Soil Erosion and Sediment Yield Modelling in the Pra River Basin of Ghana using the Revised Universal Soil Loss Equation (RUSLE)

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Abstract

There has been an upsurge of uncontrolled land use activities in the Pra River Basin in Ghana which are likely to promote surface soil erosion into the fluvial sediment transport system of the basin. The revised universal soil loss equation (RUSLE) was integrated with Geographic Information System (GIS) to model the spatial patterns in soil erosion and sediment yield in 2008 within the catchment. Parameters of the model were formatted as raster layers and multiplied using the raster calculator module in ArcGIS to produce a soil erosion map. The concept of sediment delivery ratio (SDR) was used to determine the annual sediment yield of the catchment by integrating a raster SDR layer with that of the soil erosion map.

Predicted soil loss and sediment yield were found to be low due to good soil protective cover by vegetation and tree crops as well as a low relief of the physical landscape. Though, the elements and processes prevailing in the basin in 2008 result in low surface soil erosion and sediment yield, this condition could degenerate into very severe surface soil erosion if the current state of land degradation, particularly small scale mining (galamsey) activities are allowed to continue.

Keywords: Geographic information system; Pra River; revised universal soil loss equation; sediment delivery ratio; soil erosion modelling; sediment yield modelling.

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Introduction

Accelerated soil erosion is a worldwide problem because of its economic and environmental impacts. Soil erosion leads to loss in soil fertility and sedimentation of water bodies with associated negative impacts. The negative changes in soil quality are a worldwide concern, particularly in developing countries where soil erosion is becoming a limiting factor in increasing or even sustaining agricultural productivity (Arekhi, 2008). In most West African countries such as Cameroon, Nigeria and Burkina Faso, the productivity of a number of cereal crops such as cowpeas, millet and maize was observed to decrease drastically as a result of soil erosion (Lal, 1985). In addition, according to Arekhi (2008), about 38% of the world's agricultural land is degraded owing to soil erosion; in Africa it is 65%, in Central America 74% and in South America 45%.

Reservoir sedimentation, another indirect measure of soil erosion, is one of the major off-site damages caused by accelerated soil erosion. The state of reservoir sedimentation in Tanzania, Nigeria, Dodoma, and Arusha Districts is between 0.05 and 20 million tonnes (Lal, 1985). In Ghana, sedimentation impacts are felt in reservoirs/dams such as Akosombo and Kpong on the Volta River, Weija Lake (Densu River) and Pra catchment reservoirs such as Owabi Dam (Owabi River), Barekese Dam (Ofin River) and Brimsu Dam (Kakum River) (Akuffo, 2003; Kusimi, 2005; Ghana News Agency, 2005). Siltation of these dams and reservoirs has reduced their water holding capacities, which is negatively affecting the ability of Ghana Water Company Limited (GWCL) and Volta River Authority (VRA) to supply potable water to most towns and to generate hydro-power to meet the growing demand for industrial and domestic energy.

The Pra Basin is one of the most extensively and intensively used river basins in Ghana in terms of settlement, agriculture, logging and mining due to its rich economic tree species and mineral ore deposits and its conducive environment for farming. The vegetative cover of the basin is experiencing a rapid rate of deforestation due to these human activities and this could hamper water resources management of the basin. Forest cover outside the reserve areas is negligible and is estimated at less than 2% of the basin. These forests are heavily logged. The implication of these human activities could be sediment transport into the river and channel morphological dynamics. Large scale and small scale mining occur around Obuasi and Konongo with disruptive impact on surface cover including soils (Fig.1). Moderate to severe sheet and gully erosion poses a threat to flooding within the basin. For instance, in July 2011, the Pra and Birim rivers flooded their banks in the upper and middle courses where illegal small scale mining activities are intense, destroying lives and property (Bentil, 2011). The extensive forest clearance for mining, settlement, and infrastructural development causes considerable loss of soil minerals and could result in sediment transport into the Pra and its tributaries, silting up channels and dams. Ghana Water Company Limited shut down its treatment plant at Kibi (Fig.1), a town at the source of the Birim River, because the river has become too polluted to be treated for domestic use as a result of the activities of illegal or small scale mining activities popularly called *galamsey* (Bentil, 2011).

In order to improve water quality and restore impaired watersheds, managers need to make decisions using data that they are able to gather (Nangia, 2010). Data collection can be expensive, tedious and time consuming, so in such situations using modelling approach makes sense (Nangia, 2010), particularly in the developing countries where institutions and organizations charged with the monitoring and collection of data are ill-equipped in terms of personnel, materials and money. Models for sediment yield, when applied to those areas lacking data, provide invaluable information for predicting future impacts of agricultural activities, land use, stream stabilization and sediment storage in reservoirs (Khanchoul et al., 2010).

To minimise the cost of field measurements of soil erosion and sediment yield, many computer models have been developed and used to effectively estimate soil erosion, which aid in developing soil erosion management plans in many river basins. Sediment yield and surface erosion at a watershed or regional scale are at present modelled using empirical models such as the universal soil loss equation (USLE), modified universal soil loss equation (MUSLE) or the revised universal soil loss equations (RUSLE and RUSLE 2), WEPP, SWAT, EUROSEM (e.g., Amore et al., 2004; Arekhi, 2008; Fistikoglu and Harmancioglu, 2002; Jain et al., 2010; Mongkolsawat, 1994; Nangia et al., 2010; Roy, 2009; Wahyunto and Abdurachman, 2010). The revised universal soil loss equation (RUSLE) has been widely used with very good results; is applicable in a GIS environment and so can provide a spatial distribution of erosion and soil loss; requires a small and simple input data set; and is relatively easy to use. Secondly, its data requirements are not too complex, and literature has shown that it has been successfully used to estimate soil erosion of catchments and farmlands (e.g., Arekhi, 2008; Fistikoglu and Harmancioglu, 2002; Jain and Kothyari, 2000; Jain and Das, 2010; Jain et al., 2010; Silva et al., 2010). The other models (e.g., WEPP, SWAT, EUROSEM, MIKE SHE, ANSWERS, CREAMS etc.) are applicable at catchment scale; event based; and continuous models of spatially and temporally distribution (i.e., 2D) (e.g., Amore et al., 2004; Fistikoglu and Harmancioglu, 2002). These models require substantial data inputs as well as many calibration parameters characterized by complex laboratory analyses or hard and expensive field data collection, and thus are inappropriate to apply mostly in developing countries where physical data on river basins are non-existent or very limited (Renschler et al., 1999; Silva et al., 2010). Consequently, the revised universal soil loss equation (RUSLE) was used to model soil erosion and sediment yield in the Pra catchment as part of a larger project which assessed sediment yield, sediment sources and bank erosion in order to determine the spatial patterns/trends in surface soil erosion and sediment yield of the basin. This paper only reports on the modelling aspect of the study. Results on sediment yield, bank erosion and sediment source tracking have been submitted elsewhere for publication.

