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ESTIMATION OF SOIL ERODIBILITY AND RAINFALL EROSIVITY FOR THE BIEMSO BASIN, GHANA

N.Kyei Baffour[1]
E.T. Atakora[1]
E. Ofori[1]
B.O. Antwi[2]

[1]Department of Agricultural Engineering
Kwame Nkrumah University of Science & Technology, Kumasi, Ghana.
[2]Soil and Water Management Division, CSIR-
Soil Research Institute of Ghana, Kumasi, Ghana.

In the agroecological zone of the Biemso basin in the Ashanti Region of Ghana, soil erodibility and rainfall erosivity patterns were estimated. The study aimed at investigating the temporal variability of rainfall erosivity using the Fournier Index Method and assessing the soil erodibility parameters of a Sawah site using the WEPP model. Four plots representing the major land uses in the area for maize, oil palm, natural vegetation and plantain cultivation were selected. Results showed that soil organic matter content ranged from 1.95 to 5.52%; sand ranged from 14.34 to 31.86 %; silt ranged from 31.63 to 68.77%; clay ranged from 16.04 to 20.08% and very fine sand from 3.38 to 8.84%. The derived interrill erodibility (Ki) values ranged from 44.26 to 51.70 kg s m^{-4} under all land uses considered at the study site and soils in the study area were moderately resistant to erosion by raindrops. The derived rill erodibility (Kr) values ranged from 0.005 to 0.012 s m^{-1} under all land uses considered at the study site. Rill erodibility values were higher at the foot slopes under all land uses except under Oil Palm land use. Rainfall values exceeded the 20-25 mm threshold value for erosive rains. Erosivity values determined for the study site revealed a moderate erosion risk in the major rainy season (April-July); low erosion risk in the minor rainy season (August-October) and very low erosion risk in the dry season (November-March). It is recommended that soil and land management practices that would reduce water erosion during the major rainy season should be implemented such as bunding, mulching and contour farming.

INTRODUCTION

The detachment, runoff and deposition of soil and nutrients on land surfaces by erosion is widespread globally and significantly affects the productivity of crops (El-Swaify et al. 1982; Lal and Stewart, 1990; Pimentel 1993; Shelton 2003; Pimentel 2006) . Globally, it is estimated that one-sixth of the world's soils are affected by water erosion and in Africa, 8.5% of the mean yield loss is associated with past water erosion (Eswarant et al., 2001).

In developing countries like Ghana whose economies depend on agriculture, soil erosion has been of much concern since it affects the output of food production and by extension the general contribution of agriculture to the Gross Domestic Product of the country. Several research works done in Ghana have revealed that, Ghana is among countries which are more susceptible to rainfall erosion (Adu, 1972; Norman, 1981; Quansah, 1990). It is expected that population pressure coupled with the increase in demand for land for farming and other purposes will intensify soil erosion.

Past studies estimate that 69% of the total land surface is prone to severe or very severe soil erosion (EPA, 2002), the main manifestation of land degradation in Ghana. A recent study estimated soil erosion to cost around 2% of the national GDP (World Bank, 2006), thus offsetting some of the past achievements of the country in terms of economic growth, and limiting the capacity of Ghana to fulfill its full potential for growth. Sustainable utilization of the country's land resources is therefore a necessary precondition for achieving and maintaining the economic growth rate necessary for Ghana to reach its main development objectives as a middle income nation.

Despite the problems stated above, very little quantitative data on erosion is available in the country particularly in the different basins. Quantification of erosion rates and an understanding of erosion processes will help rural households reduce the incidence of erosion on the farms.

Soil erodibility and rainfall erosivity are two important physical factors that affect the magnitude of soil erosion (Lal and Elliot, 1994). Soil erodibility, the resistance of the soil to both detachment and transport, is a function of soil physical characteristics and the management of the soil (Hudson, 1995; Morgan, 1995). Rainfall erosivity is the aggressiveness of the rain to cause erosion and is a function of the physical characteristics of rainfall (Lal, 1990; Morgan, 1995).

It has been established that a few, very intense rainfall events are responsible for the largest part of soil erosion and sediment delivery (Gonzalez-Hidalgo et al., 2007). It is also an established fact that soil erodibility represents the effects of soil properties and soil profile characteristics on soil loss by erosion (Romkens et al., 1996 cited in Fufa et al., 2002). However, the quantification of these two factors stated above is the basis to an understanding of soil erosion (Lal and Elliot, 1994).

