IMPACT OF LAND USE CHANGES ON SOIL EROSION AND SEDIMENTATION IN THE TONO RESERVOIR WATERSHED USING GeoWEPP MODEL

By

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Declaration

I hereby declare that this submission is my own work towards the MSc and that, to the best of my knowledge, it contains no material previously published by another person nor material which has been accepted for the award of any other degree of the University, except where due acknowledgement has been made in the text.

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Abstract

Sediment delivery from the Tono watershed in the Upper East Region of Ghana is a major concern in determining the rate of siltation of the Tono Reservoir. As part of a broader effort to develop a sediment budget for the Tono Reservoir, this study determined the current volume of silt in the reservoir through bathymetric survey, mapped land cover changes by maximum likelihood supervised classification of Landsat images acquired for 1991, 2005 and 2013 and used a process-based watershed hydrology and upland erosion model, Water Erosion Prediction Project (WEPP), to simulate hydrology and sediment dynamics for three land-use/land-cover scenarios. The Geo-spatial interface for WEPP (GeoWEPP) was used to characterize upland overland flow elements based on their land use/land cover, soil, and slope profiles. A significant land cover change was observed as shrub land had decreased by 8%, bare-land area had increased by 9.1%, and the Reservoir area had also decreased by 3.7%. Using characteristics obtained from GeoWEPP as inputs for the WEPP model runoff fluxes, soil loss rates, and sediment delivery ratio (SDR) for three environmental scenarios: land-use/land-cover with agricultural lands under fallow tilled management (Scenario 1), land-use/land-cover with agricultural lands under corn, soybean no till management (Scenario 2), land-use/land-cover with non-agricultural lands under shrub-perennial (Scenario 3) were estimated. Over the simulated 29-year period; runoff depth, soil loss rate and SDR were estimated to be 118.4mm, 22.8 t/ha, and 0.68 for Scenario 1; 94.6mm, 2.8 t/ha, and 0.31 for Scenario 2; and 57.7mm, 0.6t/ha, and 0.92 for Scenario 3. The volume of silt since 1991 to 2013 from the bathymetric results was 1.62 X 10^{5} m^3 of silt per year. This is about 1.74% reduction in reservoir capacity on annual basis.

Keywords: GeoWEPP, bathymetry, reservoir, land use change, sediments.

Dedicated to Imam Ali (A.S.)

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List of Abbreviations and Acronyms

ASCII	American Standard Code for Information Interchange
BCM	Billion Cubic Meters
Ca	Calcium
CSA	Critical Source Area
CSNT	Corn Soybean No Till
CLIGEN	Climate Generator
CGIAR-CSI	Consultative Group for International Agricultural Research-Consortium for Spatial Information
EUROSEM	European Soil Erosion Model
FASCOM	Farmers Services Company
FT	Fallow Tilled
GIS	Geographical Information System
ICOUR	Irrigation Company of Upper East Region
K	Potassium
Landsat TM	Land Satellite Thematic Mapper
LISEM	Limburg Soil Erosion Model
MCM	Million Cubic Meters.
MSCL	Minimum Source Channel Length

MUSLE	Modified Universal Soil Loss Equation
Mg	Magnesium
N	Nitrogen
OC	Organic Carbon
P	Phosphorous
PRISM	Parameter-elevation Regressions on Independent Slopes Model
PS	Perennial Shrubs
RUSLE	Revised Universal Soil Loss Equation
SDR	Sediment Delivery Ratio
SEDD	Sediment Delivery Distributed Model
SLEMSA	Soil Loss Estimation Model for Southern Africa
SRTM	Shuttled Data Topography Mission
TOPAZ	Topographic Parameterization
USLE	Universal Soil Loss Equation
WEPP	Water Erosion Prediction Project
WRRI	Water Resources Research Institute
WRI	Water Research Institute

CHAPTER 1: INTRODUCTION

1.0 General Background

On local, regional and global scales, the most significant human impacts on the hydrologic system are caused by land-use change. Conversion of forest land for agriculture, mining, industrial, or residential uses significantly alters the hydrologic characteristics of the land surface and modifies pathways and rates of water flow. If this type of major shift in the hydrologic balance occurs over large or critical areas of a watershed or region, it can have significant short- and long-term impacts, including increased downstream flooding and decreased long-term deep and shallow groundwater supply as well as increased siltation in surface water bodies (Walling, 2005; cited in Walling, 2009).

Because of their close links to land cover, land use and the hydrology of a river basin, erosion and sediment transport processes are sensitive to changes in climate and human activities. These activities include forest cutting and land-clearance, the expansion of agricultural land , mineral extraction, urbanization and infrastructural development, sand mining, dam and reservoir construction, and programs for soil conservation and sediment control (Walling, 2005; cited in Walling, 2009).

Most reservoirs are constructed by erecting a dam across a river. In this same light, the Tono Irrigation Project came to exist as a result of the construction of a dam across the Tono River. This created a reservoir of 1800hectares in area and 93 million cubic meters in capacity. The catchment area of the reservoir is about 650 square kilometers (WRRI, 1996).

With the help of 250km of canals and 100km of service roads, the reservoir water is able to irrigate over 2000hectares of land South-West of Navrongo. Crops grown include rice, corn, tomatoes, groundnut and soybean (WRRI, 1996).

Irrigation season begins in October each year through to March the following year. The actual irrigated area to be cropped each time is confirmed at the start of each season and this depends on the volume of water in the reservoir and irrigation water available.

Soil erosion is integrally linked to land degradation, excessive soil loss results from poor land management and has important implications for crop productivity and food security – and thus for the sustainable use of the global soil resource (Montgomery, 2007 cited in Walling, 2009).

Land use change, including land conversion from one to another and land cover modification through land use management has greatly altered a large proportion of the earth's land surface to satisfy mankind's immediate demands for natural resources (Rahman *et al* 2012). Land use change can be characterized by the complex interaction of behavioral and structural factors associated with demand, technological capacity, and social relations, which affect both demand and environmental capacity, as well as the nature of the environment in question (Verburg *et al*., 2004). The impacts of land use changes have received considerable attention from ecologists, particularly with respect to effects on aquatic ecosystems and biodiversity (Turner *et al*., 1996 cited in Verburg *et al*., 2004).

Land use changes in a watershed can impact water supply by altering hydrological processes such as infiltration, groundwater recharge, base flow and runoff (Turner *et al*., 1996 cited in Verburg *et al*., 2004). Estimates of runoff volumes and sediment yields from watersheds help to predict the volume of silt that will collect in the water body.

Erosion prediction models can be useful tools for this purpose, as they reveal new information related to complex interactions in the soil environment, and allow for new land-use ideas to be evaluated before they are implemented. In the case of soil erosion, simulation models have become important tools for the analysis of hillslope and watershed processes and their interactions, and for the development and assessment of watershed management scenarios (Santhi *et al.,* 2006; Miller *et al.*, 2007 cited in Baigorria and Romero, 2007).

Knowing drainage basin erosion rates is of significant interest because they influence both water quality and quantity available for human use (Sthiannopkao *et al.,* 2007 cited in Sosa-Gonzalez, 2012). Sedimentation of water bodies, an effect of erosion, is associated with deterioration of water quality including increased turbidity and temperature and changes in dissolved oxygen (Bilotta and Brazier, 2008 cited in Sosa-Gonzalez, 2012). The yield of water in reservoirs can be affected by erosion, since their capacity decreases as they are filled with sediment. Although erosion rates may be related to natural factors, such as geology and climate, accelerated erosion is often triggered by human activities (Douglas, 1969; Ouyang *et al*, 2010 cited in Sosa-Gonzalez, 2012). According to (Foley *et al.*, (2005); Marshall and Shortle, (2005) cited in Sosa-Gonzalez, (2012)) deforestation and impervious surfaces can significantly increase erosion.

Erosion has been quantified in the past using a variety of methods. In the 1960s, the volume of sediment deposited in standing water (artificial reservoirs or lakes) was measured and normalized by the area of the basin draining to the sampling point in order to obtain erosion rates under the assumption of steady state (Judson and Ritter, 1968 cited in Sosa-Gonzalez, 2012). Another method used to estimate erosion rates was the measurement of suspended solids carried by streams (Judson and Ritter, 1968 cited in Sosa-Gonzalez, 2012). These methods assumed that sediment production and transport are equal over the time interval of sampling.

