 9. The least and highest mean annual soil losses were recorded at the Libga and Vea catchments respectively. The estimated mean annual soil loss at the Vea and Karni catchments were observed to have exceeded the FAO tolerable soil loss limits of 4.20–7.20 t/ha/y for deep soils (FAO, 1984), but lower than the global tolerable soil loss limit of 11.20 t/ha/y as reported by USDA-NRCS (1999). The estimated mean annual soil loss at the Bontanga, Golinga, Libga, Gambibgo, Tono, Gambibgo, Daffiama and Sankana catchments 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 catchment using GeoWEPP model. The wide difference between the estimated mean annual soil loss rate at the Tono catchment (6.91 t/ha/y) in this study and that of Abubakari (2014) could be due to the differences in the estimation models; spatially integrated RUSLE as against GeoWEPP model. Also, this study covered the entire Tono catchment area of 650 km^2 whilst Abubakari (2014) covered only 150 km^2, a section of the catchment within the Ghana boundary, where indiscriminate deforestation and conversion of buffer zone into farmlands were observed to be practiced. Moreover, the wide difference could be attributed to the differences in the landuse/landcover (LULC) classes delineated and used in the estimation. The LULC classes used by Abubakari (2014) were water body, built-up land, shrubs and barelands whereas this study delineated cropland, open savannah woodland, closed savannah woodland, built-up land and water body as the LULC classes in the catchment and these were used in the estimation. Atakora*et al.* (2013) estimated mean annual soil loss of 6.8–10.2 t/ha/y at the catchment of Biemso valley in Ghana and this relatively similar 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 obtained in this study. Also, Mesele (2015) estimated lower mean annual soil loss of 1.42 t/ha/y at Kumasi-Anwomaso in Ghana. The wide differences between the values recorded in this study and that of Owusu (2012) and Mesele (2015) could be due to differences in the ecological zones, climatic factors, landuse/landcover types, vegetation, soil types and other catchment characteristics as well as the differences in the estimation models.

As presented in Table 9, the severity of annual soil loss in the catchments 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 36.7– 67.5 %. It, however, was noted as the second least contributor of about 5.5–15.4 % of the total annual soil loss. The very high severity soil loss class which constituted a coverage area between 0.1–1.3 % was noted the least contributor of about 1.1–12.8 % of the total annual soil loss at the catchments. The moderate severity loss class with a coverage area ranging from 1.7–18.8 % was noted as the highest contributor of about 25.0–51.2 % of the total annual soil loss at all the catchments except Vea where the high severity class was found contributing the highest of 29.1 % of the total annual soil loss. In a decreasing order of magnitude, the coverage area of the soil loss severity classes was found to be in the order of very low (36.7–67.5 %) > low (22.1–29.6 %) > moderate low (5.6–18.0 %) > moderate (1.7–18.8 %) > high (1.2–13.1 %) > very high (0.1–1.3 %) whilst the average percentage contribution to the total annual soil loss by the soil loss severity classes at the catchments was in the order of moderate (16.4–51.2 %) > moderate low (15.9–29.1 %) > high (8.5–22.9 %) > low (5.9–22.8 %) very low (5.5–15.4 %) > very high (1.1–12.8 %).

It was observed from the study that the Bontanga, Golinga and Libga catchments recorded lower mean annual soil loss of 3.71–4.96 t/ha/y when compared to the estimated mean annual soil loss of 5.37–8.17 t/ha/y in the Gambibgo, Tono, Vea, Daffiama, Karni and Sankana catchments. This could be attributed to the relatively flat topography of the Bontanga, Golinga and Libga catchments as well as the dominance of acrisols and plinthosols which are group 'A' soils and planosols which are group 'B' soils intrinsically less susceptible to severe erosion (USDA-NRCS, 1985). Farhan *et al.* (2013) stated that soil loss in catchments varies spatially with changes in topography, soil characteristics and landuse/landcover. It was observed from the study that the hot spot areas which contribute high to very high soil losses in the catchments were spatially found in the steep slope parts of the catchments 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 catchment in Northern Jordan.