The main aim of the study was to assess rainfall erosivity and soil erodibility of a sawah site, specifically to investigate the temporal variability of rainfall erosivity using the Fournier Index Method and assessing the soil erodibility parameters using WEPP model.

The Fournier Index

The attraction of using readily available data on amounts of rainfall has led to a search for a method which will allow worldwide application, and as result the method developed by Fournier some years ago has attracted interest (Hudson, 1981). The approach tends to quantify indirectly the relation between erosive power and energy of rainfall using an index based on annual and monthly distribution of rainfall or precipitation. The Fournier Index described as a climatic index is defined by Oduro-Afriye (1996) as:

$$C_p = P_{max}^2/P \tag{1}$$

where C_p is the Fournier Index (mm), P_{max} the rainfall amount in the wettest month and P the annual precipitation (mm). Table 1 shows classes of rainfall erosion risk based on the Rainfall Erosivity Index. C_p values above 60 show severe to extremely severe erosion risk in average climatic conditions, Oduro-Afriye (1996).

The Fournier Index approach has several features which has made it obtain great appeal for worldwide survey particularly in areas like Ghana. The method was developed in West Africa and hence under similar climatic conditions as Ghana. Again, it incorporates relief characteristics, since it is a function of mean annual precipitation which is itself dependent on relief, making it better related to erosion. More so, its input variables are easily more obtainable (Oduro- Afriye, 1996).

STUDY AREA

The study was conducted at a 'sawah' experimental site located at Biemso in the Ashanti Region of Ghana. The study area (Figure 1) is located in the Ahafo Ano South District of the Ashanti Region. Its geographic location is within N 06^o, 52' 53.2" and W 001^o, 50' 47.3". The mean annual precipitation in the region is 1301 mm (averaged for the period from 1974 to 2004). The rainfall pattern in the area is bimodal (with two peaks). The geology of the study site consists of rock of the Lower Birimian formation comprising phyllites, greywackes, schists and gneiss whiles the soils fall under the Akumadan–Bekwai/Oda Complex association (Adu, 1992). Agriculture is the main land use in the area. The valley is mostly used for rice cultivation under the system called "sawah". The most important crop commonly grown in the upland (hillslope) where the study was conducted is maize. Maize cultivation covers about 50% the study area.

MATERIALS AND METHODS

Sampling and initial processing of samples

Field studies were conducted from January-March, 2009. Four plots, each with a dimension of 60m x 40m, and which represents the major land use types of the site were selected. These include

Table 1. Classes of rainfall erosion risk based on the rainfall erosivity index (C_p) (Oduro-Afiriyie, 1996).

Class No:	Erosivity Index C_p	Erosion Risk Class	Soil Loss (T/ha year)
1	< 20.0	Very Low	< 5
2	21.0 – 40.0	Low	5 – 12
3	41.0 – 60.0	Moderate	12 – 50
4	61.0 – 80.0	Severe	50 – 100
5	81.0 – 100.0	Very Severe	100 – 200
6	> 100.0	Extremely Severe	> 200

