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RESEARCH PAPER

ON-SITE EFFECTS AND COST OF FERTILITY EROSION FROM FIVE SMALL RESERVOIR CATCHMENTS IN THE UPPER EAST REGION OF GHANA

B. K. Amegashie[1] , C. Quansah[1], A. W. Agyare [2], M. Bonsu[1] and S. N. Odai [3]
[1]*Department of Crop Science, KNUST, Kumasi, Ghana*
[2]*Department of Agricultural Engineering, KNUST, Kumasi, Ghana*
[3]*Department of Civil Engineering, KNUST, Kumasi, Ghana*

ABSTRACT

A study was carried out in the Upper East Region of Ghana to assess the on-site effects and the cost of fertility erosion from five small reservoir catchments (Dua, Doba, Zebilla, Kumpalgogo and Bugri). The catchment soils and reservoir sediments were sampled and analyzed for their bulk density and nutrient content. The mean reduction in soil depth in the various catchments was 3.996±3.806 mm y^{-1} in the order of Kumpalgogo>Dua>Bugri>Zebilla>Doba. The corresponding decrease in the water holding capacity of the top 20 cm depth of the catchment soils ranged from 0.563 to 4.698 % per year. The percentage loss in the total nutrient stocks in the top 20 cm of the catchments as eroded sediment-bound nutrients ranged from 9.63 to 64.71, 7.87 to 56.83, 6.12 to 54.82, 1.26 to 40.14, 49.86 to 12.65, 16.84 to 72.07 for OC, N, P, K, Ca and Mg, respectively. The total amount of nutrient loss in kg ha^{-1} among the reservoirs ranged from 2383 to 19672 for OC, 153 to 3048 for N, 3.15 to 42.59 for P, 41 to 290 for K, 432 to 2158 for Ca, and 63 to 483 for Mg. The cost of N, P and K removed by erosion was calculated by the Replacement Cost Method. The total cost per year (GH¢ ha^{-1} y^{-1}) of fertilizers (sulphate of ammonia, single superphosphate and muriate of potash) was 286.15 for Dua, 74.289 for Doba, 225.061 for Zebilla, 1119.997 for Kumpalgogo and 96.376 for Bugri. The study has amply shown that soil loss through erosion reduces top soil depth, nutrient stocks and the water holding capacity of catchment soils. This will adversely affect crop productivity if no control measures are implemented. This can also lead to land degradation.

Keywords: *Deposited sediment, nutrient depletion, small reservoirs, fertility erosion, fertilizer*

INTRODUCTION

Soil erosion is a major threat to continued and sustained agricultural production in Ghana particularly in the Sudan Savanna zone (Folly, 1997). The effect of erosion may be on-site and/or off-site. The latter consequences, shown by this study and detailed out by Adwubi *et al.* (2009), resulted from downstream siltation, which has reduced reservoir capacity, enhanced the risk of flooding and shortened the design life of the reservoirs studied.

The on-site damage, which affects the catchments where the erosion originates, includes soil structure degradation, increased erodibility, surface crusting and compaction. The loss of soil reduces depth, water and nutrient storage capacities of the soil (NSE-SPRPC, 1981). The reduction in moisture reduces the soil's potential to sustain plant growth, exposes the plants to frequent and severe water stress which ultimately results in reduced crop yields.

Whilst soil loss measurement is a characteristic of most erosion research in Ghana **(**Asiamah and Antwi, 1988**),** the above implications of erosion-induced loss in soil depth for on-site damage have received very little research attention. Yet such studies are very pertinent for designing sustainable land management strategies in areas such as the Sudan Savanna zone of Ghana.

In this zone, many of the soils have predominantly light-textured surface horizons and extensive areas of shallow concretionary and rocky soils with low water and nutrient holding capacities and limited capacity for agriculture (Quansah, 1990). The latter attributes are exacerbated by the on-going water erosion in the zone.

Soil loss and runoff are almost always accompanied by losses of plant nutrients. The process, termed fertility erosion (Ellison, 1950), is selective, in that finer particles relatively high in plant nutrients and organic matter are the most susceptible to erosion. Consequently the eroded sediments contain higher concentrations of organic matter and plant nutrients in available form than the in-situ soil (Quansah and Baffoe-Bonnie, 1981). Whilst it is useful to know the magnitude of soil nutrient losses to aid replenishment strategies, their on-site costs are equally important. Unfortunately, these aspects are scarcely studied because nutrient depletion is insidious (FAO, 1990; Gachene *et al.,* 1997). In Ghana, Bøjö (1996) estimated the gross annual economic loss due to erosion which ranges from 2 to 5% of the Agricultural Gross Domestic Product (AGDP). Using the replacement cost approach (RCA), Convery and Tutu (1990) assessed the cost of annual production loss through erosion and nutrient depletion in Ghana to be US$161.4 million which was about 5% of the AGDP. Drechsel and Gyiele (1999) reported US$ 115.4 million (about 4 – 5% of AGDP) as the cost of productivity loss in Ghana. Quansah et al. (2000) assessed the seasonal cost of N, P and K lost through erosion under a maize monocrop grown under excessively tilled land (double ploughing + 3 times harrowing + 3 times spike tooth harrowing) to be US$ 7.1 per hectare. In the context of the national economy, the World Bank et al. (2006) estimated the cost of land degradation (mainly soil erosion) to range from 1.1 to 2.4 percent of the GDP, corresponding to 2.9 to 6.3 percent of AGDP.