Background of the Study Area

This study was carried out in the Pra River catchment which is located between latitudes 5º00^{l}N and 7º15^{l}N and longitudes 0º03^{l}W and 2º80^{l}W (Fig.1). It is one of the south western drainage basins in Ghana. The Pra is the largest of the four principal rivers that drain the area south of the Volta divide. Its main tributaries are the Ofin, Oda, and Birim rivers which drain from the Mampong-Kwahu and Atewa Ranges. The drainage basin area is 23,188 km^2 with a mean annual discharge of $214m^3s^{-1}$ (Akrasi and Ansa-Asare, 2008). The landscape is generally flat, characterised by an undulating topography with an average elevation of about 450 m above sea level.

The basin is underlain by eight soil types (Table 1a) weathered from the Tarkwaian and Birrimian geological formations. Acrisols and lixisols are the dominant soils. The soils are clayey and not well leached; hence they have the capacity to retain more moisture and are very cohesive. The soils are also of low fertility and poor chemical properties (Dickson and Benneh, 1995).

The basin falls within the wet semi-equitorial climatic belt which is characterized by two rainfall maxima. The first season is from May to June, with the heaviest rainfall occurring in June, and the second rainy season is from September to October. The basin comes strongly under the influence of the moist south-west monsoons during the rainy season, with high annual rainfall amounts of between 125 and 200cm. The dry season is well marked and prevails between November and March (Dickson and Benneh, 1995).

The Pra Basin is covered by the moist-semi deciduous forest vegetation which contains most of Ghana's valuable timber trees. The climatic environment promotes rapid vegetative growth, especially in the rainy season. Trees grow to heights of about 35-45m or more. This vegetative belt consists of trees, lianas, climbers and shrubs/bushes which cover the soil from erosion by rain drops and run-off. However, in the dry season, certain tree species shed their leaves during the long dry spell. Due to the rapid expansion of the cocoa industry in this zone very little of the original forest remains and most of what is left is secondary growth (Dickson and Benneh, 1995).

Land use activities within the basin are very intense. The basin contains most of the large cocoa growing areas in the Eastern, Ashanti, and Central Regions. Tree cash crop cultivation other than cocoa is mainly oil palm. Food cropping is increasingly becoming more commercialized especially around the medium and large settlements and along the major road arteries. The basin contains the highest density of settlements (both rural and urban) in Ghana. It has a high concentration of mining activities, mainly concerned with gold and other minerals. Some of the large scale mining companies in the basin include AngloGold Ashanti, Perseus Mining Ltd and Newmont Ghana Gold Ltd (Water Resources Commission, 2011). There are also several small scale miners engaged in both legal and illegal mining within the basin.

The Pra Basin serves as the source of water supply for both industrial and domestic uses for three regional capitals: Cape Coast, Sekondi and Kumasi (see inset Ghana Map, Fig.1), 41 districts and over one thousand, three hundred towns. The major tributaries are perennial and constitute an all-year-round reliable water source. However, human activities such as mining, logging are having adverse impacts and degrading the surface water resources of the basin (Ghana Survey Department; Water Resources Commission, 2011).