The processes of erosion, sediment delivery and sediment transport are key components and measures of the functioning of the earth system. Erosion and sediment redistribution processes are the primary drivers of landscape development and play an important role in soil development. Accelerated soil erosion has been globally recognized as a serious problem since people took up agriculture (Renschler, 2003).

According to De Roo and Jetten (1999), quantitative results related to the soil loss rates and conservation strategies are not usually available for areas with erosion problems. However, quantitative erosion assessments and possible strategies for management of basins are necessary for both local planning and governmental agencies associated with sustainable development. Thus, erosion simulation models, especially distributed models, are useful to evaluate different strategies for land-use and soil management improvement in these watersheds.

To design and implement an effective sediment reduction strategy there is the need to;

- identify and quantify mechanisms delivering sediment to the river network, and
- understand if/how those mechanisms have been altered from historic conditions.

This can be done in the context of a watershed sediment mass balance (a sediment budget) that accounts for all sources and sinks throughout the watershed. Watershed hydrology-erosion modeling can provide one of many useful inputs in the development of a watershed sediment budget. A large effort to develop a sediment budget for the Tono watershed was conducted between 1989 and 1991 by the Water Resources Research Institute (WRRI), now Water Research Institute (WRI).

Knowledge of sediment delivery from the Tono watershed is a major concern for effective and sustainable management of the reservoir. As part of a broader effort to develop a sediment budget for the Tono Reservoir, this study will determine the current volume of silt in the reservoir through bathymetric survey, map land cover changes by maximum likelihood supervised classification of LANDSAT images acquired for 1991, 2005 and 2013 and then implement a process-based watershed hydrology and upland erosion model, Water Erosion Prediction Project (WEPP), to simulate hydrology and sediment dynamics in three land-use/land-cover scenarios.

1.1 Research Objectives

In general, the study was to determine the effect of land use change and erosion on siltation of the Tono reservoir.

The specific objectives were to:

1. Determine land cover/landuse changes in the catchment of the reservoir from LANDSAT images
2. Estimate annual runoff depth, soil loss rate and sediment delivery ratio in the watershed through the model run for three different land cover/land use scenarios
3. Determine sediment accumulation in the Tono reservoir since 1991

1.2 Research Questions

The research seeks to address the following key questions;

i. What is the impact of land use change on the reservoir?

ii. How can the GeoWEPP model help in understanding the impact of management practices on the reservoir?

iii. What is the volume of silt in the reservoir?

iv. Which practices accelerate erosion on the watershed?

v. How often should bathymetric surveys be conducted on the reservoir?

1.3 Research Motivations/Justification

Water is essential for sustenance of all forms of life on earth. It is not evenly distributed all over the world and even its availability at the same locations is not uniform over the year. While some parts of the world, which are scarce in water, are prone to drought, other parts of the world, which are abundant in water, face a challenging job of optimally managing the available water resources.

Ghana receives an average annual precipitation of 283.2 billion cubic meters (BCM). The total actual renewable water resources is 53.2 BCM per year, 43% of which originates outside Ghana's international borders, which means that 30.3 cubic kilometers (km^3) per year are internally produced. About 22.9 km^3 of surface water enters the country annually, of which 8.7 km^3 comes from Burkina Faso, 6.2 km^3 from Côte d'Ivoire and 8 km^3 from Togo (Namara *et al*; 2010).

Even though the availability of water resources in Ghana can be judged as adequate when compared to the situation of many water-scarce countries, it is below that of water-rich countries. The per capita renewable water resources availability is about 2,489 cubic meters (m^3) per year in Ghana, while the corresponding values for sub-Saharan Africa, Europe and North America are 6,322.5 m^3, 10,655.1 m^3 and 19,992.5

m^3, respectively. The total dam capacity of Ghana is estimated at 148.5 million cubic meters (MCM).

The total withdrawal as a percentage of total renewable water resources is 1.8%. The main consumptive water uses in Ghana are for domestic, industrial and irrigation purposes. In 2000, about 235 MCM was withdrawn for domestic purposes, 95 MCM for industry and 652 MCM for irrigation, resulting in a total water withdrawal of 982 MCM. The current water use for hydroelectricity generation (only at the Akosombo Dam), which is non-consumptive water use, is 37.843 km^3 per year (FAO 2009, cited in Namara *et al*; 2010).

The per capita water withdrawal is 50 m^3 per year, which is low when compared to the sub-Saharan Africa average (173 m^3 per capita per year). For comparison purposes the corresponding value for North America is 1,663 m^3 per capita per year.

The Tono Irrigation dam is one of eight irrigation schemes under the sub-typology of reservoir or storage-based gravity-fed irrigation systems where water from an earth dam or reservoir system is diverted to the fields by gravity through intake structures and canal systems. The others are Afife in Ketu District of the Volta Region; Bontanga and Golinga in Tolon-Kumbungu District of the Northern Region; Vea in Bolgatanga districts of the Upper East Region; Ashaiman in the Ashaiman District; Kpong in Akuse District of the Greater Accra Region; and Okyereko in the Gomoa East District of the Central Region (Namara *et al*; 2010).

Tono and Vea schemes are under the management of ICOUR, which provides credit packages to farmers in the form of machinery hire services and input supply. However, considerable proportions of farmers use animal traction or even hoes for tilling the land.

Since the completion of the Tono irrigation dam in 1979, it has been serving the purpose of storing surplus river water available during wet periods and for utilization of the same during lean periods. It has been playing dual role of harnessing the river waters for accelerating socio-economic growth and of controlling floods and limiting the impact of droughts. It contributes significantly in fulfilling the following basic human needs, such as;

- Water for drinking,
- Irrigation,
- Flood control,
- Inland navigation, and
- Recreation.

While the dam provides an invaluable service to the inhabitants, the following considerations for the sustainability of the dam has been the main points on which this thesis was developed:

1.3.1 Quantification of storage loss

Storage loss is usually the main impact for dams devoted to water storage as their benefit is quite proportional to the amount of water stored. With the bathymetric survey, the current amount of silt would be quantified and the rate of siltation would be determined. The only bathymetric survey carried out on the reservoir was done 22years ago. This survey would use that survey as initial survey and determine the silt build up in the reservoir and thereby estimate the storage loss for the first time since the construction of the dam in 1979.

1.3.2 Concepts of reservoir life

With reasonable levels of maintenance, the life of a dam will ultimately be terminated by sediment accumulation rather than structural obsolescence.

1.4 Research Innovations

May 2013 was 22 years since the first bathymetric survey was conducted on the Tono reservoir. No sediment dynamics of the Tono reservoir has been done since the studies in the early 90's. The spatial heterogeneity of land classes since the 90's has altered tremendously and has impacted on the reservoir. The simulation of alternative management practices to study how they impact on the reservoir will be determined and that will be the first time.

1.5 Research Outputs

The following are the research outputs:

1. Maps of DEMs for silt volume.
2. Maps of sediment yield and soil loss.

1.6 Outline of Thesis

The thesis consists of five chapters.

Chapter 1: Gives a general introduction and outlines the objectives and questions answered among others.

Chapter 2: Reviews other research work on modeling impact of land use change and erosion on water resources in general and with using GeoWEPP model in particular.

Chapter 3: Describes the research methods from pre-fieldwork, field data collection and post fieldwork. The materials used in the research are described in this section.

Chapter 4: Discusses the results obtained and gives synthesis of the research.

Chapter 5: Provides conclusions and recommendations for effective and sustainable management of the Tono reservoir in particular and water resources in general.

CHAPTER 2: LITERATURE REVIEW

2.0 Introduction

Excessive loading of fine sediments is a leading cause of impairment in rivers of the United States and many places around the world that have experienced significant disturbance from changes in land and water use (Naden, 2010; Palmer *et al*., 2000; USEPA, 2011., cited in Maalim *et al*., 2013). Significant gains in agricultural production have come at a cost of pervasive changes in hydrology and erosion (Montgomery, 2007; Trimble and Cross on, 2000 cited in Maalim *et al*., 2013). Over the past few decades, agricultural producers appear to have made improvements in tillage practices and runoff management, but the actual effectiveness of these improvements is difficult to quantify at the scale of large watersheds due to the complexity of the sediment routing system because improvements at the local scale can be buffered at larger scales (De Vente *et al*., 2007., cited in Maalim *et al*., 2013). While many challenges remain in attaining the goal of accurately predicting how local changes in a watershed affect sediment loads measured at the outlet of a large watershed (Smith *et al*., 2011 cited in Maalim *et al., 2013*), information gleaned from watershed hydrology-erosion models can be useful to guide management, policy, and restoration/rehabilitation.