For countries such as Ghana whose economies depend heavily on the agricultural sector, the loss of agricultural productivity particularly through erosion, implies loss of revenue for the socio-economic development of the country (Bonsu and Quansah, 1992).

In order to contribute the requisite information for filling the above identified gaps in erosion research, this study aimed at assessing (i) the on-site effects of catchment erosion and (ii) the magnitude and cost of fertility erosion.

MATERIALS AND METHODS

Study site

The study was carried out on five representative small reservoirs in the Upper East Region of Ghana. Their characteristics are given in Table 1. The Upper East Region is the north-easternmost part of Ghana's 10 regions. It is located between latitudes 10^{o} 15' and 11^{o} 10' north and longitudes 0^{o} and 1^{o} west. It covers an area of 8,842km^{2} with eight administrative districts (Bolga, Bongo, Builsa, Kasena-Nankana, Talensi Nabdam, Bawku West, Bawku East and Garu Tempani; Fig. 1). According to the 2000 population and housing census (GSS, 2005), the region has a population of 920,089 made up of 442,492 males and 477,597 females with a population growth rate of 3% per annum. The region has a high population density of 104.1 persons km^{-2} compared to a national average of 79.3 persons km^{-2}. Over 80% of the population live in the rural areas with agriculture as their major economic activity (Birner *et al.*, 2005).

The climate is semi-arid with an aridity index of 0.54 and a unimodal rainfall pattern of about 1000 mm per annum lasting 5 to 6 months. Rainfall is often erratic with considerable variations between successive rainy seasons, with regard to the time of onset, duration and amount of rainfall. Rainfall intensities are high, often exceeding soil infiltrability with a consequent generation of large volumes of runoff with high potential erosion rates (Liebe *et al.*, 2005). Temperatures are consistently high, with

Table 1. Characteristics of studied reservoirs in Upper East Region of Ghana

Reservoir	YR	A	SC	LS	DS	HD	SE	CE
Doba	1998	70	185	180.0	5	4.6	177	178
Dua	1997	35	99.6	98.6	1	4.2	228	229
Zebilla	1998	105	460.0	452.0	8	7	225.8	227.25
Kumpalgogo	1998	40	120.0	N/A	N/A	3.8	193	193
Bugri	1994	216	510.0	508.9	1.1	7.5	499.25	500.75

YR, year of rehabilitation; A, catchment area (ha); SC, design storage capacity (10^3 m^3); LS, live storage (10^3 m^3); DS, dead storage (10^3 m^3); HD, height of dam wall (m); SE, spillway elevation (m.s.l); CE, dam crest elevation (m)

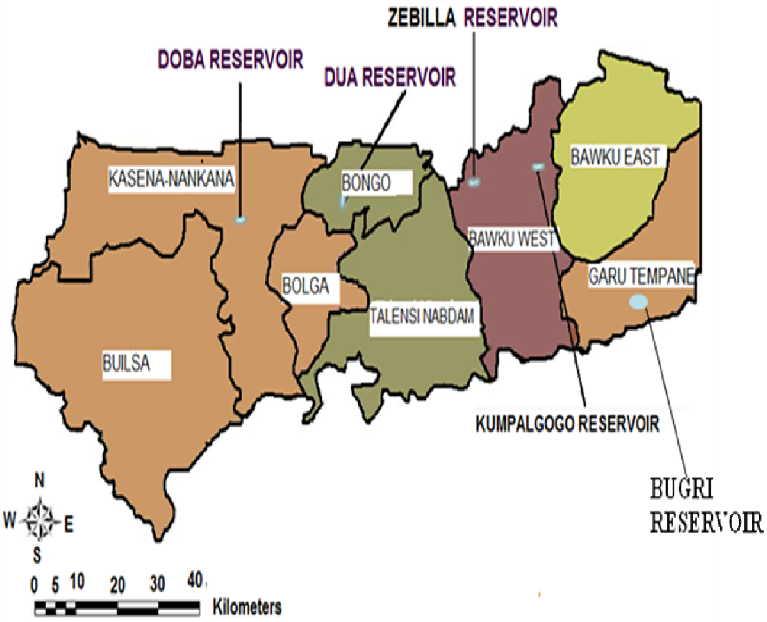

Fig.1: Location of study reservoirs and administrative districts in Upper East Region, Ghana

an average of 28.6°C. The mean annual relative humidity is 55%. There is a high variability in temperature and relative humidity thereby resulting in high evapotranspiration levels (1652 mm/y) and drying of reservoirs.