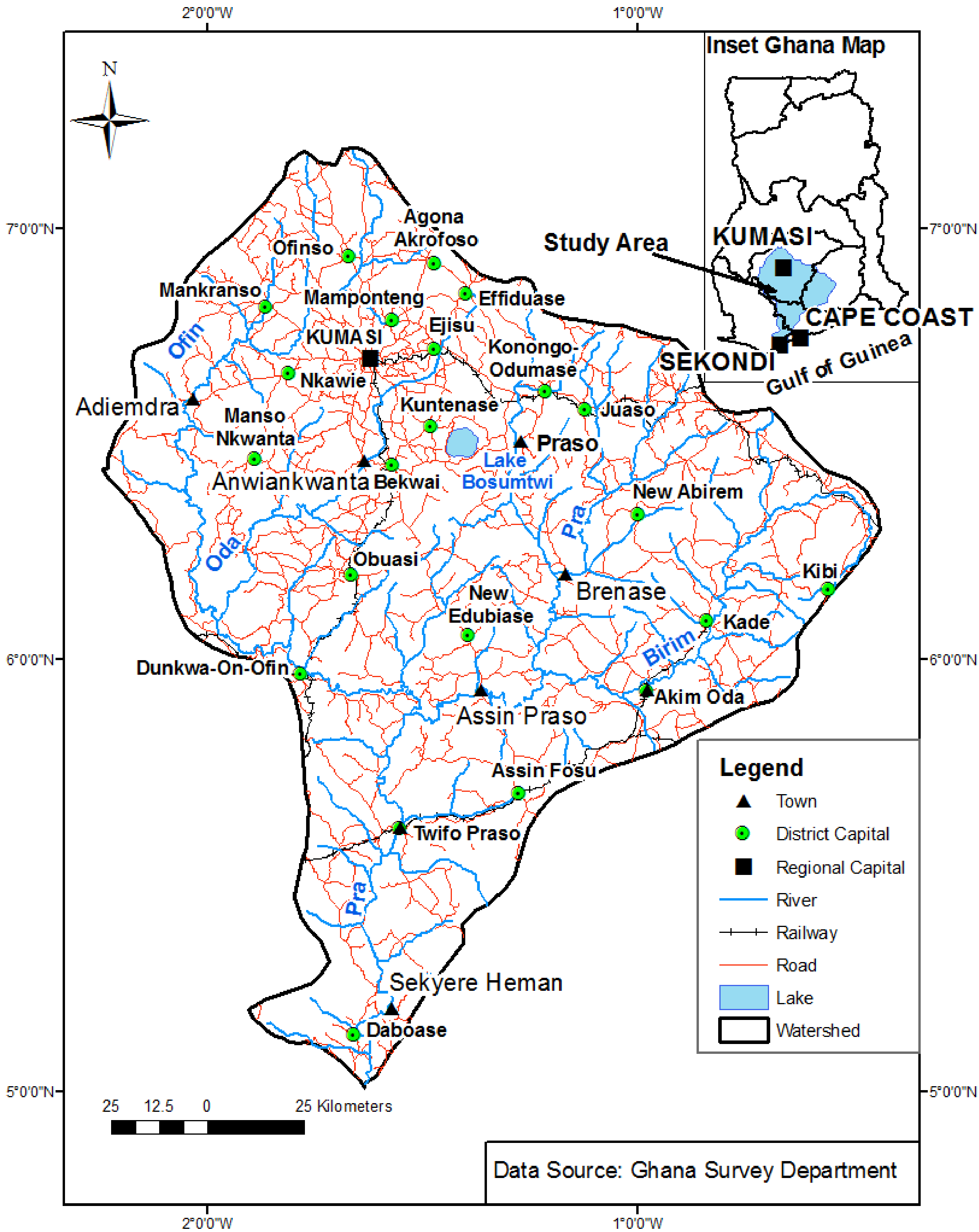

Fig.1: Map of the Pra River Basin

Materials and Methods

The revised universal soil loss equation (RUSLE) model has been used to model soil erosion in the Pra Basin. It is defined (Bonilla et al., 2010; Kouli et al., 2008; Renard et al., 1991) as

$A = RKLSCP$ ……………………. (1),

Where: A is the soil loss (t/ha/yr); R the rainfall run-off erosivity factor (MJ mm ha/h/yr); K the soil erodibility factor (t h MJ^{-1} mm^{-1}); LS the slope length and steepness factor; C the vegetative cover factor; and P the conservation practice factor are dimensionless.

Vector maps of parameters of equation (1) were generated and then converted to raster layers. The raster maps were multiplied using the raster calculator module in ArcGIS to generate soil erosion and sediment yield maps of cells depicting varying magnitude of soil loss in the catchment (Fig.2). The approach for deriving each parameter is discussed below.

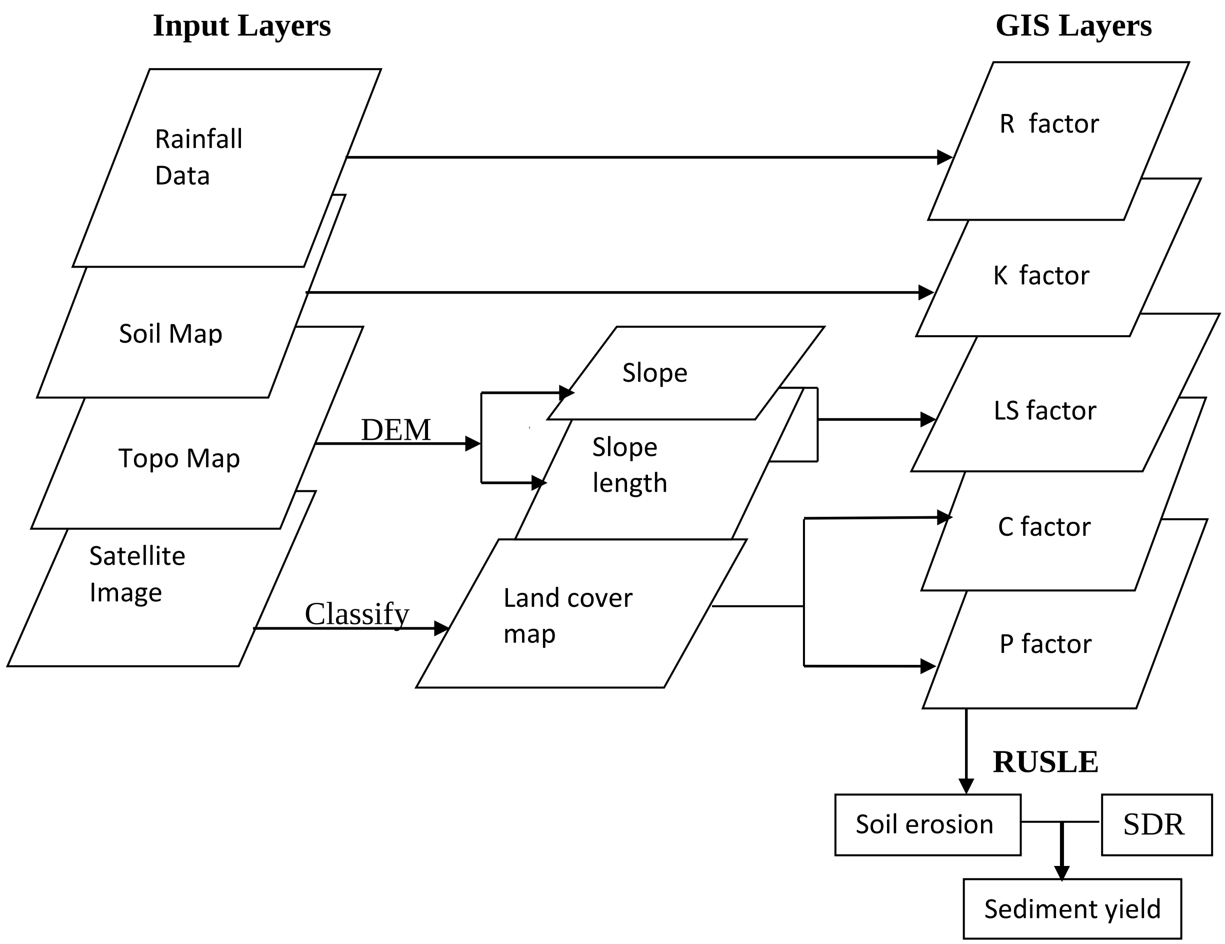

Fig.2: Schematic chart of GIS applications to soil erosion mapping and the derivation of Sediment Delivery Ratio - SDR (Modified from Mongkolsawat et al. 1994).