2.1 Water Erosion and Catchment Soils

In a study of five small reservoir catchments (Dua, Doba, Zebilla, Kumpalgogo and Bugri) in the Upper East Region of Ghana, Amegashie *et al.,* (2012), indicated that soil loss through erosion reduces top soil depth, nutrient stocks and the water holding capacity of catchment soils. The catchment soils and reservoir sediments were sampled and analyzed for their bulk density and nutrient content. They observed that, the mean reduction in soil depth in the various catchments was 3.996±3.806 mm/y 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, and 16.84 to 72.07 for OC, N, P, K, Ca and Mg, respectively. The total amount of nutrient loss in kg/ha 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/y) 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 (Amegashie *et al.*, 2012).

2.2 Land Use Change and Water Resources

Land use/land cover (LULC) change is a dynamic and complex process that can be exacerbated by a number of human activities. Factors driving LULC change include an increase in human population and population response to economic opportunities (Lambin *et al.*, 2001. cited in Leh *et al.*, 2011). Despite the social and economic benefits of LULC change, this conversion of LULC usually has an unintended consequence on the natural environment. For example, LULC change has been shown to have negative effects on stream water quality (Zampella *et al.*, 2007; Tang *et al.*, 2005., cited in Leh *et al.*, 2011), quantity (White and Greer, 2006., cited in Leh *et al.*, 2011) and stream ecosystem health (Wang *et al.*, 2000; Wang *et al.*, 2001., cited in Leh *et al.*, 2011). Changing land use has also been shown to influence weather patterns (Stohlgren *et al.*, 1998., cited in Leh *et al.*, 2011) and the generation of stream flow (Bronstert *et al.*, 2002; Weng, 2001., cited in Leh *et al.*, 2011). Also, a number of studies have shown that increase in agricultural land use has direct consequences on sedimentation, nutrients and pesticides in streams (Osborne and Wiley, 1988; Soranno *et al*., 1996., cited in Leh *et al*., 2011).

Land cover in areas surrounding aquatic systems greatly transforms the hydrological cycle, because it influences storage patterns and water discharge (Richardson & McCarthy, 1994 cited in Ruiz-Luna and Berlanga-Robles 1999). The effect land-cover has on the interconnection and mobility of ecological processes within these areas is of great importance in maintaining biodiversity (Pearson *et al*., 1996; Keitt *et al*., 1997 cited in Ruiz-Luna and Berlanga-Robles 1999). Independent of the intrinsic transcendence of the wetlands, the patterns of cover and land use reflect the nature of interactions of societies with their physical environments (Campbell, 1996 cited in Ruiz-Luna and Berlanga-Robles 1999).

2.3 Erosion Models and Water Resources

Sediment delivery from agricultural fields is difficult to constrain for several reasons (Smith *et al*., 2011). First and foremost, the uplands cover a large spatial extent of heterogeneous human land and water management practices. Even very small errors over large spatial extents will result in gross over- or under-estimates of sediment delivery. Second, the relatively flat topography promotes storage within the landscape and dictates that sediment delivery is controlled by very subtle topographic features, many of which may not be identifiable even with aerial lidar data (average 18 cm vertical resolution, but likely worse in locations covered by dense vegetation during the lidar flight). For these reasons, simple point measurements of surface soil erosion generically scaled up to the entire watershed would be insufficient to constrain sediment delivery.

Land use heterogeneity overlain on terrain with subtle topographic changes also limits our ability to use first principles to model sediment delivery from agricultural fields at the watershed scale. Therefore, a model that combines physical processes of watershed hydrology with empirically-derived erosion relationships for soil erosion provides a useful approach to constrain sediment delivery from agricultural fields at the watershed scale (Smith *et al*., 2011).

Any model used for computing potential soil loss from an area must deal with a large number of parameters concerning vegetation, management, soil, topography and climate (Amore *et al*., 2004). Performance of a model depends upon the number of parameters it is considering for runoff and soil loss computation based on scientific theory. Performance of such model may not differ much on different scales. Topography and nature of rainfall are quite dominant parameters in generation of runoff and soil erosion particularly in hilly watersheds.

Erosion prediction models apply physics and mathematics to simulate real-world processes. Various types of computer models are used to simulate erosion processes on landscapes; empirical and process-based models.

2.4 The Empirical Models for Simulating Erosion Processes

The empirical model is the simplest and oldest computer model used, and is based on statistically significant relationships between model inputs and expected output derived from specific lab and field data. Empirical models are simple to use and understand, but are not valid for areas or conditions where data is not available. Thus they are highly limited in their application (Morgan and Quinton, 2001).

The Universal Soil Loss Equation (USLE) is one of empirical black box model and one of the simplest model for Erosion prediction, which estimates long-term average annual soil loss with acceptable accuracy. The USLE estimates soil loss per unit of area and takes into account the following parameters:

- rainfall-runoff erosivity,
- soil erodibility,
- topography,
- cover-management and
- support practices (Wischmeier and Smith, 1978 cited in FAO, 1996).

INTRINSIC LIMITATIONS OF THE USLE MODEL

- The model applies only to sheet erosion since the source of energy is rain; so it never applies to linear or mass erosion.
- The type of countryside: the model has been tested and verified in peneplain and hilly country with 1-20% slopes, and excludes young mountains, especially slopes steeper than 40%, where runoff is a greater source of energy than rain and where there are significant mass movements of earth.
- The type of rainfall: the relations between kinetic energy and rainfall intensity generally used in this model apply only to the American Great Plains, and not to mountainous regions although different sub-models can be developed for the index of rainfall erosivity, R.
- The model applies only for average data over 20 years and is not valid for individual storms.
- Lastly, a major limitation of the model is that it neglects certain interactions between factors in order to distinguish more easily the individual effect of each. For example, it does not take into account the effect on erosion

of slope combined with plant cover, nor the effect of soil type on the effect of slope.

Although these are negative aspects, the USLE has been used in simulations on basins with varying drainage area (Jain *et al*., 2010; Fistikoglu and Harmancioglu, 2002; Onyando *et al*., 2005; Pandey *et al*., 2007; Dabral *et al*., 2008; Ozcan *et al*., 2008), so that researchers can compare simulated soil loss with acceptable values for the same kinds of soil.

For application of the USLE to simulate soil erosion distribution on basins, it is necessary to utilize mapping and interpolation techniques in order to create a suitable database for soil erosion simulation. The database must include all necessary input for the model taking into account homogeneous cells as small as possible, thus allowing erosion to be characterized with a good resolution. Presently, USLE application with the support of Geographical Information System (GIS) and geostatistical techniques has received special attention of researchers, mainly in developing countries, such as Turkey, India and Thailand (Bhattarai and Dutta, 2007; Irvem *et al*.,2007; Pandey *et al*., 2007; Ozcan *et al*., 2008). All of these authors have demonstrated relevant potential of this approach as a soil management tool.

As reported by De Roo and Jetten (1999), the main reason for using a GIS is that the erosion process varies spatially and, thus, grid cells must be used so that this spatial variation can be taken into account.

According to the same researchers, another important consideration is the amount of data necessary for a great quantity of cells that is required for accurate representation of the basin. Since it is unfeasible to input data manually, GIS can be used to gather and access databases.

Ferro and Porto (2000) also implemented the SEDD in the ephemeral basin of Crepacuore stream, which drains to the Ionian Sea for evaluating the quantity of sediment that is transferred, in a given time interval, from eroding sources through the hillslope and the channel network to the basin outlet. The model is based on the Universal Soil Loss Equation (USLE), in which different expressions of the erosivity and topographic factors are considered, coupled with a relationship for evaluating the sediment delivery ratio (SDR) of each morphological unit. Then the SEDD is calibrated by sediment yield, rainfall and runoff measurements carried out, at annual and event scales, in three small Calabrian experimental basins. At event scale, the analysis showed that a good agreement between measured and calculated basin sediment yields can be obtained using the simple rainfall erosivity factor; the agreement is independent of the selected equations for estimating the topographic factors. The analysis developed at annual scale showed that the model reliability increases from the event scale to the annual scale. Finally, a Monte Carlo technique was used for evaluating the effects of the uncertainty of the model parameters on calculated sediment yield (Ferro and Porto, 2000).