The agroecology is Sudan savanna, consisting of short drought - and fire-resistant deciduous trees interspersed with open savanna grassland. Grass is very sparse with most areas exhibiting severely eroded soils. The soils in the area are generally developed from granites, Birimian rocks and alluvia of mixed origin (Asiamah, 1992). The major soils comprise Acrisols, Lixisols, Nitisols, Vertisols, Plinthosols, Cambisols, Gleysols (Asiamah, 1992; MoFA, 1998). A large part of the area (82%) is underlain by metamorphic and igneous complexes with gneiss and granodiorite predominating (Fig. 2). Most of the soils are low in organic matter, buffering and cation exchange capacities and inherent fertility. The predominant clay mineral is kaolinite with nitrogen and phosphorus being mostly deficient.

Site selection

Due to time and limited financial resources, it was not possible to carry out this study on all reservoirs in the region. Five reservoirs representative of the catchments in the region were therefore selected for the study (Fig. 1).

This was done through desk study and reconnaissance survey with details presented by Adwubi *et al.* (2009).

Catchment characteristics

A large proportion of the catchments studied had gentle slopes less than 5 per cent. However in the upper slope reaches of the catchment, where homesteads and compound farms were located, the slopes could reach 10 per cent. All the reservoirs had patches of marshy land of varying sizes around them. These marshy sites served as sinks for sediment transported from the source areas thereby reducing the amount of sediment reaching the reservoirs. Some of the marshy sites were planted to rice. Land use in the catchments comprised compound farms cultivated to a variety of crops including millet (*Panicum milliaceum*), sorghum (*Sorghum bicolor*) and okra (*Abelmoschus esculentus*). The cultivation practices, including bullock ploughing, loosen the soil and make it more erodible. In some cases, vegetables are cultivated very close to the periphery of the reservoirs, as observed at Zebilla. Nutrient management mainly involved the use of farmyard manure and compost which are often inadequate. Mineral fertilizers are scarcely used. Crop production in the catchments therefore depended mainly on the low natural inherent fertility of the soils. Most of the reservoirs studied (Doba, Dua, Bugri and Kumpalgogo) had strips or patches of vetiver along their periphery, dam wall and spillway.

Field Survey

Bathymetric survey

Bathymetric survey is one of the methods used in quantifying sediment deposition in reservoirs that are filled with water and allow boat-based survey. Bathymetric surveys were conducted from 20th September to 2nd October 2007 to derive the current water storage capacity of the five reservoirs. The details of the reservoir sediment studies can be found in Adwubi *et al.,* (2009).

Reservoir sediment and catchment soil sampling

Reservoir sediments

Undisturbed wet sediment samples of known volume were taken using a beeker sampler from each reservoir. The beeker sampler is a piston corer with clear perspex tubes (Ø=57 mm) of different lengths (600, 1000 and 1500 mm). At the bottom of the piston, an inflatable valve assures no sediment losses when raising the piston corer to the surface. Soil samples were taken from each reservoir 10 m away from the upstream end of the reservoir, 5-10 m away from the dam wall, in the middle of the reservoir and the remaining from other locations in the reservoir. In all, ten samples were collected from each reservoir with two samples per sampling point. One sample per sampling point was used for the determination of bulk

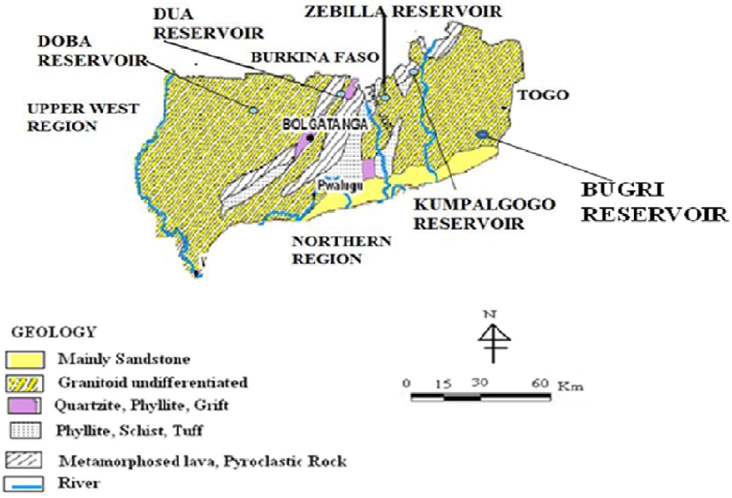

Fig. 2: Geology map of Upper East Region, Ghana, showing study sites (Kesse 1985)

density and the other for the particle size and soil chemical properties determination.