The rainfall erosivity index *R* measures the potential ability of rain to cause soil erosion. High *R* values mean high rainfall intensity with a higher potency of dislodging soils, hence the expected soil erosion from the land surface and subsequent sediment yield will be high. Low *R* value implies low rainfall intensity and run-off, consequently erosion and sediment yield will be low. Not all rainfall events caused erosion. An erosive event is a rainfall event with more than 12.50 mm of total rainfall accumulation or with at least 6 mm of rainfall accumulation in 15 minutes (Petkovšek and Mikoš, 2004; USDA-ARS, 2008). Erosive rainfall events are called effective events and were denoted by *Re* in the study. In this study the rainfall erosivity index was calculated using effective events *(Re)* to derive *R* of equation (1). The *Re* factor map was derived from monthly EI_{30}[1] values using Shamshad et al's. (2008) regression equation (2) based on the modified Fournier index (*MFIe*[2]):

$$R = 227MFIe^{0.548} \;..............\; (2).$$

The modified Fournier index (*MFIe*) was estimated using total effective monthly erosive rainfall amounts (Smithen and Schulze, 1982):

$$MFIe = \frac{Pe_i^2}{P_t} \;.............\; (3);$$

where: Pe_i, represents effective monthly precipitation of month i, P_t, annual rainfall amount (mm). Erosive event was fixed at ≥ 12.5 mm of total rainfall accumulation within 24 hours (Petkovšek and Mikoš, 2004; USDA-ARS, 2008). The rationale for the choice of these equations is that they were developed in humid tropics such as West Africa and Malaysia which are characterised by similar rainfall conditions (intensity and amounts) as the study area (Fig.1). The mean annual erosivity map (isoerodent map) was then produced in ArcGIS for the erosivity index using effective rainfall data (i.e, *Re*).

K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and run-off (Stone and Hilborn, 2000). When the *K* value is high, it implies deterioration in the physical properties of the soil such as low organic matter, coarse soil texture, coarse granular structure etc.; thus the soil is more prone to erosion. Therefore, the higher the *K* value, the more the soil is prone to erosion. When *K* values are low, it implies an enhancement in the physical properties of the soil such as increase in organic matter, fine soil texture, fine granular structure

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[1] *EI_{30} refers to the erosivity index of a storm in 30 min. E is the total kinetic energy for the event and I_{30} is the maximum 30 min intensity, i.e., the potential ability of rain to cause soil erosion within 30 min of the storm.*

[2] Fournier index (F) is a parameter used in estimating rainfall erosivity (*R*) of a region by dividing the mean monthly rainfall of the month with the highest rainfall by the mean annual rainfall. The Modified Fournier index (*MFIe*) is an estimation of the rainfall erosivity of a region using only the effective rainfall events which is divided by the annual rainfall.

etc., which increases the cohesiveness of soil particles to resist erosion. This will result in low soil erosion and sediment yield. The FAO *K* factor values of soils in the basin (Table 1a) were used to produce a raster layer of *K* factor map. Table 1b shows the susceptibility classes of soils to erosion.

Table 1a: K factor values of the soil types

Soil Type	Area (Km^2)	K factor
Acrisols	18,328.8	0.00090
Alisols	213.4	0.00000
Arenosols	1.2	0.00000
Ferralsols	1.4	0.02800
Leptosols	206.2	0.00002
Lixisols	3,564.9	0.00000
Fluvisols	854.1	0.06460
Luvisols	11.0	0.00400

Source: FAO

Table 1b: Soil erodibility classification

Soil erodibility Classes	Soil *K* Factor
Very High	>0.70
High	0.50-0.70
Moderate	0.25-0.50
Low	0.13-0.25
Very Low	<0.13

Source: Hagos (2004)

LS measure the effects of topography on soil erosion and the steeper and longer the slope, the higher the risk for erosion, and vice versa. The *LS* factor map for a cell area was computed with equation (4) below in ArcGIS using upslope contributing area and slope gradient computed from the digital elevation model (DEM) of the watershed. The DEM was generated from a 1:50,000 scale contour map sourced from the Ghana Survey Department. The contours were interpolated at 30 m pixel resolution using the 'topo to raster' command in ArcGIS to create a hydrologically correct DEM (e.g., Jain et al. 2010; Jain and Das, 2010). The generated DEM was further reconditioned to a depressionless DEM using the 'fill sink' command to determine the maximum downhill slope and the flow direction which will maintain continuity of flow to catchment outlet (e.g., Jain et al., 2010; Jain and Das, 2010). The slope (*S*) factor and flow accumulation were then derived from the depressionless DEM and then an *LS* map was generated based on equation (4) in AcrGIS using the raster calculator module (Jain et al., 2010; Jain and Das, 2010; Engel, 2003):

$$LS = \left(\frac{A_s}{22.13}\right)^{0.4} \cdot \left(\frac{\sin \emptyset}{0.0896}\right)^{1.3} \ldots\ldots\ldots\ldots\ldots (4);$$

where A_s is the upslope contributing area for overland grid per unit width normal to flow direction and θ is the slope angle in degrees. On the basis of total length of stream channels of a 1:50,000 topographic map of the basin and the basin area, a channel initiation threshold value of 0.65 km^2 was extracted and used to define channel cells (e.g. Jain and Das, 2010).