In Ghana only one literature was found implementing the use of USLE (Owusu, 2012). The researcher developed a PCRaster GIS soil loss risk maps for the Densu basin in the coastal watershed in Ghana using models of Universal Soil Loss Equation (USLE) and Revised Universal Soil Loss Equation (RUSLE). Soil loss factors such as rainfall erosivity, soil erodibility, slope and slope length were also mapped for the basin. The model predicted average, minimum and maximum – annual soil loss rates of 2.2, 0, and 63 t/ha/y, respectively, indicating that some areas in the basin are above tolerance level of 5.0 t/ha/yr. The total soil loss was 756,507 tonnes per hectare per year. Among the soil types, Lixisols experienced the highest soil loss of 402,080 t/ha/yr with

Plinthosols experiencing the lowest soil loss of 64 t/ha/yr. Among the administrative districts in the basin Suhum, Kraboa and Coaltar experienced the highest absolute soil loss of 216,957 t/ha/yr while Fanteakwa experienced the highest average soil loss of 4.5 t/ha/yr (Owusu, 2012).

Other empirical models for estimating soil loss are Soil Loss Estimation Model for Southern Africa (SLEMSA) (Elwell 1981; Elwell and Stocking 1982 cited in FAO, 1996) and a model to estimate change developed in Indonesia, called INDEROSI (Gnagey 1991 cited in FAO, 1996). Table1 summarizes some other empirical models.

Table 1: Empirical Models

Model	Reference
Musgrave Equation	Musgrave (1947) cited in Lane *et al.*, 1988
Equation (MUSLE) Sediment	Renfro (1975) cited in Lane *et al.*, 1988
Delivery Ratio Method	Dendy and Boltan (1976) cited in Lane *et al.*, 1988
Soil Loss Estimation Model for South Africa (SLEMSA)	Elwell (1978) cited in FAO, 1996
Flaxman Method	Flaxman (1972) cited in Lane *et al.*, 1988
Pacific Southwest Interagency Committee (PSIAC) Method	Pacific Southwest Interagency Committee (1968) cited in Lane *et al.*, 1988
Dendy-Boltan Method	Dendy and Bolton (1976) cited in Lane *et al.*, 1988

2.5 The Process-based Models for simulating erosion processes

Many people prefer process-based models, which attempt to simulate significant processes in a real-life system, and are based on laws and theories of physical processes. The process-based models are easily applied to a large variety of landscapes and situations, but they are very complex and parameter intensive, which makes the isolation of problems within the model difficult. Process-based models may be spatially averaged, or spatially distributed.

Spatially averaged models lump together components within a landscape into single homogenous units and follow one-dimensional patterns. These models are relatively easy to use and can be very effective for simulating erosion-related processes on simple landscapes. However, because landscapes are inherently complex and follow two-dimensional patterns, these models only perform an adequate job of simulating erosion processes.

In contrast, spatially distributed models represent the spatial variability of landscape components, and can thus be used to simulate soil erosion on complex slope, soil, and land-cover patterns.

The European Soil Erosion Model (EUROSEM) is a dynamic distributed model, able to simulate sediment transport, erosion and deposition over the land surface by rill and interill processes in single storms for both individual fields and small catchments. Model output includes total runoff, total soil loss, the storm hydrograph and storm sediment graph.

Compared with other erosion models, EUROSEM has explicit simulation of interill and rill flow; plant cover effects on interception and rainfall energy; rock fragment (stoniness) effects on infiltration, flow velocity and splash erosion; and changes in the shape and size of rill channels as a result of erosion and deposition. The transport capacity of runoff is modelled using relationships based on over 500 experimental observations of shallow surface flows. EUROSEM can be applied to smooth slope planes without rills, rilled surfaces and surfaces with furrows (Morgan *et al.*; 1998).

Several physically-based models have been developed in order to quantify erosion in basins, such as WEPP (Flanagan and Nearing, 1995; cited in Flanagan *et al*., 2007), LISEM (De Roo and Jetten, 1999), and SWAT (Arnold *et al*., 1998; cited in Gassman *et al.*, 2007).

The WEPP model (Water Erosion Prediction Project) is capable of simulating climate, plant growth and residue decomposition, tillage, infiltration, water balance, surface runoff, soil loss, deposition, and sediment delivery for different time steps (Flanagan and Nearing, 1995 cited in Gassman *et al.*, 2007).

The Limburg Soil Erosion Model (LISEM) is a physically-based model that was written in a raster Geographical Information System, and allows simulating the hydrology and sediment transport during and immediately after a single rainfall event in catchments (De Roo and Jetten, 1999). According to De Roo and Jetten, (1999) the processes incorporated in the LISEM model are rainfall, interception, surface storage in micro-depressions, infiltration, vertical movement of water in the soil, overland flow, channel flow, detachment by rainfall and through fall, detachment by overland flow, and transport capacity of the flow. In addition, De Roo and Jetten, (1999) point out that it is able to simulate the influence of machine tracks and small paved roads on the hydrological and soil erosion processes. As a disadvantage, De Roo and Jetten, (1999) reported that the LISEM model has been used so far only in small catchments.

The Soil and Water Assessment Tool (SWAT) is a physically based, continuous-time model and was developed to simulate the impact of management on water, sediment, and agricultural chemical yields at a basin-scale (Gassman *et al.*, 2007). The same researchers report that the main model components are weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management. An ArcGIS–ArcView extension, named as ArcSWAT, was created for the SWAT model.

The three models discussed above have the following disadvantages:

- need extensive data sets as input and many calibration parameters;
- require either complex laboratory analyses or hard and expensive field data collection, which may be unfeasible to use in many developing countries; and
- in spite of having some calibration parameters, the models (except SWAT) don't have an optimization method embedded in the software.

Some strength of these models can be emphasized:

- they are physically based models, basic processes are incorporated in them; and
- they take into account spatial variability of input and output, thus better.

The Water Erosion Prediction Project (WEPP) is a well-documented process-based erosion prediction model originally designed for the management of sediment on agricultural areas. WEPP was developed as a replacement for the USLE model to provide users with a model that;

- could be applied to a variety of situations,
- could predict erosion losses from both single storm events and long-term averages,
- estimate erosion and deposition on both hill-slopes and watersheds,
- estimate deposition in small impoundments, and

- is user-friendly for field technicians (Flanagan *et al*., 2001 cited in Gassman *et al.*, 2007).

There has been a great effort to calibrate WEPP parameters for agricultural fields (Zhang *et al*., 1995a; Zhang *et al*., 1995b; Lienbow *et al*., 1990) and rangelands (Savabi *et al*., 1995; Nearing *et al*., 1989), and a moderate effort to calibrate WEPP parameters for forests (Elliot and Hall, 1997).