3.8 Effect of Ecological Zones, Soil Classes and Catchment Sizes on Annual Soil Loss in the Reservoir Catchments

3.8.1Effect of Ecological Zones on Annual Soil Loss in the Reservoir Catchments

There are two (2) ecological zones in northern Ghana namely; Guinea Savannah and Sudan Savannah (Issaka*et al.*, 2012). The study reservoir catchments were all located in the Guinea Savannah ecological zone. Therefore, on the basis of ecological zones, the study found that mean annual soil loss rate of reservoir catchments in the Guinea Savannah ecological zone was 5.98 ± 1.47 t/ha/y with details presented in Table 10.

3.8.2 Effect of Soil Classes on Annual Soil Loss in the Reservoir Catchments

The Bontanga, Golinga and Libga catchments have similar soil classes namely acrisols, plinthosols and planosols which are groups ‘A’ and ‘B’ soils whereas the Tono, Vea, Gambibgo, Daffiama, Karni and Sankana catchments also have similar soil classes namely lixisols, fluvisols, leptosols and vertisols which are groups ‘C’ and ‘D’ soils.The estimated mean annual soil loss at the reservoir catchments with the groups ‘A’ and ‘B’ soils ranged from 3.17–4.96 t/ha/y whilst the mean annual soil losses at the catchments with groups ‘C’ and ‘D’ soils varied between 5.37 t/ha/y and 8.17 t/ha/y. The mean annual soil loss of catchments with the groups ‘A’ and ‘B’ soils were noted to be lower than that of catchments with groups ‘C’ and ‘D’ soils. This could be attributed to the less susceptibility of group ‘A’ and ‘B’ soils to erosion than groups ‘C’ and ‘D’ soils as reported by USDA-NRCS (1985). According to USDA-NRCS (2002), groups ‘A’ and ‘B’ soils are low erodible soils than groups ‘C’ and ‘D’ soils because they have high infiltration rates (>7.5 mm/h) and low runoff potentials, which do not have much influence on erosion.

An independent-samples t-test was conducted to compare the mean annual soil loss of reservoir catchments with groups ‘A/B’soils and those with ‘C/D’ soils and the results presented in Tables 11a and 11b. The results indicated that there was a significant difference between soil loss of catchments with groups ‘A/B’ soils (M = 4.46, SD = 0.66) and catchments with groups ‘C/D’ soils (M = 6.75, SD = 1.08; t (7) = –3.29, p = 0.013, two-tailed). The magnitude of the differences in the means (mean difference = 2.29, 95% CI: –3.93 to –0.65) was very large (eta squared = 0 .541). Hence, the effect size of soil classes and hydrologic soil groups on soil loss measured by the eta squared is 54.1 %. This implies that soil classes and hydrologic soil groups account for about 54.1 % of the variance in mean annual soil loss in the catchments. This is very large according to the guidelines proposed by Cohen (2013). It was therefore noted that soil types, classes and hydrologic soil groups have very significant influence on soil loss in catchments.

3.8.3 Effect of Catchment Sizes on Annual Soil Loss in the Reservoir Catchments

According to Singh (1994), reservoir catchments < 250 km^2 are classified as small sized catchments, between 250–2,500 km^2 are medium sized catchments and > 2,500 km^2 are large sized catchments. Based on this classification, all the study reservoir catchments are small sized catchments except the Tono catchment which is medium sized catchment. However, for the purpose of this study, the reservoir catchments were classified into two (2) namely; catchments < 100 km^2 which included Gambibgo (1.7 km^2), Daffiama (21 km^2), Libga (31 km^2), Karni (35 km^2) and Golinga (53 km^2) and catchments between 100–650 km^2 which included Vea (136 km^2), Sankana (141 km^2), Bontanga (165 km^2) and Tono (650 km^2).