The cover management factor *C* is used to determine the relative effectiveness of soil and crop management systems in terms of preventing soil loss. High *C* factor implies low vegetation cover in the catchment, hence there is an increased opportunity for rainfall to detach sediments and overland flow to scour and transport sediments, ultimately causing an increase in sediment production, and when *C* values are low, it implies good vegetative cover and erosion will be low. The cover management factor map for *C* was determined using a classified land cover and land use map of Landsat ETM + 2008 image (e.g., Jain et al., 2010; Jain and Das, 2010; Jain and Kothyari, 2000). The image was classified with reference to topographical maps, Google Earth and training

Table 2: Land Cover Types and Cover Management (C) factor values

Land Cover Type	Area (km^2)	C Factor
Closed canopy	10,760.5	0.0001
Water bodies	3,109.4	0.0000
Built-ups & Barelands	1,160.6	0.3500
Open forest with shrubs & mixed arable tree Crops	10,412.1	0.0003
Open savannah woodland with shrubs & grassland	9,593.1	0.0020
Coastal scrub & grassland	9,855.9	0.0400
Bush fallows & cropland with natural vegetation mosaic	4,929.0	0.5429

Source: Processed Landsat ETM+ 2008 and Jain & Kothyari, 2000

areas of sites taken in the field using a global positioning system (GPS). Seven land cover types were classified using the maximum likelihood classifier module in Idrisi (Table 2). *C* factor values suggested by Wischmeier and Smith (1978) were assigned to cells of the respective classes as shown in Table 2.

Table 3: Attributes of Landsat ETM+ 2008

Year & Image Scene	Date of Acquisition	Row	Path	Resolution	Level of Processing
2008 Landsat ETM+ (Kumasi and Pra's Mouth Scenes)	01/02/08 (for both scenes)	055 and 056	194	30m	L1T

Source: usgs.gov

The basin covers two Landsat scenes (Table 3). The images were downloaded from the Global Land Cover Facility website glovis.usgs.gov. The 2008 image was chosen based on the availability of good satellite images covering the study area; because of thick cloud cover most images were not suitable for use. The 2008 images had no cloud cover. The images were merged and cropped to size using the geographic coordinates of the basin. The classified image was then exported to ArcGIS and cropped to size using the vector layer of the drainage basin.

The P factor reflects the effects of soil erosion support practices that will reduce the amount and rate of the water runoff and thus reduce the amount of erosion. The P factor varies from 1 for bare soil with no erosion control to 0.01 where there is much cover on gentle slopes (Arekhi, 2008). No specific soil erosion control management is practised by farmers, but the classified image backed by field observation shows that except in the urban centres, the watershed is well protected by vegetative cover such as forests and shrubs as well as tree crops including cocoa, coffee, oranges, oil palm and food crops such as plantain and cocoyam. A P factor of 1 was assigned to the built-ups and barelands class, 0 to water bodies and 0.5 was the factor for strip cropping of 2 year rotation to other classes of the classified image which had some form of land cover.

The annual sediment yield of the watershed was estimated by multiplying the soil loss map and the sediment delivery ratio map (Fig.2) as expressed by equation (5) (Fistikoglu and Harmancioglu, 2002):

$$Y = A \times SDR \quad \text{……………………………..} \quad (5);$$

where Y is the sediment yield (t/ha/yr), SDR is the sediment delivery ratio, and A is $RKLSCP$ (gross erosion per unit area above a measuring point) (Arekhi, 2008; Silva et al., 2010; USDA-ARS, 2008).

SDR is defined as the ratio of sediment delivered at a given area in a stream system (sediment yield) to the gross erosion or the fraction of gross erosion that is transported from a given catchment in a given time interval. For each land cell, SDR depends upon several physical characteristics of the watershed including surface roughness, land slope, soil hydrologic conditions, and length of the travel path (flow length) to the stream and vegetative cover (Kothyari and Jain, 1997).

The sediment delivery ratio for each cell i (SDR_i) is a function of travel time (Jain and Kothyari 2000; Fu et al., 2006):

$$SDR_i = \exp(-\beta t_i) \quad \text{................} \quad (6);$$

where t_i is the travel time (h) for each cell_i to the nearest channel cell down the drainage path and β is a watershed-specific parameter regarded constant. The total travel time along a flow path is expressed as (Jain and Kothyari, 2000):

$$t_i = \sum_{i=1}^{m} \frac{l_i}{v_i} \quad \text{..................} \quad (7);$$

where: l_i is the flow length (i.e., the length of segment *i*) in the flow path (*m*), which is equal to the length of the side or diagonal of a cell depending on the flow direction in the cell, and v_i the flow velocity for the cell (m/s). Flow length was derived from the digital elevation model (DEM). Flow velocity is derived from Manning's equation which is a function of the land surface slope and the land cover characteristics (Jain and Kothyari, 2000; Fu et al., 2006):

$v_i = a_i S_i^{0.5}$........ (8);

where: S_i is the slope of the *ith* cell and a_i is a land use coefficient. The land use co-efficient values (Table 4) were assigned to each grid cell in the land cover image. The final flow velocity for the overland flow was calculated from Equation (8); i.e., by multiplying the assigned land cover map and the square root of slope for each grid cell. If equations 7 and 8 are substituted into 6 the following equation results:

$SDR_i = \exp\left(-\beta \sum_{i=1}^{m} \frac{l_i}{a_i S_i^{0.5}}\right)$.................. (9).

Table 4: Land cover co-efficient values

Land use/land cover type	a_i value/velocity co-efficient
Closed canopy	0.7600
Water bodies	0.1250
Built-ups & barelands	6.3398
Open forest with shrubs & mixed arable tree crops	0.6401
Open savannah woodland with shrubs and grassland	0.4267
Coastal scrub and grassland	0.4572
Bush fallows & cropland with natural vegetation mosaic	0.3962

Source: Jain & Kothyari, 2000 & Mutua and Klik, 2006

Sediment yield was simulated within a β range of 0.1 to 1.5 with an incremental value of 0.1 and it was found that sediment yield was insensitive to β value (e.g., Fu et al., 2006; Jain and Kothyari, 2000; Mutua and Klik, 2006), so β value was taken as 1 for computation.