Catchment soils

In each catchment, soil samples were taken to a depth of 0-20 cm from the upper, middle and lower toposites along the soil catena. At each toposite, a composite sample made up of 10 bulked representative samples was taken for soil physical and chemical analyses.

Chemical and physical analyses

The following chemical and physical parameters were determined: pH using the Suntex pH (mv) Sp meter (701) for soil: water ratio of 1:2.5 (McLean, 1982), organic carbon (OC) by a modified Walkley-Black wet oxidation method (Nelson and Sommers, 1982), total N by Kjeldahl digestion and distillation procedure (Bremner and Mulvaney, 1982), available P by Bray P_1 method (Olsen and Sommers, 1982), exchangeable bases (Ca, Mg, K and Na) were determined in 1.0 *M* ammonium acetate (NH_4OAc) extract (Black, 1965) and the exchangeable acidity (H and Al) in 1.0 *M* KCl extract (McLean, 1965). Particle size distribution was by the hydrometer method (Bouyoucos, 1963) and bulk density of the catchment soils was by the metal core sampler method (Blake and Harte, 1986).

Sediment volume determination

The data collected from the bathymetric survey was analyzed using Golden Software Surfer 8 (Golden Software Inc., 2003). The elevation of the current reservoir bed (top of sediment) at each measurement point was defined by subtracting the recorded depth from the water surface level, measured with Automatic levelling instrument. Storage capacity and water surface area of the reservoirs at 1m interval was calculated using Surfer’s “Volume” function, based on which the current capacity curves of the reservoirs were constructed. The total volume of sediment deposition was then calculated by subtracting current water storage capacity from the initial water storage capacity.

Sediment mass

Sediment mass (SM) was calculated as:

$$SM = SV \times \rho_b \qquad [1]$$

Where SV is sediment volume and ρ_b is sediment bulk density

Soil depth reduction due to soil loss

The physical loss of soil through erosion reduces the depth of soil needed for water and nutrient storage and increased root room. It was expressed as:

$$\rho_b = \frac{M_s}{V_t} = \frac{M_s}{Axh} \qquad [2]$$

Where h is depth reduction due to soil loss (m), M_s is weight of dry soil loss (kg), V_t is total volume of soil loss (m^3), A is area from which soil is lost (m^2) and ρ_b is bulk density of in-situ soil from which eroded sediment originated (kg m^{-3}).

Reduction in water holding capacity due to loss in soil depth

In this study, it is assumed that the water holding capacity of the surface (20 cm) sandy loam for Dua, loamy sand for Doba, Zebilla, Kumpalgogo, Bugri reservoirs, respectively, was 100 mm per metre soil depth (Hudson, 1995). Assuming even distribution of water along the metre depth, the top 20 cm depth will hold 20 mm of water (i.e. 0.1 mm)/mm depth). Using the depth loss values (Equation 2) the percentage reduction in the water holding capacity of the top 20 cm was calculated as:

% Reduction in water holding capacity (WHC)

$$WHC = \frac{(\text{depth loss}(mm) x\ 0.1mm) x100}{(20mm\ \ x\ 0.1mm)} \qquad [3]$$

Total Nutrient Stocks

The implication of nutrient loss for on-site productivity is the loss of the nutrient stocks in the catchment soils. Nutrient stocks of the top 20 cm depth of soil were calculated as the sum of remaining nutrients in the soil and that in the eroded sediments.

Total amount of nutrients and organic matter in the reservoir sediments

The total amount of nutrients and organic matter in the reservoir sediments were determined by multiplying the total weight of the reservoir sediments by the concentration of their nutrient constituents.

Percentage (%) reduction in total nutrient stocks

Percentage (%) reduction in the total nutrient stocks in the catchment soils was calculated as the ratio of the total of each nutrient in the eroded sediment and the total stock of each nutrient in the parent soil.