The estimated mean annual soil loss of reservoir catchments < 100 km^2 were found to range from 3.17–7.78 t/ha/y whilst the mean annual soil loss of catchments between 100–650 km^2 ranged from 4.96–8.17 t/ha/y. An independent-samples t-test was conducted to compare the mean annual soil loss for the catchments < 100 $km^2$and those between 100–650 km^2 and the results presented in Tables 12a and 12b. The results showed that there was no significant difference in annual soil loss for catchments < 100 km^2(M = 5.50, SD =1.52) and catchments between 100–650 km^2(M = 5.68, SD =1.34; t (7) = –1.117, p = 0.301, two-tailed). The magnitude of the differences in the means (mean difference = 0.183, 95% CI: –3.373 to 1.180) was very small (eta squared = 0 .0230). Hence, the effect of catchment size on annual soil loss measured by the eta squared is 2.3 %. This implies that catchment size explains only 2.3 % of the variation in annual soil loss. This is very small according to the guidelines proposed by Cohen (2013). It was therefore established that the size of a reservoir catchment has very little influence on soil loss.

Also, a regression analysis performed recorded an R^2 of 0.088 and this indicates that only 8.8 % of the variation in annual soil loss in reservoir catchments is caused by the size of the catchment. The results also indicated that for every additional km^2 in catchment size could lead to an increase in annual soil loss by 0.22 % as presented in Equation 4.It was therefore noted that catchment size very little influence on soil loss rate in reservoir catchments.

$$MASLR = 5.69 + 0.0022\,(RCS) \qquad (4)$$

where*MASLR* – Mean Annual Soil Loss Rate (t/ha/y) and SRC – Size of reservoir catchment (km^2)

Table 9. Severity and Coverage of Annual Soil Loss in the Study Reservoir Catchments

Reservoir Catchment		**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	6,996.0	42.4	6,296.4	9.7	2,899.1	54.7	2,724.2	11.0	1866.2	60.2	1,747.5	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	15.90	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	106.0	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	1.1
Total	-	**16,500**	**100**	**81,760.1**	**100**	**5,300**	**100**	**24,885.9**	**100**	**3,100**	**100**	**11,501.6**	**100**
Mean	-	-	-	**4.96**	-	-	-	**4.70**	-	-	-	**3.71**	-

Reservoir Catchment		**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	5.9	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	16.4
25.1 - 60.0	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**	-

Reservoir Catchment		**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	5.5	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**	**27,204.8**	**100**	**14,100**	**100**	**88,626.8**	**100**
Mean	-	-	-	**5.94**	-	-	-	**7.78**	-	-	-	**6.29**	-