Results and Discussion

The generated GIS layers of RUSLE for the determination of the magnitude of soil erosion in the Pra Basin are shown in Figs. 3 – 7. Annual rainfall erosivity ranges from 553 – 1,166 MJ mm/ha/h/yr with a mean value of 780.9 MJ mm/ha/h/yr (Fig. 3). Higher intensities of *R* prevail around Praso-Konongo-Juaso (Fig.1), a reflection of the climatic trend within the basin. Thus zones of high erosivity will be more erosive due to the higher intensity of rainfall events. Similar patterns in rainfall erosivity of the basin were observed in an erosivity map of Ghana and West Africa produced by Oduro-Afriyie (1996) and Roose (1977). With reference to *R* classification of $R \leq 2{,}452$ = low erosivity; $2{,}452 < R \leq 4{,}905$ = medium erosivity; $4{,}905 < R \leq 7{,}357$ = medium-strong erosivity; $7{,}357 < R \leq 9{,}810$ = strong erosivity; $R > 9{,}810$ = very strong erosivity (Silva, 2004), the rainfall erosivity index of the basin is low.

The Pra catchment is underlain by 8 major soil types (alisols, acrisols, arenosols, ferralsols, fluvisols, leptosols, lixisols and luvisols), with alisols, acrisols and lixisols having erodibility values of 0 and fluvisols being the most erodible (0.065 t h MJ^{-1} mm^{-1}) (Table 1a and Fig.4). The most erodible soils (fluvisols) are concentrated in the river valleys (Table 1b). All the soils are classed as having very low erodibilities when exposed.

The length and steepness of slopes are high at the source of the basins such as the Atewa Mountains and the Ashanti Mampong-Kwahu Scarps which serve as the source of the Pra, Birim and Oda Rivers, and around Lake Bosomtwi due to the mountain formations. The *LS* of the other parts of the basin, particularly the southern part is very low (Fig.5). Much of the basin area is characterised by low values of *LS* and transport of eroded materials will be very limited owing to the low gradient.

The *C* factor varies from 0 to 0.54 with a mean of 0.03 (Fig.6). Forest reserves making up the closed canopy had the best vegetative cover while urban centres and barelands (mine sites) had sparse vegetative cover. Over 81% of the catchment was protected by vegetative cover composing of forest reserves, open/secondary growth, savannah and coastal scrub/grassland with only about 22% being covered by bushes/cropland and built-ups/barelands. The *P* factor ranges from 0 – 1 (Fig.7) with an average value of 0.51. The *P* factor reflects the land use and land cover of the basin.