Estimation of Cost of Nutrients in the Eroded Sediments Using the Replacement Cost Method

The N, P and K content of the eroded sediments was converted to the forms in which they exist in straight fertilizers, i.e. N, P_2O_5 and K_2O (kg), respectively by multiplying by the following constants (Quansah *et al.*, 2000)

$$kg\ N = kg\ N \qquad [4]$$

$$kg\ P \times 2.29 = kg\ P_2O_5 \qquad [5]$$

$$kg\ K \times 1.2 = kg\ K_2O \qquad [6]$$

The current cost of fertilizers per bag used in this study for estimating the cost of fertilizer lost was:

Sulphate of ammonia (50kg) cost = GH¢ 30.00

Single Superphosphate (50 kg) cost = GH¢ 45.00 and

Muriate of Potash (50 kg) cost = GH¢ 80.00

Calculation of the number and cost of bags of fertilizer lost

Example: The Dua catchment

The losses of N, P and K from the catchment into the reservoir were:

Nitrogen = 536 kg N/ha
Phosphorus = 35.14 kg P/ha = 80.47 kg P_2O_5/ha
Potassium = 290 kg K /ha = 348 kg K_2O/ha
1 bag of each straight fertilizer = 50 kg

(i) 100 kg of Sulphate of Ammonia contains 21 kg N

Therefore 536 kg N = 100kg × $\frac{536\ kg}{21\,kg}$ =2552.38kg ÷ 50 = 51.05 bags of Sulphate of Ammonia

(ii)100kg of Single Superphosphate contains 18 kg P_2O_5

Therefore 80.47 kg P_2O_5 = 100 kg × $\frac{80.47kg}{18kg}$

= 447.06 kg ÷ 50 = 8.94 bags of Single Superphosphate

(iii)100 kg of Muriate of Potash contains 60 kg of K_2O

348kg K_2O = 100 kg × $\frac{348\ kg}{60\ kg}$ × 580 ÷ 50

= 11.60 bags of Muriate of Potash

The total cost of fertilizers lost was calculated by multiplying the number of bags of each straight fertilizer lost by the respective cost/50kg of each fertilizer.

Statistical analysis

The data obtained were analysed by Analysis of Variance (ANOVA) using GENSTAT Statistical Package (GENSTAT, 2007). Standard error difference (s.e.d) at 5% was used to compare treatment means.

RESULTS AND DISCUSSION

On-site effects of catchment erosion

In order to assess the on-site effects of catchment erosion, soil-loss induced reduction in soil depth, water holding capacity and soil nutrient stocks in the various catchments were determined. The results are discussed in the following sections.

Reduction in soil depth and water holding capacity

The reduction in soil depth in the various catchments ranged from 0.1126 to 0.9396 cm y^{-1}. (Table 2) The loss in soil depth does not only reduce rooting depth but the storage capacity of the soil for water and nutrients. The results of the study showed the reduction in the water holding capacity of the top 20 cm of the catchments to range from 5.44 to 42.28 mm y^{-1} for Doba and Kumpalgogo, respectively (Table 2).

In a predominantly rainfed-agricultural zone, such as the study area, where shallow soils are common and smallholder farmers depend on the relatively nutrient rich 20 cm top soil with its in-situ moisture storage for growing their crops, the reduced soil depth and water holding capacity will have significant adverse impacts on crop growth, yield and agricultural productivity. Thames and Cassel (1979) demonstrated a close relationship between soil depth, available water capacity and dry matter production on a sandy soil with a shallow fragipan horizon. For soil depths of 26, 29 and 45 cm, the respective available water capacities (mm) were 32, 52, 64 and dry matter (t ha^{-1}) was 5.9, 7.4 and 9.1.

According to Lal (1984) the majority of tropical soils have edaphically inferior subsoil and shallow rooting depth as observed in most soils in the Sudan savanna zone underlain by petroplinthite. Consequently, crop yield declines drastically as topsoil thickness is reduced. A major concern is that, the loss of the surface layer cannot be fully compensated for by additional inputs of nutrients as demonstrated by Mbagwu *et al.* (1983). Research information on the ef-

Table 2. Loss of depth and reduction in water holding capacity (WHC) due to cumulative soil loss

Reservoir	Age	Bulk Density (kg m^{-3})	Sediment Mass (t)	Depth Loss (mm)	Depth loss per year (mm y^{-1})	Reduction in WHC per year (mm y^{-1})
Dua	10	1511.96	35,183	66.49	6.649	33.25
Doba	9	1508.10	11,480	10.87	1.208	5.44
Zebilla	9	1640.31	24,849	14.43	1.603	7.22
Kumpalgogo	9	1638.35	55,413	84.56	9.396	42.28
Bugri	13	1589.93	50,310	14.64	1.126	7.32
Average		**1577.73**	**3516.37**	**38.20**	**3.996**	**19.10**

fect of soil depth reduction due to natural erosion is scanty. Most of the evidence is from artificially desurfaced experiments. Lal (1976) reported a maize yield reduction of 23% after removing 2.5 cm of topsoil of an Alfisol in Ibadan, Nigeria. In Cameroon the removal of 2.5 cm topsoil caused a 50% drop in maize yield (Rehm, 1978).