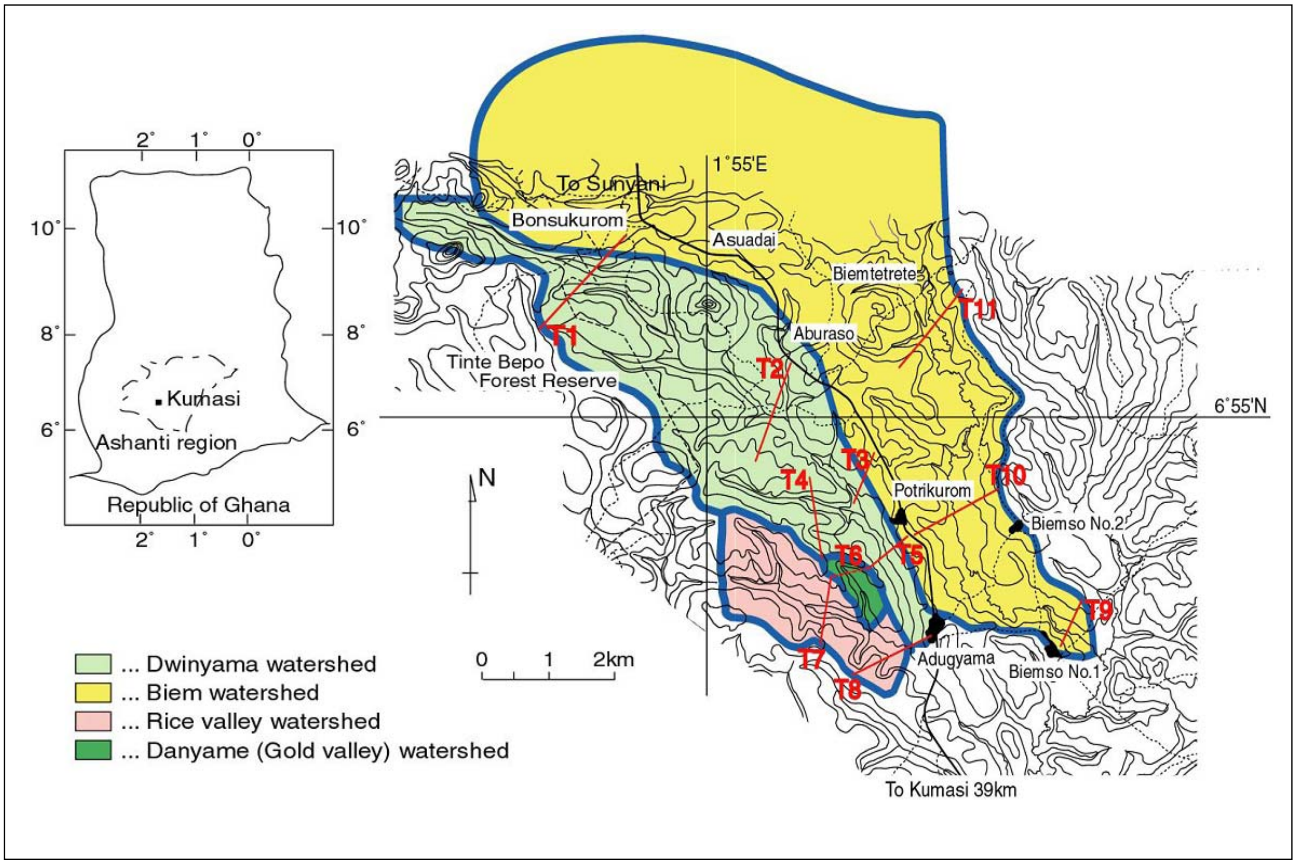

Figure 1. Location of the study area and sampling sites at Biemso, Ghana.

maize, oil palm, natural vegetation and plantain fields. Field data were collected at a grid of 20 x 20 metres on each plot.

Determination of Soil Properties

Soil samples collected from the site were air dried for 5 days and then passed through a 2-mm sieve. Gravels which did not pass through the sieve, after removal of any adhering material were weighed and their content was recorded as a percentage of the whole sample. Particle size distribution was determined by the hydrometer method (International Institute of Tropical Agriculture (IITA), 1979). Soil organic carbon was measured by wet digestion method (Nelson and Sommers, 1996). Soil Organic Matter (SOM) was then obtained by multiplying soil organic carbon values by a factor of 1.724.

QUANTITATIVE ANALYSES

Soil Erodibility Parameters Estimation

To estimate soil erodibility in the study area three regression equations included in the WEPP model (interrill erodibility K_i, rill erodibility K_r and rill critical shear (τ_c) was considered appropriate. These equations are defined by Flanagan and Livingston (1995) as follows:

$$K_i = 2728000 - 192100 \times VFS \tag{2}$$

$$K_r = 0.00197 + 0.00030\, VFS + 0.03863 e^{-1.84\, ORGMAT} \tag{3}$$

$$\tau_c = 2.67 + 0.065 CLAY - 0.058\, VFS \tag{4}$$

where

VFS = percent very fine sand (%) ≤ 40% (if > 40%, use 40%)

ORGMAT = organic matter in the soil surface (%) > 0.35% (if < 0.35%, use 0.35%)

CLAY = percent clay (%) ≤ 40% (if > 40%, use 40%)

For cropland soils containing less than 30% sand, the equations are:

$$K_i = 6054000 - 55130\ CLAY \tag{5}$$

$$K_r = 0.0069 + 0.134e^{-0.20CLAY} \tag{6}$$

$$\tau_C = 3.5 \tag{7}$$

where in equations (5) and (6), CLAY ≥ 10% (if < 10%, use 10%).