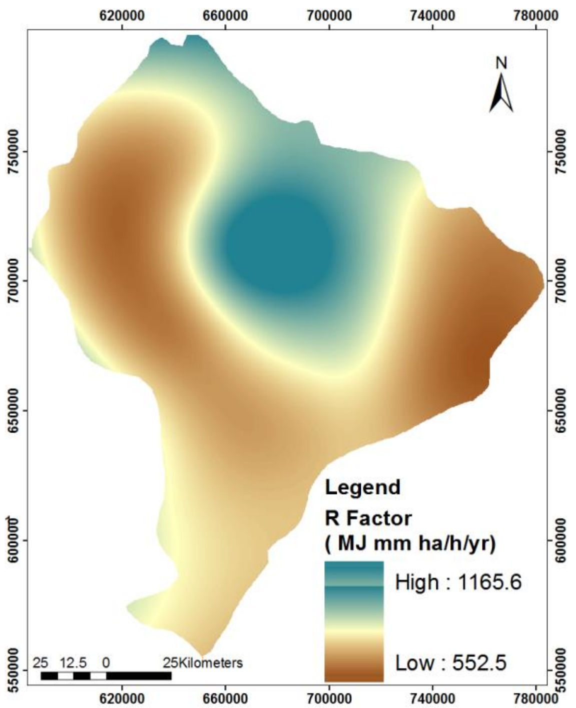

Fig.3: Rainfall erosivity (R) factor map of basin

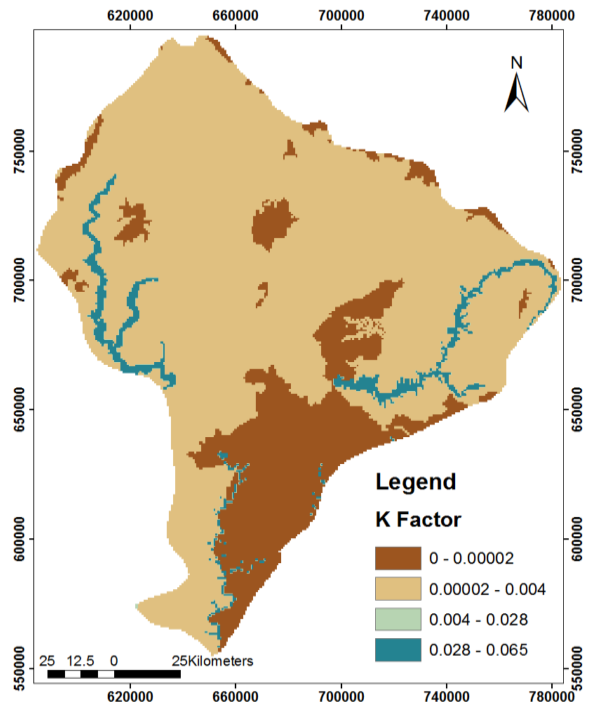

Fig.4: The soil erodibility (K) map of the basin

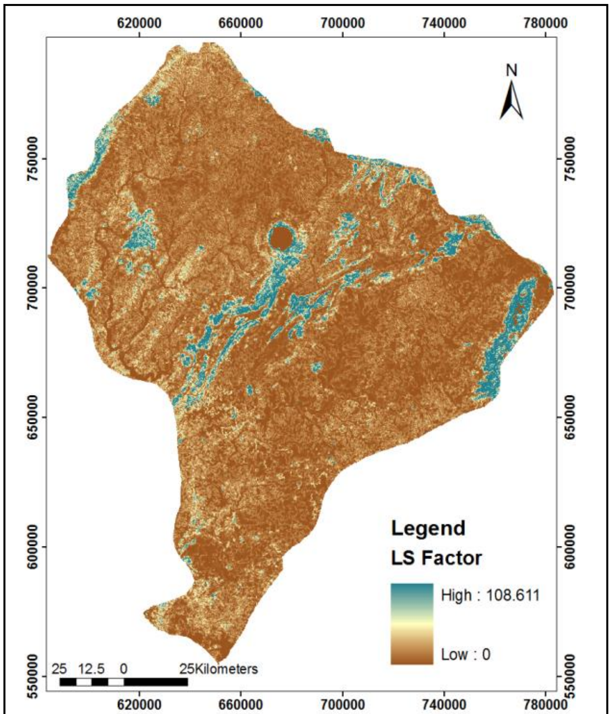

Fig.5: Slope length and steepness (LS) map of the basin

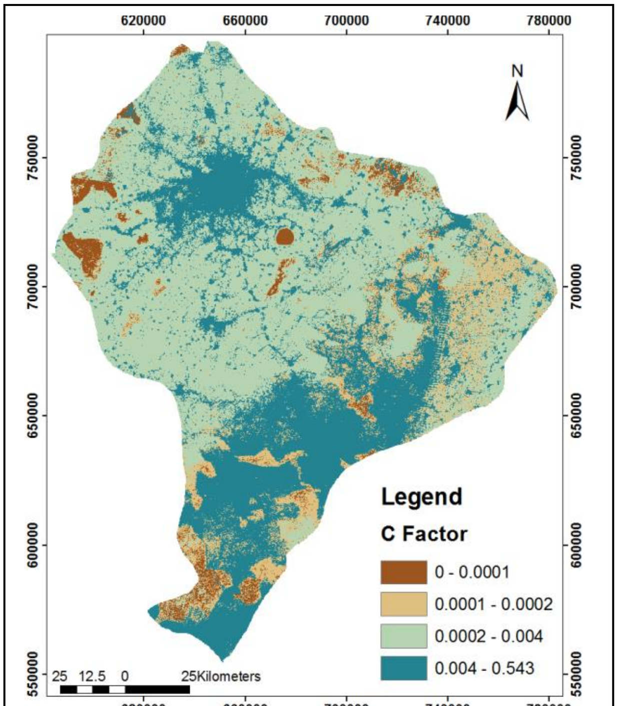

Fig.6: Cover management factor (C) map derived from satellite image classification

Figure 8 illustrates the gross soil erosion for the annual rainfall year 2008. Estimated soil loss from a cell ranged from 0 – 390. 5 t/ha/yr with a mean of 0.08 t/ha/yr and a standard deviation of 2.06 t/ha/yr. Comparing the mean value of soil loss to the classification scheme of FAO (1967, cited by Silva et al., 2010) in t/ha/yr: (a) < 10 = very low, (b) 10–50 = moderate, (c) 50–120 = high, and (d) >120 = very high, the catchment is characterised by low soil loss risk. The low soil erosion risk is due to the well protected landscape by vegetative cover and low gradient of the topography. Zones susceptible to moderate to high erosion risks are very few and these occur in built-up and exposed landscapes (galamsey areas) and also along steep slopes and within the river valleys underlain by fluvisols which are very susceptible to erosion (Fig.8). The highest soil loss occurs in river valleys and the erosion tends to increase downstream as a result of increase in flow accumulation down slope from the source towards catchment outlet. Most urban centres are characterized by moderate soil erosion and this is due to the exposed nature of these urban landscapes (unpaved and not grassed). High run-offs generated during rainfalls cause serious urban erosion, creating rills/gullies and entraining sediments into gutters/gullies which are channelled into nearby streams and rivers. Figs.9 and 10 illustrate cases of urban erosion at Konongo-Odumase where field measurements showed that most building foundations and structures have been eroded to depths of between 0.6 and 1.5 m.

The sediment delivery ratio values range from 0 – 1 (Fig.11). At mean annual temporal scale, *SDR* generally assumes values ≤1, but for a given event, *SDR* can be >1 because sediments deposited on the hillslopes or stored into the channel network in some previous events can be remobilised (Ferro and Porto, 2000). Higher values are found in river channels whilst lower values are recorded in overland regions outwards river channels, thus much eroded surface sediments are entrained into the river channels with little deposition in uplands.

The spatial variations in sediment yield across the entire catchment are very low (Fig.12), with a range of 0 – 193 t/ha/yr. Higher sediment yield values occur in residential areas, particularly in Kumasi and on steep slope landscapes of the catchment. Urban erosion tends to be high owing to the exposed state of the landscapes. There is virtually no sediment yield from surface erosion except in a few built-up environs and along slopes of the Atewa Range, Ashanti Mampong and the Kwahu Scarps. The low sediment yield is a result of the low relief of the basin and the protective vegetative cover, which covers over 80% of the entire basin.