A major factor of significance in the loss of soil depth due to erosion is the length of time it takes to replace the lost soil. Hudson (1995) estimated that, under ideal soil conditions in the tropics the rate of new soil formation was about 2.5 cm in 30 years (i.e. 0.83 mm/y). From other sources (Lal, 1987), new soil is formed at the rate of about 2.5 cm in 300 to 1000 years (i.e. 0.083 to 0.025 mm y $^{-1}$) under normal conditions. Available information suggests that it takes hardly one year to lose 1 cm of topsoil but 1000 years to replace it (Lal, 1984). In this study it has taken 9 to 13 years to lose 1.1 to 8.4 cm of topsoil which, by the above calculations by Lal (1984), will take between 1000 to 8000 years to replace. The mismanagement of the reservoir catchments can therefore readily lead to irreversible soil degradation.

Reduction in soil nutrient stocks

Apart from the physical loss of soil depth and water holding capacity, the soil lost through erosion is usually the most fertile part containing the plant nutrients, humus and any fertilizers that the farmer has applied. The implication of nutrient loss for on-site soil fertility and productivity is the loss of the nutrient stocks in the catchment soils. In order to assess this loss, the nutrient stocks of the top 20 cm depth of each catchment were calculated. The results (Table 3) showed the total nutrient stocks (kg ha^{-1}) in the top 20 cm to range from 19084 to 30399, 1884 to 5363, 39.79 to 80.34, 147 to 3253, 2040 to 4328, 358 to 784 for OC, N, P, K, Ca and Mg, respectively. For a period of 9 to 13 years, representing the ages of the reservoirs, the percentage loss in the total nutrient stocks in the catchments (Table 4) as eroded sediment-bound nutrients ranged from 9.63 to 64.71, 7.87 to 56.83, 6.12 to 54.82, 1.26 to 40.14, 49.86 to 12.65, 16.84 to 72.07 for OC, N, P, K, Ca and Mg, respectively.

These losses are indicative of the magnitude of soil productivity loss in the catchments. Crops grown on such soils will, implicitly, produce low yields with potential adverse effects on

Table 3. Total nutrient stock in the catchment soils

Reservoir	OC	N	P	K	Ca	Mg
			kg/ha			
Dua	19084	2154	80.34	806	4328	776
Doba	24733	1945	39.79	968	2040	358
Zebilla	23656	1884	60.35	147	2561	483
Kumpalgogo	30399	5363	77.69	1707	3387	784
Bugri	21916	2371	51.45	3253	2991	374
Average	**23957.6**	**2743.4**	**61.92**	**1376.2**	**3061.4**	**555**

Table 4. Percentage reduction of total nutrient stock in the catchment soils

Reservoir	OC	N	P	K	Ca	Mg
			%			
Dua	31.25	24.88	43.74	35.98	49.86	62.24
Doba	9.63	7.87	10.03	5.99	12.65	72.07
Zebilla	13.94	32.64	11.52	40.14	38.58	38.10
Kumpalgogo	64.71	56.83	54.82	16.17	44.73	55.10
Bugri	16.75	16.03	6.12	1.26	14.44	16.84
Average	**27.26**	**27.65**	**25.25**	19.91	**32.05**	**48.87**

household food availability and security. In such a situation, more fertilizer amendments are needed to maintain crop yield. This increases production cost which many smallholder farmers cannot afford. Farmers are therefore compelled to grow their crops with little or no soil amendments leading to soil nutrient mining; yet the addition of mineral fertilizers alone cannot compensate for the productivity loss.

The loss of agricultural production in the affected districts and communities, as shown by crop production figures of the Upper East Region of Ghana (MoFA, 2009), means a loss of household incomes, agricultural revenue and delayed district plans for development. The rural population finds life increasingly hard and seeks a better life in the towns and cities. In the study area, this is exemplified by the seasonal migration of the youth to the south of the country during the long dry season to search for jobs and better living standards. These impacts underscore the urgent need to promote sustainable land management interventions in the catchments of reservoirs and other water bodies in the Sudan savanna zone as enshrined in Ghana’s Agricultural Sustainable Land Management Strategy and Action Plan (2009-2015) (MoFA, 2008). In these developments, it is recommended that the watershed is taken as the planning unit and integrated watershed management effected by involving the active participation of the affected communities.

Total amounts of nutrients and organic matter in the reservoir sediments

An examination of nutrient concentrations in soils and reservoir sediments showed the latter to contain higher concentrations of organic matter and plant nutrients in available form than the original soil. The assessment of the total amount of soil fertility constituents lost from the catchments was therefore necessary to ascertain the magnitude of soil fertility decline. The results are presented in Table 5.