Performance of the WEPP model was compared with the ANSWERS (Bhuyan *et al*., 2002), EPIC (Bhuyan *et al*., 2002), and SWAT (Shen *et al*., 2009). They found that the performance of the WEPP model was at par with ANSWERS and better than EPIC and SWAT in simulating different management scenario for reduction of sediment yield. However, for Ghana conditions only one study could be found on use of the WEPP (Atakora *et al.*, 2013) in literature. They implemented WEPP model at a 'Sawah' technology experimental site located in the Ashanti Region of Ghana to simulate sediment transport to the rice fields. A digital elevation model (DEM) was created from ground survey and used to select the various plots (hillslopes) and to select slope input parameters. Four plots (hillslopes) were selected for the model simulation. Data on local daily values of rainfall and on minimum and maximum temperatures were used to set a CLIGEN model station file to determine climate input parameters for the model. Rainfall characteristics (erosivity and distribution) were analysed. Soil erodibility was also determined. Soil and crop management input parameters required by the model were identified and/or estimated from field measurements and secondary sources. The model was run for two management scenarios: fallow and continuous maize systems. The results of the simulation showed that 2.9 to 3.9 and 6.8 to 10.2 t/ha/year of sediments were eroded from upper catchment to valley bottom under fallow system and maize, respectively. The range of values for runoff produced under fallow was 17.4 to 40 mm whereas that under maize system was 158.7 to 233.62 mm. The study has shown that land use system in the study area has a great influence on geological fertilization. In addition, the valley bottom where rice is produced under the Sawah system is enriched with organic matter from upslope (Atakora *et al.*, 2013). Other process based models are (Table 2);

Table 2: Process based Models

Model	Reference
Erosion Kinematic Wave Models	Hjelmfelt, Piest and Saxton (1975), Shirley and Lane (1978), Singh and Regl (1983) cited in Lane *et al.*, 1988.
Quasi-Steady State	Foster, Meyer and Onstad (1977) cited in Lane *et al.*, 1988
Chemical Runoff and Erosion from Agricultural Management Systems (CREAMS)	Knisel and Douglas-Mankin (2012)
Water Erosion Prediction Project (WEPP)	Laflen *et al* (1991) cited in Flanagan and Livingston (2007)
European Soil Erosion Model (EUROSEM)	Morgan *et al.*, (1998)

2.6 Conceptual Models

Conceptual models are a mixture of empirical and physically based models (Table 3) and their application is therefore more applicable to answer general questions. These models usually incorporate general descriptions of catchment processes without specifying process interactions that would require very detailed catchment information. These models therefore provide an indication of quantitative and qualitative processes within a watershed. Table 3, summarizes conceptual models and the literature.

Table 3: Conceptual Models

Model	Reference
Sediment Concentration Graph	Johnson (1943) cited in Lane *et al.*, 1988
Renard-Laursen Model	Renard and Laursen (1975) cited in Lane *et al.*, 1988
Unit Sediment Graph	Rendon-Herrero (1978) cited in Lane *et al.*, 1988
Instantaneous Unit Sediment Graph	Williams (1978) cited in Lane *et al.*, 1988
Sediment Routing Model	Williams and Hann (1978) cited in Lane *et al.*, 1988
Discrete Dynamic Models	Sharma and Dickinson (1979) cited in Lane *et al.*, 1988
Agricultural Catchment Research Unit (ACRU)	Schulze (1989) cited in Tarboton and Schulze 1991
Hydrologic Simulation Program, Fortran	Bicknel *et al.*, (1996)

Commonly used erosion and soil erosion models developed in the last decades tend to shift in their methodology from empirical approaches in the 1970s to physically based and conceptual approaches in the present (Table 4).

Table 4: Erosion and Soil Erosion Models

	Model	Reference
USLE	Universal Soil Loss Equation	Wischmeier and Smith (1978) cited in Lane *et al.*, 1988
RUSLE	Revised USLE	Renard *et al.*, 1991
dUSLE	Differentiated USLE	Flacke *et al.*, 1990
CREAMS	Chemical runoff and erosion from agriculture management systems	Knisel and Douglas-Mankin (2012)
ANSWERS	Areal Nonpoint Source Watershed Environment Response System	Bhuyan *et al.*, (2002)
WEPP	Water Erosion Prediction Project	Laflen *et al* (1991) cited in Flanagan and Livingston (2007)
EUROSEM	European Soil Erosion Model	Morgan *et al.*, (1998)
LISEM	Limburg Soil Erosion Model	De Roo *et al.*, 1996 cited in Gassman *et al.*, 2007

One limitation of the WEPP model is that the user must manually create landscapes by estimating parameters such as land-cover, soil type, and slope for an entire hillslope. Because these parameters can vary dramatically over relatively small areas, it is often necessary to account for these variations in order to accurately predict erosion and deposition rates.

In response, Renschler (2003) developed GeoWEPP, a geospatial interface for WEPP that operates within ArcGIS. GeoWEPP uses a Digital Elevation Model (DEM) supplied by the user to create channels and sub-watersheds, runs the WEPP model on individual raster cells containing soil, land-cover, and elevation information, and outputs the data both as maps and as estimated runoff volume and sediment yield for each sub-watershed. This allows the user the capability to pinpoint specific areas of erosion and depositions within the watershed, along with the ability to predict how much runoff and sediment to expect from a watershed during a rainstorm.

No literature has so far been found on the use of the GeoWEPP model in Ghana. Also, no literature has been found both locally and internationally where a holistic approach has been adopted, incorporating bathymetric survey, impact of land use change and finally modeling efforts using GeoWEPP to study sediment dynamics in a watershed. This research has adopted all these methodologies to do a holistic study on the Tono Irrigation Project in the Kassena Nankana District of the Upper East Region of Ghana.

CHAPTER 3: MATERIALS AND METHOD

3.1 General Characteristics of the Study Area

3.1.1 Location

The Tono Irrigation project with watershed area of about 650km^2, is located between latitude 10°56' and 10°51' North and longitude 1°8' and 1°12' West in the Kasena Nankana District of the Upper East Region of Ghana. It is one of two irrigation projects under the management of the Irrigation Company of Upper Regions (ICOUR). The project is one of twenty two irrigation projects constructed by the Ghana Irrigation Development Authority in Ghana. The dam is one of the largest agricultural dams in West Africa.

The Kasena-Nankana District lies within the Guinea Savannah woodlands. The district falls approximately between latitude 11°10' and 10°3' North and longitude 1°West. It is one of the eight (8) districts in the Upper East Region of the Republic of Ghana. The District has a total land area of about 1,674 sq.km and stretches about 55km North-South and 53km East-West. The District shares boundaries to the North with Burkina Faso, to the East with Bongo and Bolgatanga Districts, West with the Builsa District and Sissala District (in the Upper West Region) and South with West Mamprusi District (in the Northern Region). The District has a total of 216 communities.

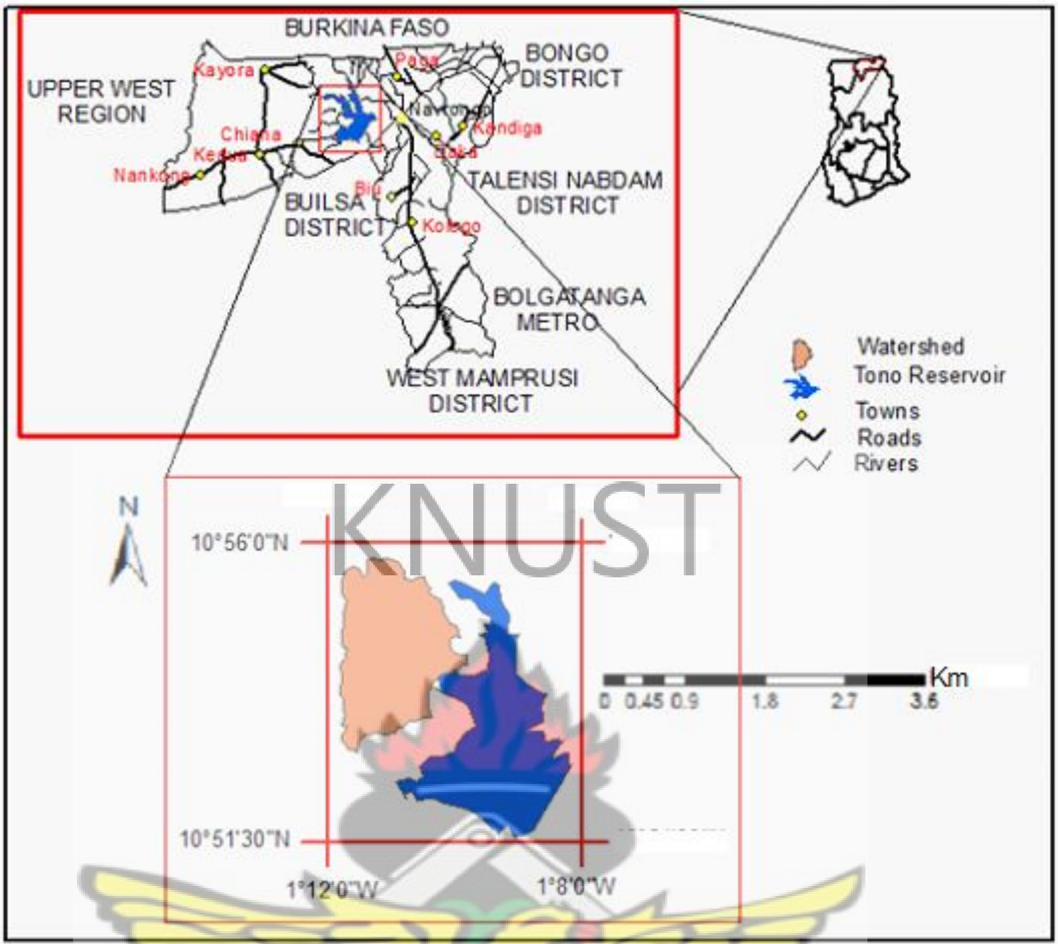


Figure 1: A Map Showing Study Area in Kassena Nankana District in the Upper East Region of Ghana