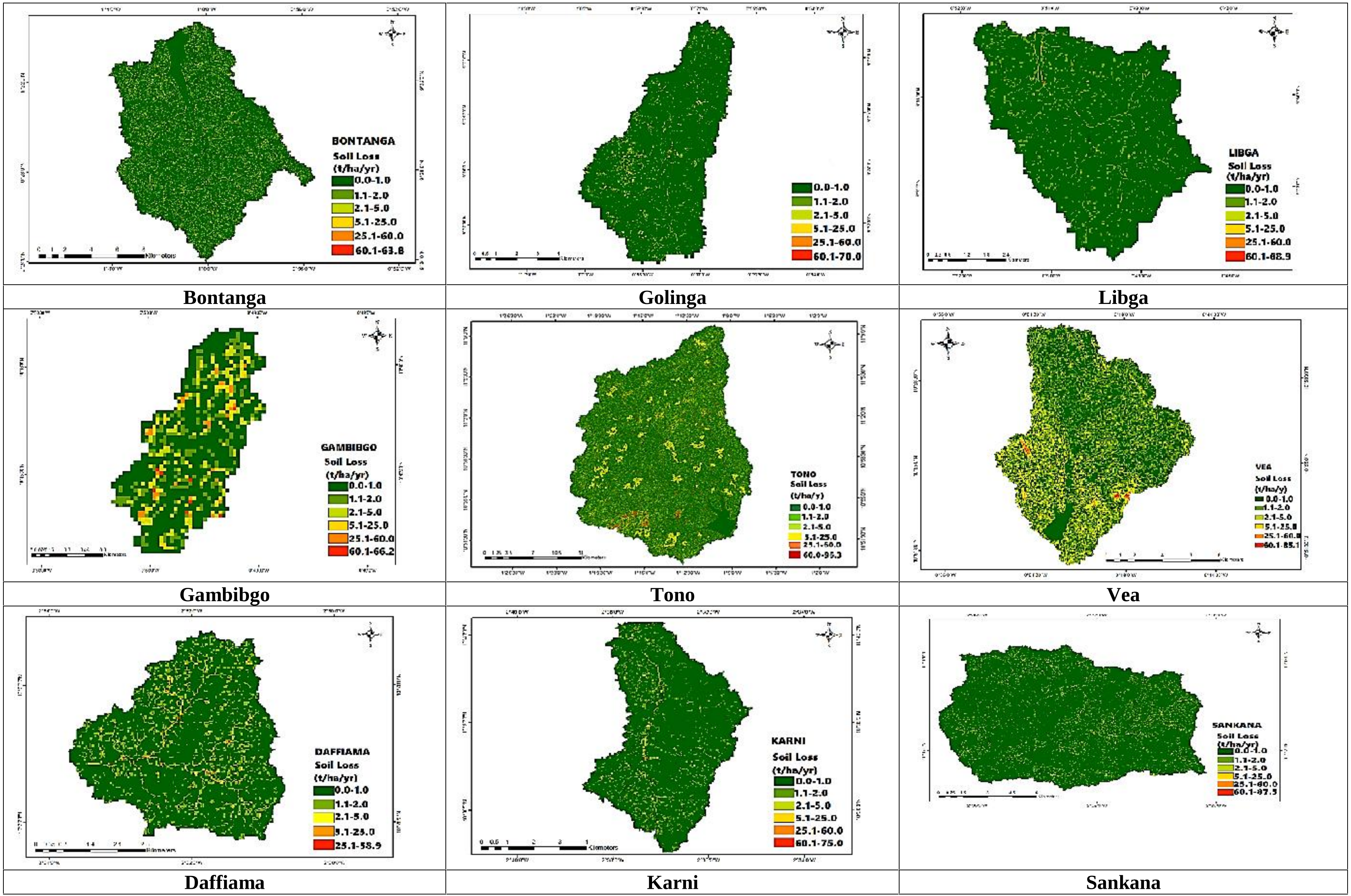


Figure 8. Spatial Distribution of Soil Loss in Study Reservoir Catchments

Table 10: Mean Annual Soil Loss Rate of Reservoir Catchments in the Guinea Savannah Ecological Zone

Reservoir Catchment	**Mean Annual Soil Loss (t/ha/y)**
Bontanga	4.96
Golinga	4.70
Libga	3.71
Gambibgo	5.37
Tono	6.91
Vea	8.17
Daffiama	5.94
Karni	7.78
Sankana	6.29
Average	**5.98**
Standard deviation	1.47
S.e.d	0.49
CV (%)	24.58

S.e.d – Standard error of the difference; CV – Coefficient of variation

Table 11a: Group Statistics of Independent Samples Test of Mean Annual Soil Losses across Hydrologic Soil Groups

Variable	**HSGs**	**N**	**M**	**Std. Deviation**	**Std. Error Mean**
Soil Loss (t/ha/y)	Groups ‘A/B’	3	4.46	0.66	0.38
	Groups ‘C/D’	6	6.74	1.08	0.44

HSGs – Hydrologic soil groups; N – Number of samples; M – Mean; Std. – Standard

Table 11b: Independent Samples Test of Mean Annual Soil Losses across Hydrologic Soil Groups

Variable	**Assumptions**	**LTEV**		**t-test for Equality of Means**						
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	95 % CID	
									Lower	Upper
Soil Loss (t/ha/y)	EVA	1.45	0.27	-3.29	7.00	0.013	-2.29	0.69	-3.93	-0.65
	EVNA			-3.92	6.39	0.007	-2.29	0.58	-3.69	-0.88

EVA-Equal variances assumed; EVNA-Equal variances not assumed; LTEV- Levene's Test for Equality of Variances; MD-Mean Difference; SED-Std. Error Difference; CID-Confidence Interval of the Difference

Table 12a: Group Statistics of Independent Samples Test of Mean Annual Soil Losses across Catchment Sizes