The total carbon content of the reservoir sediments varied between 2383 and 19672 kg ha^{-1} with a mean value of 6997.6 kg ha^{-1}. There was a considerable spatial variability in the organic carbon among the reservoirs as indicated by the CV of 40.8 per cent. Kumpalgogo recorded significantly greater organic carbon storage than the remaining reservoirs which had no significant differences in their OC contents.

Organic matter is one of the first soil constituents to be removed through erosion, yet it is among the hardest to replace. It is the main source of nitrogen, phosphorus and sulphur for crops in no-fertilizer smallholder agriculture (Acquaye, 1990). It is estimated that in tropical soils, the humus content accounts for 80 per cent of the cation exchange capacity under savanna conditions. Therefore the loss of soil organic matter does not only result in the depletion of one of its valuable components, but significant quantities of nutrients, such as nitrogen and phosphorus are removed with organic matter.

The high losses of organic matter are of particular concern because mineral fertilizers are far less effective in supplying nutrients on soils which are low in organic matter than those which contain adequate amounts of it (Swift, 1997). The implication is that if the losses of N, P and K from the catchments were to be replenished by mineral fertilizers, the desired effect on crop yield would hardly be attained because of the low soil organic matter. Soil fertility replenishment in the catchments should therefore aim at integrated nutrient management. This should involve the combined use of organic and inorganic inputs for sustaining soil fertility and crop yield (Swift, 1997; Sanchez *et al.*, 1997; Quansah, 1997).

The losses of nitrogen varied from 153 kg ha^{-1} to 3048 kg ha^{-1} for Doba and Kumpalgogo reservoirs respectively with a mean of 946.4 kg ha $^{-1}$. Except for Doba and Bugri, Bugri and Dua

Table 5. Total amount of nutrients in eroded sediment for five (5) reservoirs in the Upper East Region of Ghana

Reservoirs	**OC**	**N**	**P**	**K**	**Ca**	**Mg**
			kg/ha			
Dua	5964	536	35.14	290	2158	483
Doba	2383	153	3.99	58	258	113
Zebilla	3297	615	6.95	59	988	184
Kumpalgogo	19672	3048	42.59	276	1515	432
Bugri	3672	380	3.15	41	432	63
Average	**6997.6**	**946.4**	**18.36**	**144.8**	**1070.2**	**255**
s.e.d	2333.6	213.3	2.964	36.6	155.2	84.3
CV(%)	40.8	27.6	19.8	30.9	17.8	40.5

and Dua and Zebilla, all other differences in total nitrogen were significant. The variability in the total N content of the reservoirs was medium according to Warrick's (1998) guidelines for variability of soil properties.

The total available phosphorus in the reservoir sediments ranged from 3.15 to 42.59 kg ha^{-1} with a mean of 18.36 kg ha^{-1}. The differences in the available P content among the reservoirs were significant. The magnitude of P content was smaller than all the other nutrients probably due to its low mobility.

Nitrogen and phosphorus losses also present a major concern considering that they are the most deficient nutrients in savanna soils. On the other hand, soluble forms of nitrogen (nitrate and ammonium) constitute a major source of pollutants in rivers, lakes, reservoirs and groundwaters.

Total potassium losses showed medium variation (CV=31%), according to Warrick's (1998) guidelines for variability of soil properties, among the reservoirs and ranged between 41 and 290 kg ha^{-1} with a mean of 144.8 kg ha^{-1}. The Dua and Kumpalgogo reservoirs recorded significantly greater K content in their sediments than the three other reservoirs which did not differ significantly in their K content.

The results showed that the catchments have lost tremendous amounts of Ca in the range of 432 to 2158 kg ha^{-1} with a mean of 1070.2 $kgha^{-1}$. The Dua reservoir recorded the highest Ca content, followed by Kumpalgogo, Zebilla, Bugri and Doba. The differences in the Ca content were significant.

The total magnesium losses varied from 63 kg ha^{-1} to 483 kg ha^{-1} with a mean of 255 kg ha^{-1}. The Dua and Kumpalgogo reservoirs had significantly higher values than the remaining reservoirs. The variability in Mg content among the reservoirs was rated medium (CV=40.5%). The contribution of the other nutrients, such as potassium, magnesium and calcium in sustaining crop growth and yield is no less important. The huge amounts of nutrient losses from the catchments, stored in the reservoir sediments, have cost implications for nutrient replenishment in the catchments for sustainable agricultural production.

The significant amount of nutrients and organic matter in the reservoir sediments as shown by the loss in soil nutrient stocks, is indicative of the magnitude of soil fertility and productivity decline in the contributing catchments as well as pollution of the reservoir waters.

The practice of integrated soil, water and nutrient management and conservation would be required to sustain the fertility and productivity of the catchments and avert the pollution of the reservoirs by nutrients and sediments exported from the catchments through erosion.