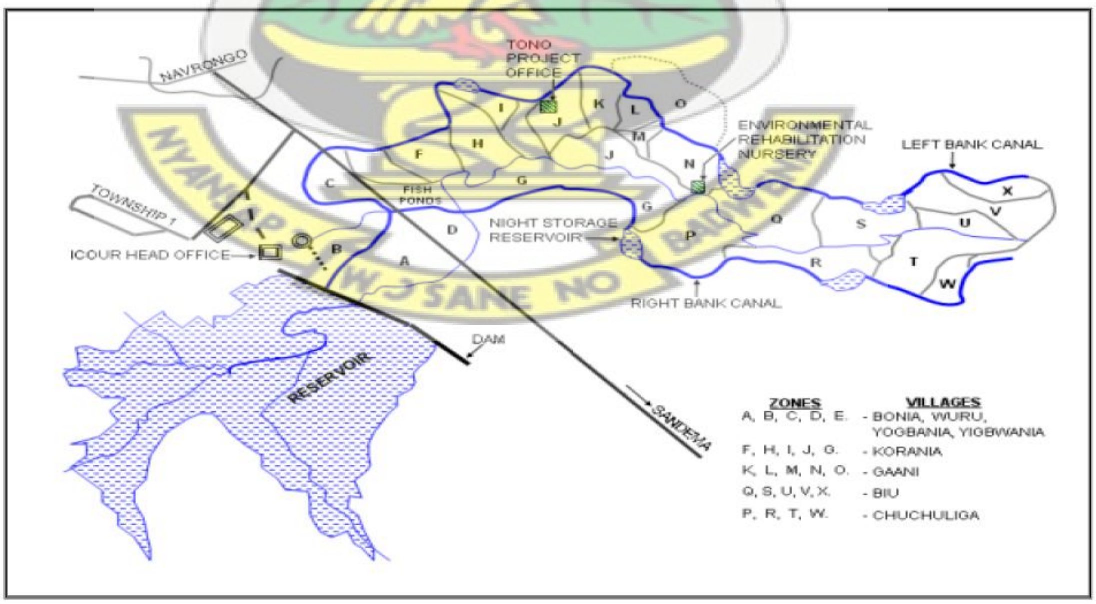


Figure 2: A Map of Tono Irrigation Project Site

Source: DERF Networks, (2010) cited in Okrah (2010)

3.1.2 Geology and soil

The geology of the district comprises mainly of granite and shale, although the rock formations are actually of a diverse nature (Ghana Districts, Kassena Nankana District Information).

Two main types of soil within the District are Lixisols and Fluvisols. The northern and eastern parts of the district are covered by the Lixisols, while the rest of the District has Fluvisols (Ghana Districts, Kassena Nankana District Information).

The Lixisols are porous, well drained, sandy and sandy loam, mildly acidic and interspersed with patches of black or dark-grey clay soils. This soil type is suitable for cultivation and hence accounts for the arable land sites including most parts of the Tono Irrigation Project sites where both rainy and dry season farming activities are concentrated. The Fluvisols are developed mainly over shale and granite and covers approximately 60 per cent of the District's land area (Ghana Districts, Kassena Nankana District Information).

Due to the underlying rock type (granite), they become waterlogged during the rainy season and dry out during the dry season, thus causing cemented layers of iron-stone (hard pan), which makes cultivation difficult.

3.1.3 Topography & drainage

The topography is low-lying with an average height of 100 meters above sea level (Ghana Districts, Kassena Nankana District Information).

The landscape is generally undulating with isolated hills rising up to about 300 metres in the western parts of the District. Notable among these hills include Fie (280 metres), Busono (350 metres) and Zambao (360 metres) (Ghana Districts, Kassena Nankana District Information).

The drainage system of the District is constituted mainly around the tributaries of the Sissili River – Asibelika, Afumbeli, Bukpegi and Beeyi (Ghana Districts, Kassena Nankana District Information).

A tributary of the Asibelika River (Tono River) has been dammed to provide irrigation facilities, which is of great economic importance to the entire District. There are some few dugouts and ponds, which are used for livestock, crop farming and domestic purposes in the Districts.

3.1.4 Climate & vegetation

The vegetation of the study area is of the Guinea and savannah type. The study area comprise of open savannah with fire-swept grassland and deciduous trees.

Some of the most densely vegetated parts of the study district can be found along river basins and forest reserves. Examples are the Sissili and Asibelika basins and Kologo and Naaga forest reserves. The region is characterized by a deciduous type of forest in which trees shed off their leaves during the dry season. However, the activities of man over the years have affected the original (virgin) vegetation cover. Common trees found are *Parkia biglobosa (*dawadawa), *Adansonia digitata (*baobab), *Butryospermum parkii* (sheanut) and *Mangifera indica (*mangos). The climate conditions of the study district are characterized by the dry and rainy seasons, which are influenced mainly by two (2) Air Masses – the North-East Trade winds (Harmattan) and the South-Westerly (Tropical Maritime). The Harmattan which spans November through to April the following year is usually dry and dusty as it originates from the Sahara Desert. During such periods, rainfall is virtually absent due to low relative humidity, which rarely exceeds 20 percent and low vapor pressure less than 10 mb.

Day temperatures are high recording 42° C (especially February and March) and night temperatures are as low as 18° C. The study district experiences the Tropical Maritime Air Mass between May and October. This brings rainfall averaging 950/mm per annum.

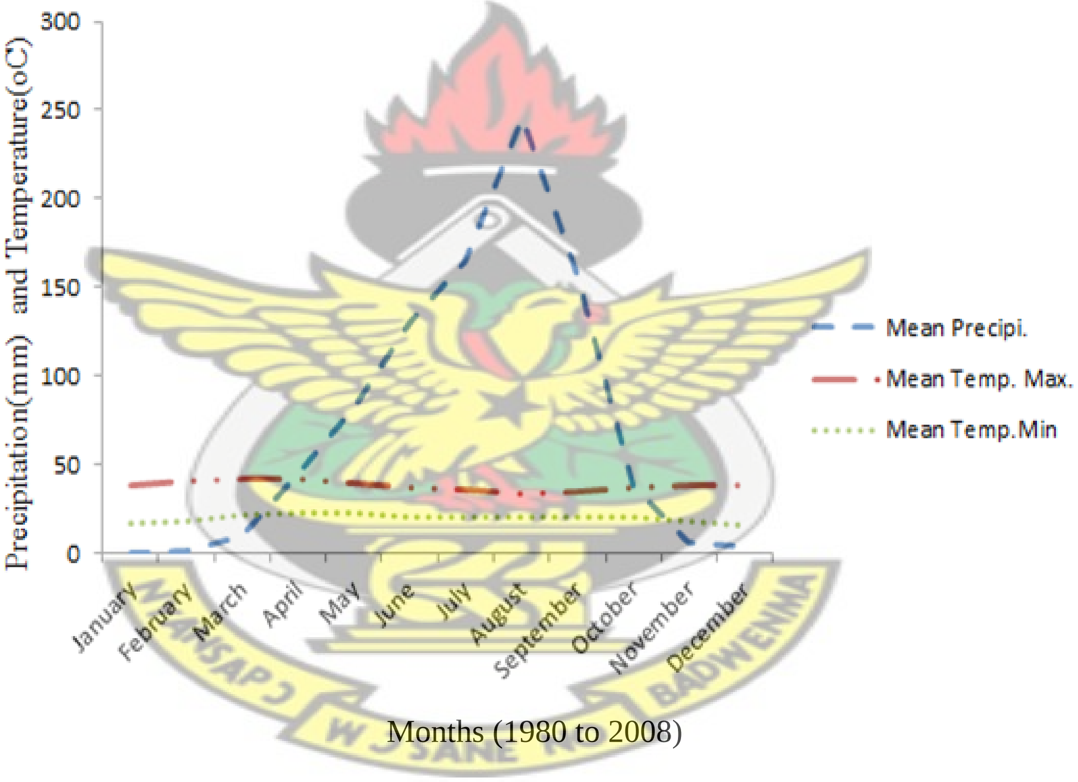


Figure 3: Monthly mean (1980 – 2008) precipitation (mm), temperature (Maximum and Minimum) °C from WRRI report (1996)

3.1.5 The Reservoir

The reservoir is 1800 hectares in area and 93 million cubic meters in capacity. (WRRI, 1996). The catchment area is about 650Km^2. The construction of the project started in 1975 and completed in 1985. The scheme is managed by the Irrigation Company of Upper Region (ICOUR). The primary purpose of the Tono project is to provide water storage for supplemental irrigation of farmlands for the inhabitants of the Kasena Nankana District of the Upper East Region. It also provides flood control, recreation, fish and wildlife benefits.