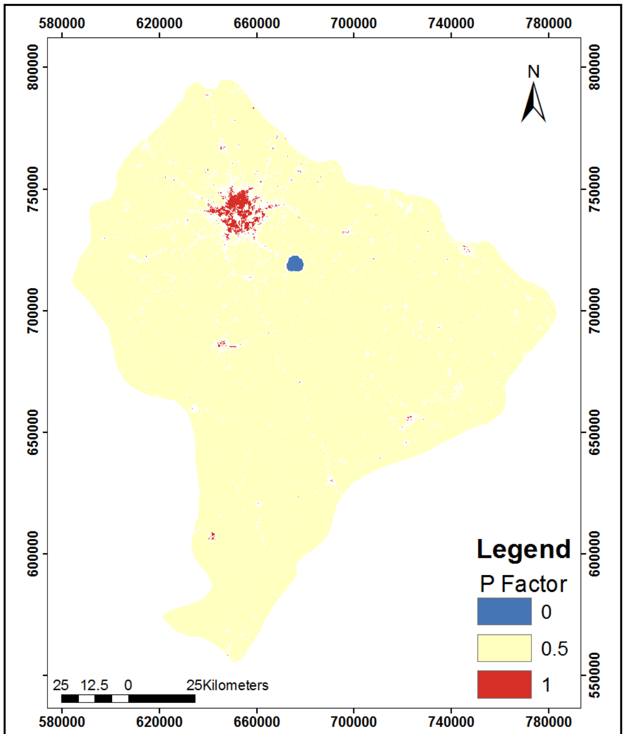

Fig.7: P factor map of the basin

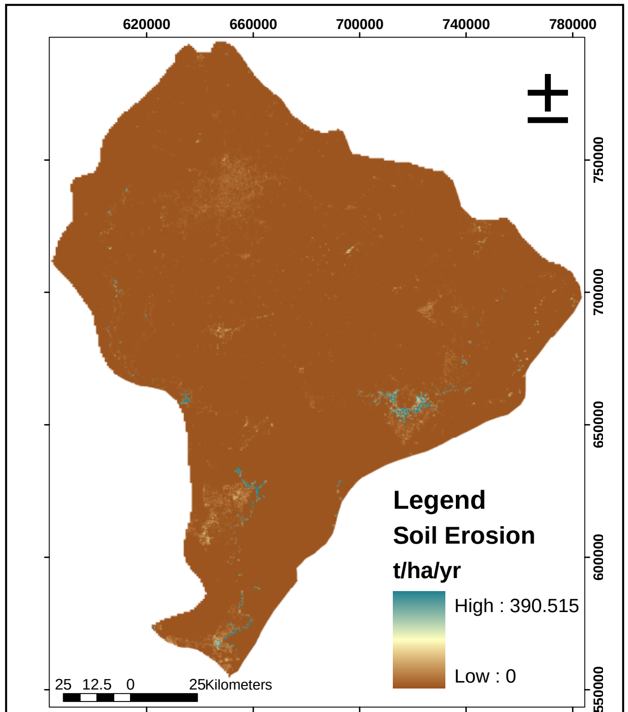

Fig.8: Gross soil erosion map of 2008

Fig.9: Erosion of a well and house foundations at Odumase

Fig.10: Eroded plant root at Konongo

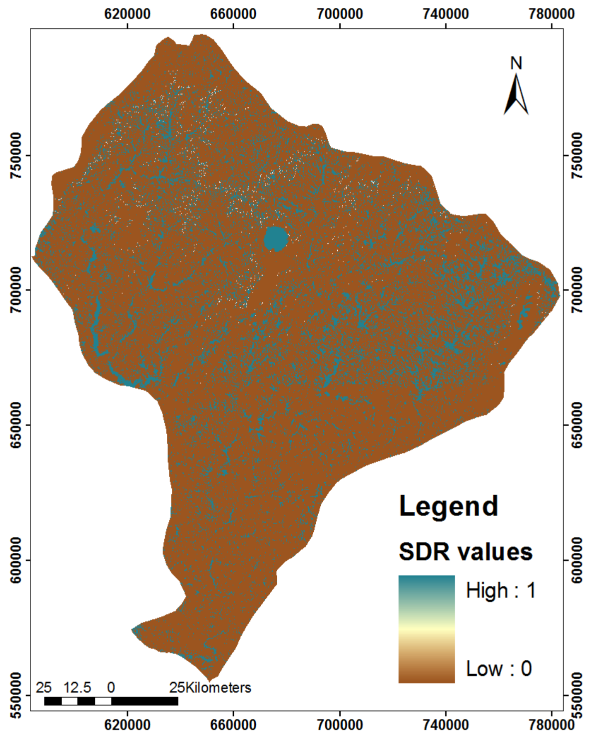

Fig.11: Sediment delivery ratio map of the basin

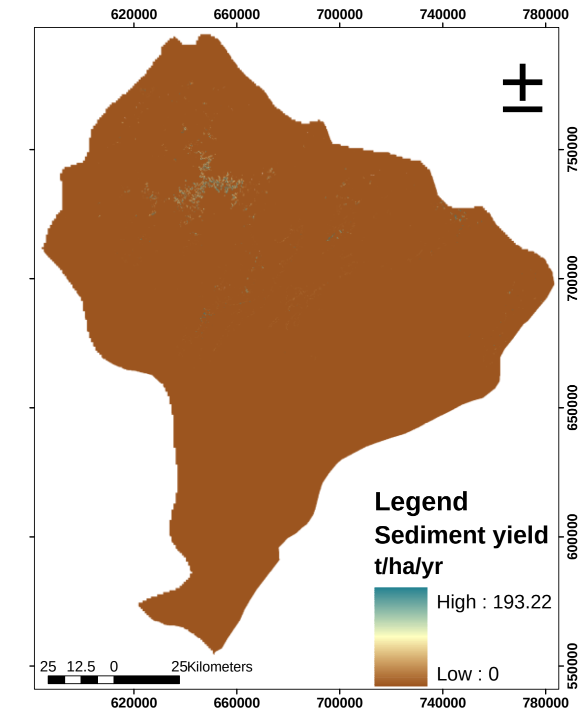

Fig.12: Sediment yield map of the Pra Basin-2008

The vegetative cover protects the soil from the erosive power of the torrential tropical rains which is capable of dislodging particles into concentrated channels. Also, except at the source of the rivers which are characterised by steep slopes, the topography is gentle, with much of the catchment slope being less than 20 degrees, thus the decrease in slope with increasing basin size downstream will lead to low-energy levels of run-offs which hinder sediment transport and facilitate sediment storage as indicated in Akrasi (2011). Similarly, Akrasi (2011) attributed the low specific sediment yield in Ghanaian Rivers including the Pra to low gradients of the river basins and the associated low-energy conditions and low efficiency of sediment delivery from the catchment surface to, and through, the channel system.

Conclusion

The study showed a very effective combination of RUSLE with GIS in mapping the spatial patterns in soil erosion and sediment yield. Results of soil loss and sediment yield derived from the integration of RUSLE into GIS give a vivid spatial dimension in soil erosion and sediment yield in the Pra Basin. Given the elements and processes prevailing in the drainage basin in 2008, surface soil erosion and sediment yield predicted were very low and this is attributed to the good vegetative cover and low slope gradient. Zones susceptible to moderate-high erosion risks were few and these occurred in built-ups, high rainfall intensity and exposed landscapes and also along steep slopes and within the river valleys underlain by fluvisols which are very susceptible to erosion.

But this condition could degenerate into very severe surface soil erosion and sediment yield if the current state of illegal small scale mining and land clearance is allowed to continue, as these activities will expose the landscape and accelerate soil erosion. Measures must be put in place by state institutions to protect the vegetative cover of the basin. Urban greening to protect the soil and the construction of good drains to carry run-off into streams should also be embarked upon by Local Government Authorities to protect the soil from urban erosion.

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