Table 6. Equivalent forms in fertilizers of total nutrients in deposited sediments

Reservoir	Total N	P_2O_5	K_2O
		kg/ha	
Dua	536	80.47	348
Doba	153	9.14	69.60
Zebilla	615	15.92	70.80
Kumpalgogo	3048	97.53	331.20
Bugri	380	7.21	49.20

Estimating Cost of Nutrients in the Eroded Sediments

In estimating the cost of fertility erosion, the eroded sediment-bound nutrients were converted to existing fertilizers in the form of sulphate of ammonia, single superphosphate and muriate of potash. The results showed the nutrient losses to range from 153 to 3048, 7.21 to 97.53 and 49.20 to 331.20 for nitrogen, phosphorus (P_2O_5) and potassium (K_2O), respectively (Tables 6). The conversion of the nutrient loss to bags of fertilizer per hectare gave values in the range of 14.57 to 290.29, 0.80 to 10.84 and 1.64 to 11.60 bags per hectare for sulphate of ammonia, single superphosphate and muriate of potash respectively (Table 7).

On the other hand, the cost of fertilizers lost ranged from 437.10 to 8708.70, 36.00 to 487.80 and 131.20 to 928.00 GH¢/hectare for sulphate of ammonia, single superphosphate and muriate of potash respectively (Table 8). The total cost (GH¢ ha^{-1} y^{-1}) of these fertilizers was 286.15 for Dua, 74.289 for Doba, 225.061 for Zebilla, 1119.997 for Kumpalgogo and 96.376 for Bugri. The values represent a hidden cost to agricultural production in the respective reservoir catchment areas. This implies that if straight fertilizers were to be bought to compensate for the losses of N, P and K from the respective catchment areas of the reservoirs, the above costs will be incurred.

These cost figures, at best, represent only the cost of the mineral fertilizers required to replace the lost N, P and K and do not account for the losses of other nutrient elements including micronutrients nor the cost of transporting the fertilizers to the catchment areas as well as their application. Therefore the interpretation of the results of the replacement cost approach for assessing the cost of erosion as it affects prod-

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Table 7. Bags of fertilizer lost per hectare per year

	Sulphate of ammonia	Single superphosphate	Muriate of potash
Reservoir		Bags/ha/y	
Dua	5.104	0.894	1.160
Doba	1.619	0.113	0.258
Zebilla	6.508	0.197	0.262

Table 8. Cost of fertilizers lost per hectare

Reservoir	Sulphate of ammonia	Single super-phosphate	Muriate of potash	Total cost	Total cost per year
		*GH¢/ha			GH¢/ha/y
Dua	1531.20	402.30	928.00	2861.50	286.15
Doba	437.10	45.90	185.60	668.60	74.289
Zebilla	1757.10	79.65	188.80	2025.55	225.061
Kumpalgogo	8708.70	487.80	883.20	10079.70	1119.997
Bugri	1085.70	36.00	131.20	1252.90	96.376

**GH¢ 1.42 = USD $1*

uctivity should, recognize the following limitations (Enters, 1998):

a. Soil erosion does not only affect the nutrient status of the soil, but also its organic matter content and physical structure.
b. Soil nutrients may not be the most limiting factor in crop production.
c. Fertilizer applications are not necessarily the most cost effective options available to farmers for maintaining yields; in extreme cases, e.g. on deep and fertile soils, farmers may not even experience any yield decline with nutrient losses (Stocking, 1996).
d. It is only a proxy for actual productivity loss.
e. Mineral fertilizers supply nutrients in plant available forms, whereas erosion also removes fixed elements.

CONCLUSION

The study has amply shown that soil loss through erosion reduces top soil depth, nutrient stocks and the water holding capacity of catchment soils. This will adversely affect crop productivity, if no control measures are implemented. The total cost per year (GH¢ ha^{-1} y^{-1}) of fertilizers (sulphate of ammonia, single superphosphate and muriate of potash) needed to compensate for the lost nutrients (N, P and K) in the catchment areas is more than what the resource poor farmer can afford. The cost incurred as a result of fertility erosion represents a hidden cost to agricultural production. Catchment area protection, is therefore needed to control erosion from the catchments and reduce both on-site (fertility and productivity loss) and off-site (sedimentation, pollution) impacts of erosion. These should include afforestation, improved cover using recommended cover and forage species, sustainable land management practices and vegetative barriers (vetiver) around reservoirs. Desilted nutrient-rich sediments could be used as a soil amendment to improve the productivity of catchment soils. This will require field experimentation to ascertain the benefits of these sediments in enhancing crop yields and biomass production. However, the heavy metals, pollutants/pathogens content of the desilted sediments must be ascertained through further research studies before they are used as soil amendments.

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