Table 5: Tono Catchment Characteristics

GENERAL INFORMATION	**TONO**
Catchment Area	650 Km^2
Reservoir Area	18.6 Km^2
Volume	92.6 X 10^6 m^3
Gross Project Area	3860 hectares

Source: Adapted from Gordon, (2006) cited in Okrah, (2010)

Figure 4: Aerial image of the Tono Reservoir

The water level in the Tono reservoir is also fluctuating and this has an influence both on the amount of water that would often be available for irrigation and also for other purposes. From 1983 to 1987, there has been some drastic trend in the water levels in the reservoir. See graphs in Figure 5.

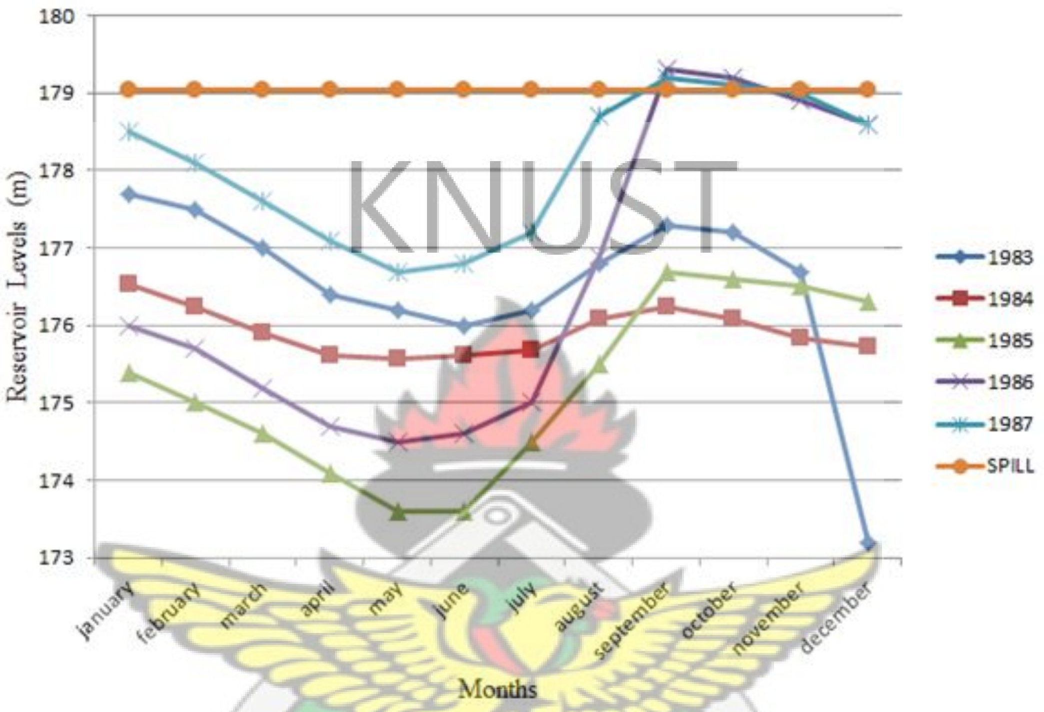


Figure 5: Reservoir Levels (1983-1987) Extracted from the WRRI Report

3.2 Bathymetric Survey

Dams have the function to store rainfall and runoff water from the catchment and serve as water storage for domestic use, irrigation, and stock watering. At the same time, they are potential sinks for upstream sediments. Soil accumulating in the reservoirs can lead to decrease in water storage capacity. Small and medium reservoirs in particular are affected by these storage losses as the maximum water depth is often only a few meters and an accumulated sediment layer of a few decimeters at the bottom of the reservoir causes a comparatively large reduction in water volume. Estimates of siltation rates in small reservoirs can be obtained from several methods:

- indirectly by measurements of suspended sediment fluxes, sediment traps or runoff/sediment yield estimations and
- directly by bathymetric surveys or sediment coring of deposited bottom sediments.

3.2.1 Historical bathymetry

The construction of the Tono reservoir was completed in 1985.The first bathymetric survey was conducted in 1991 (WRRI, 1996). A field survey on the bank of the reservoir was carried out to pick ground control points using a handheld Global Positioning System (GPS). A point shape file was created in ArcCatalogue and assigned the coordinate system of the study area; Universal Transverse Mercator Zone 30 (UTM zone 30) systems based on the World Geodetic System 1984 (WGS84) Datum in meters. The scanned existing bathymetric map was scanned and added to ArcMap and georeferenced (image to map) by entering the ground control coordinates acquired during the field survey. The points on the georeferenced map were digitized on-screen, using the “heads-up” method or softcopy digitizing (Figure 6).

This data was then processed using ArcGIS 9.3 to produce a modeled surface of the historical reservoir bottom.

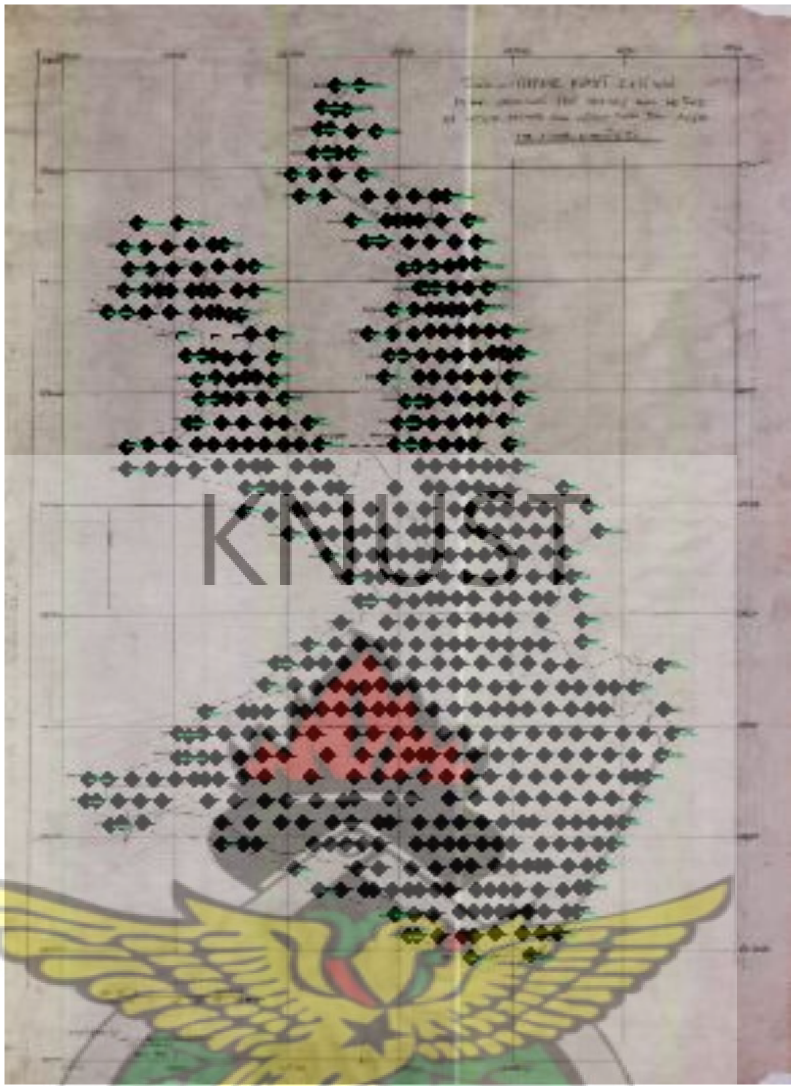


Figure 6: Digitized existing bathymetric map

3.2.2 Bathymetric data collection

The total number of digitized points on the map was 450. However 183 points were selected for this study. The selection was strategically done such that points were approximately equidistant to each other and covered almost the entire reservoir area. The means of transport on the water was a canoe. The instruments for the survey were

- metal load attached to a string (line sounding equipment/lead line),
- a handheld GPS and
- a tape measure.