The choice of using the regression equations in the WEPP model in erodibility estimation is due to the fact that they depend on soil properties (Flanagan and Nearing, 1995) which have been found to be good indicators of soil erodibility (Moore and Singer, 1990). In addition, they are easily determined, do not consume time and are not expensive thus making them more desirable in poor countries like Ghana than the use of rainfall simulators which requires cost, time to construct suitable simulator and logistics (Meyer, 1994). More so, they were developed after extensive research aimed at defining the water erosion process and providing data for testing erosion prediction technologies (Elliot and Laflen, 1993). Again they provide a better practical alternative to Wischmeier nomogragh which has been found to be unsuitable for estimating the erodibility of soils in the tropics (Vanelslande et al, 1984; Folly, 1997).

Rainfall Erosivity Estimation

Rainfall erosivity in the study area was estimated using the Modified Fournier Index (MFI) (Arnoldus, 1980). The method was considered ideal due to the fact that rainfall data in the study area lack rainfall intensity records necessary to compute the erosivity index $EI_{30,}$ (Wischmeier and Smith, 1978).

Rainfall Analysis

Monthly rainfall data for the Kwadaso substation were obtained from the Ghana Meteorological Agency, Kumasi, Ghana. The Kwadaso station from which the data was collected from is the nearest with reference to the study site. The data spanned 1945 to 2008. The average monthly and annual rainfall values were computed using Microsoft Excel. Seasonal variations in erosivity were then estimated.

RESULTS AND DISCUSSIONS

Rainfall Erosivity

Table 2 shows the mean monthly rainfall amount (mm) of the study site. It shows that the months which received lower amounts of rainfall are January (22.40 mm), February (57.66 mm), November (75.97 mm) and December (29.00 mm). These months correspond to the dry season months in the study site. Furthermore, the period which receives the greatest amount of rainfall is from April to July and this corresponds to the major rainy season of the study site. In general, monthly mean rainfall amount range between 22.40 and 180.89 mm. These values exceed the 20-

Table 2. Mean monthly rainfall amount of the study site (1945 to 2008).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Rainfall amounts (mm)												
1945- 1974	22.73	65.34	141.05	150.42	197.04	220.45	144.01	89.69	159.81	196.60	97.08	30.39
1975- 2008	22.07	49.98	113.18	144.64	164.73	204.37	134.50	74.76	174.26	150.61	54.86	27.61
Total mean	22.40	57.66	127.11	147.53	180.89	212.41	139.26	82.23	167.03	173.60	75.97	29.00

25 mm threshold value for erosive rains (Hudson, 1976; Lal, 1976). The results obtained suggest that rains could cause significant soil loss throughout the year in the study site.

Table 3 shows some statistical characteristics of the annual total rainfall amount and Fournier Index values of the study site. Erosivity values determined for the study site reveals a moderate erosion risk in the major rainy season (April to July); low erosion risk in the minor rainy season (August to October) and very low erosion risk in the dry season (November to March). The results show erosivity is least in the dry season and greatest in the major rainy season. The Least erosivity values occurring in the dry season could be explained by the relatively low amount of rainfall and high temperatures which could make most of the rainfall amount in the season lost through evapotranspiration as explained by Odunze et al., (1995). The greatest erosivity values occurring in the major rainy season could also be explained by high rainfall amount in the period (Table 2) and the soils being bare particularly in July when the land is being prepared for another cultivation in the year. The situation confirms the view that soil erosion is accelerated when preparing the land for production of food and fibre and that soil erosion decreases exponentially with increasing ground cover (FAO, 1978; Aina, 1979)

Soil Erodibility Parameters

Table 4 shows the soil properties measured from the study site. Soil organic matter content ranged from 1.95 to 5.52%; sand from 14.34 to 31.86 %; silt ranged from 31.63 to 68.77%; clay from 16.04 to 20.08% and very fine sand from 3.38 to 8.84%. The measured data seem to indicate that overland flow and surface runoff of soil nutrients since organic matter seem quite low under arable farms.