Variable	**CS (km^2)**	**N**	**M**	**Std. Deviation**	**Std. Error Mean**
Soil Loss (t/ha/y)	< 100	5	5.50	1.52	0.68
	100–650	4	5.78	1.34	0.67

CS – Catchment size; M – Mean; N – Number of samples; Std. – Standard

Table 12b: Independent Samples Test of Mean Annual Soil Losses across Catchment Sizes

Variable	**Assumptions**	**LTEV**		**t-test for Equality of Means**						
		F	Sig.	t	df	Sig. (2-tailed)	MD	SED	95 % CID	
									Lower	Upper
Soil Loss (t/ha/y)	EVA	0.05	0.83	-1.12	7.00	0.30	-1.08	0.97	-3.37	1.21
	EVNA			-1.14	6.89	0.29	-1.08	0.95	-3.34	1.18

EVA-Equal variances assumed; EVNA-Equal variances not assumed; LTEV- Levene's Test for Equality of Variances; MD-Mean Difference; SED-Std. Error Difference; CID-Confidence Interval of the Difference

4. Conclusions

The study used the spatially integrated RUSLE to estimate the magnitude of annual soil loss and the spatial distribution of soil loss severity classes in nine (9) reservoir catchments in northern Ghana. It was found that there has been occurrence of soil loss in the various reservoir catchments at varying rates ranging from 0.0–96.30 t/ha/y with the estimated mean annual soil loss ranging from 3.71–8.17 t/ha/y. Estimated mean annual soil loss of seven (7) reservoir catchments i.e.Bontanga, Golinga, Libga, Gambibgo, Tono, Daffiama and Sankana were within tolerable soil loss limits based on FAO (1984) and USDA-NRCS (1999) classification. Mean annual soil loss estimated for two (2) reservoir catchments i.e. Vea and Karni exceeded the FAO tolerable soil loss limits, but lower than the global tolerable loss limit.

Averagely, the study revealed that reservoir catchments in the Guinea Savannah ecological zone lose soil at a rate of 5.98±1.47 t/ha/y, which was within the FAO and global tolerable soil loss limits. Soil types, classes and hydrologic soil groups significantly influence annual soil loss in reservoir catchments as they account for about 54.1 % of the variation in annual soil loss in the catchments. Reservoir catchments with dominant soils as groups ‘A’/‘B’ incur lower mean annual soil loss than reservoir catchments with dominant soils as groups ‘C’/‘D’. The size of a reservoir catchment has very little influence on annual soil loss as it accounts for only 2.3 % of the variance in annual soil loss.A unit increase in catchment size results in a unit increase in mean annual soil loss by 0.22 %.

The severity of annual soil loss rates in reservoir catchments in the Guinea Savannah ecological zone ranged from very low class (0.0–1.0 t/ha/y) to very high class (> 60.0 t/ha/y). Across all the reservoir catchments, the very low severity class constituted the largest area of 36.7–67.5 % but noted the second least contributor of 5.5–15.4 % to the total annual soil loss. The very high severity soil loss class contributes the least of about 1.1–12.8 % of the total annual soil in the reservoircatchments. The moderate severity loss class contributes the highest of about 25.0–51.2 % of the total annual soil loss at all the catchments except Vea where the high severity class contributes the highest of about 29.1 % of the total annual soil loss. The high and very high severity loss classes contribute substantially to the total annual soil loss at the catchments in the Gambibgo, Vea and Sankana and this could be attributed to the presence of leptosols and fluvisols.

Farming practices such as ploughing along the slope, slashing and burning, and farming very close to the banks of water courses in the reservoir catchments were some of the main causes of soil loss in the reservoir catchments. High terrain and slope steepness in some parts of reservoir catchments also contributed to high soil loss.Soil and water conservation measures such as contour ploughing, stone/earth bunding and upstream afforestation of the reservoir catchments 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 reservoir catchments.Also,analysis of the temporal distribution of the soil loss in the reservoir catchments is necessary and therefore recommended for future studies. Soil loss estimation using conceptual or physically-based models in the reservoir catchments is recommended and the results compared with soil loss values estimated by the spatially integrated RUSLE.

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