Table 5 shows the estimated soil erodibility parameters. The derived interrill erodibility (K_i) values in Table 5 ranged from 44.26 to 51.70 x 10^5 kgsm^{-4} under all land use considered in the study site. Generally the K_i values were higher at the foot slopes. The K_i values range given for agricultural soils in the USA is between 20 x 10^5 kg s m^{-4} and 110 x 10^5 kg s m^{-4} (Flanagan and Livingstone, 1995), this indicates that soil in the study area are moderately resistant to erosion by raindrops. Similar results were obtained by Albaradeyia (2006).

The derived rill erodibility (K_r) values ranged from 0.005 to 0.012 s m^{-1} under all land use considered in the study site. Again rill erodibility values were higher at the foot slopes under all land use except under Oil Palm. The standard K_r values for agricultural soils in the USA are usually

Table 3. Seasonal variation of erosivity (Fournier Index) and erosion risk class.

Year	Dry Season	Erosion Risk Class	Major Rainy	Erosion Risk Class	Minor Rainy	Erosion Risk Class
1945 – 1974	15.0	Very Low	50.5	Moderate	36.2	Low
1975 – 2008	14.2	Very Low	51.3	Moderate	34.0	Low

Table 4. Measured soil properties from study site.

Land use	Position	Sand (%)	Silt (%)	Clay (%)	Very fine sand (%)	Organic Matter (%)
Fallow Land	FS	15.58	31.63	16.05	4.76	4.5
Fallow Land	US	23.68	56.24	20.08	5.56	4.1
Maize	FS	27.02	54.94	18.04	3.38	5.52
Maize	US	31.86	48.13	20.01	8.84	2.83
Oil Palm	FS	18.74	61.21	20.05	7.74	3.9
Oil Palm	US	22.16	61.8	16.04	6.28	2.97
Plantain	FS	15.01	68.77	16.03	7.22	1.95
Plantain	US	14.34	63.69	22.07	5.38	2.48

Table 5. Estimated soil erodibility parameters.

Landuse	Position	K_i x10^5 (kg s m^{-4})	K_r (sm^{-1})	t_c(Nm^{-2})
Fallow	FS	51.69	0.012	3.5
Fallow	US	49.47	0.009	3.5
Maize	FS	50.59	0.011	3.5
Maize	US	44.26	0.005	3.46
Oil Palm	FS	49.49	0.009	3.5
Oil Palm	US	51.70	0.012	3.5
Plantain	FS	51.70	0.012	3.5
Plantain	US	48.37	0.009	3.5

between 0.002 and 0.45 s m^{-1} (Flanagan and Livingstone, 1995). These derived values were within the standard range for cropland agricultural soils in the USA, but with a great difference between the two higher values. The results obtained from the study indicate that soils in the study area are also moderately likely to be resistant to detachment and transport by water.

The derived critical hydraulic shear (τ_c) values were almost the same for all land use and landscape position and ranged between 3.46 and 3.50 Nm^{-2}. The values were almost the same under all position in the study site. The standard values for cropland agricultural soils in the USA are usually between 1.0 and 6.0 Nm^{-2} (Flanagan and Livingstone, 1995). The results obtained from the study indicate that soils at the study site are moderately resistant to detachment and transport by flow in rills. Again the lowest value was obtained at the upper slopes of maize land use had lower values of K_r and K_i values.

CONCLUSION

The study shows that monthly rainfall amounts throughout the year exceed the erosive limit of 20-25 mm, and are therefore erosive in nature. The study revealed that Fournier Erosivity Index is lowest in the dry season (November to March) and highest in the major rainy season (April to July). Higher erosion rates are therefore expected in the major rainy season especially in July when the soils are largely bare due to land preparation for a second crop.

Derived soil erodibility parameters at different slope position from the study site reveals that soil erodibility is moderate as compared to the standard soil erodibility expected for similar US soils. The study showed that rill and interrill erodibility is higher at the foot slopes. Critical shear stress was, however, almost the same at different slope positions. The study has so far shown that soils are likely to be moderately resistant to erosion by rain drops, detachment and transport by water into rills. It is recommended that further analysis of the Fournier Index and WEPP are applied to other basins to generate data for erosion control targeted at detachment and transport. The use of lowlands for rice cultivation under sawah benefits from the erosion from upslope and deposition downslope.

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ADDRESS FOR CORRESPONDENCE
E.T. Atakora
Department of Agricultural Engineering
Kwame Nkrumah University of Science & Technology
Kumasi, Ghana

Email:atakusgh@gmail.com