The coordinates of the desired locations were loaded onto the handheld GPS. While aboard the canoe, the handheld GPS was used for navigation to the desired point. At the point, the canoe is stabilised. The metal load and string is lowered into the water until it touches the bed of the water. At that point, the measurement on the string was noticed and recorded. The same procedure was repeated to measure the depths of water to reservoir bed for all the 183 points. The level of the water was recorded and used as benchmark to compute the new reduced levels of the reservoir bed. The reduced levels obtained from this operation was used to compute the volume of silt in the reservoir.

3.2.3 Mean pool level adjustments

The bathymetric data collected presented measurements based upon the distance between the surface of the water in the reservoir and the top of the water-sediment interface. Due to fluctuations in the reservoir level, the bathymetric data was adjusted to a known reference level using water level measurements recorded by a gauge located in the dam and operated by the management of the Tono project. The reservoir is 179.05 M above the mean sea level. Therefore all depths were adjusted to this level. (Table 6)

Table 6: Mean Pool Level Recordings and Adjustments

	MEAN POOL LEVEL RECORDINGS AND ADJUSTMENTS				
	MEAN SEA LEVEL (Meters)				
	TIME(LOCAL)			DAILY	DEPTH
DATE	0800	1200	1600	AVERAGE	ADJUSTMENT (Meters)
9 Feb. 2013	176.20	176.10	176.00	176.10	2.95
16 Feb. 2013	175.97	175.95	175.92	175.95	3.10
9 Mar. 2013	176.96	176.93	176.93	176.94	2.11
10 Mar. 2013	176.98	176.94	176.90	176.94	2.11
11 Mar. 2013	176.94	176.94	176.94	176.94	2.11

3.2.4 Sediment volume

The study consists of two components. The first was measuring and modeling the current bathymetry of the reservoir. The second phase determined sediment thickness and sediment accumulation rates in Tono reservoir. Historical survey were digitized and checked for accuracy. Sediment thickness map were generated by subtracting the current bathymetry from the historical bathymetry.

3.2.5 Development of raster surfaces

The raw reservoir bed topographic point (x,y,z) data of both the existing and new bathymetric survey were saved in Exel as csv comma delimited file. These were each then imported into ArcGIS 9.3 data frame. The points were now projected into UTM zone 30 coordinate system; the coordinate system of the study area. The layers, each of the projected csv files was converted into shapefiles. From each of these shapefiles, a TIN (Triangular Irregular Network) surface was developed. The TIN surfaces were each, edited, modified and the updated reservoir bed topographic point data were exported into a new .csv file. This new .csv files were used to develop a new TIN surface that represents the boundary extent of the reservoir without spikes. From the new TINs generated, digital elevation models (DEMs) were developed for each of the surfaces.

The new bathymetric map was superimposed on the existing and the silt thickness for each point was extracted.

3.2.6 Volume of sediment

A zero grid was formed and cut/fill calculation done with the sediment thickness grid using the Spatial Analyst Extention in ArcMap. From this operation, the volume of sediment in the reservoir was obtained.

3.3 Land Use Change Detection Study of the Tono Watershed

Remote Sensing data of the Tono Irrigation watershed were aquired for the purpose of determining land use / cover change by means of supervised classification of 1991, 2005 and 2013 Landsat images over the period of study.

3.3.1 Remote Sensing data used

- Landsat 8 and
- Landsat 7

Table 7: Landsat 8 Data

Spectral bands	Wavelength (micrometers)	Resolution (meters)
Band 1 – Coastal/Aerosol	0.43 – 0.45	30
Band 2 – Blue	0.45 – 0.51	30
Band 3 – Green	0.53 – 0.59	30
Band 4 – Red	0.64 – 0.67	30
Band 5 – Near IR	0.85 – 0.88	30
Band 6 – SWIR 1	1.57 – 1.65	30
Band 7 – SWIR 1	2.11 – 2.29	30
Band 8 – Panchromatic	0.50 – 0.68	15
Band 9 – Cirrus	1.36 – 1.38	30
Band 10 – TIRS 1	10.60 – 11.19	100
Band 11 – TIRS 2	11.50 – 12.51	100

Table 8: Landsat 7 Data

Spectral bands	Wavelength (micrometers)	Resolution (meters)
Band 1 – Blue	0.45 – 0.52	30
Band 2 – Green	0.52 – 0.60	30
Band 3 – Red	0.63 – 0.69	30
Band 4 – NIR	0.77 – 0.90	30
Band 5 – SWIR 1	1.55 – 1.75	30
Band 6 – TIR	10.40 – 12.50	30/60
Band 7 – SWIR 2	2.09 – 2.35	30
Band 8 – Panchromatic	0.52 – 0.90	15

Table 9: Satellite data used in this study

System	Data Acquisition Date	Path/Row	Comments/Quality
Landsat 8	5th November, 2013	194/53	High Quality, No cloud cover
Landsat 7	7th November, 2005	194/53	High Quality, No cloud cover
Landsat 7	7th November, 1991	194/53	High Quality, No cloud cover

3.3.2 Land use classification

Land use classification in this study was performed by digital image classification. Digital image classification is defined as the process of sorting all the image pixels into a finite number of classes or categories of data. The categorization is based on the data file values of individual pixels and it follows a set of criteria. Two major approaches are generally known: supervised and unsupervised classification. In this study Landsat 8 and Landsat 7 data sets were used for digital image classification and visual interpretation in terms of Land Use Classification.

Bands were combined and composited in ArcMap, clipped to the study area and opened in ENVI 4.8 for classification using the National Remote Sensing Agency (NRSA) land use classification scheme of 1995 (Table 10)

Table 10: Landuse/Land cover Classification Scheme

SNo.	LEVEL – I	LEVEL – II
1.	Built-up Land	• Towns / Cities • Villages
2.	Agricultural Land	• Crop Land • Fallow • Plantation
3.	Forest	• Evergreen/Semi-evergreen • Deciduous (Moist & Dry) • Scrub Forest • Forest Blank • Forest Plantations • Mangrove
4.	Wastelands	• Salt Affected Land • Waterlogged Land • Marshy/Swampy Land • Gullied/Ravenous Land • Land with Scrub • Land without Scrub • Sandy area (Coastal and desertic) • Mining/Industrial Wasteland • Barren Rocky/Stony Waste/Sheet Rock Area
5.	Water Bodies	• River/Stream • Canals • Lake/Reservoirs/Tank
6.	Others	• Shifting Cultivation • Grassland/Grazing land

SOURCE: NRSA (1995)

In ENVI 4.8, Regions of Interest (ROI) (Figure 7) were created on the image. Regions of interest (ROIs) are portions of images, either selected graphically or selected by other means such as thresholding. The regions can be irregularly-shaped and are typically used to extract statistics for classification, masking, and other operations. (ENVI Tutorials, 1997)

Figure 7: Typical Illustration of Landsat image with Regions of Interest (ROI) selected to enable Supervised Classification

In this study, ROIs were graphically selected and used to effect supervised classification of 1991, 2005 and 2013 Landsat images by Maximum Likelihood method in ENVI 4.8 software.

The classified images were added to ArcMap 10.1 (Figures 8, 9, 10). To be able to compute the statistics of the output maps with some degree of certainty, accuracy assessment was performed.

3.3.3 Accuracy assessment

Accuracy Assessments are performed on classified images to determine how well the classification process accomplished the task. Accuracy Assessments are performed on unsupervised and supervised classification methods. An accuracy assessment compares the classified image to an image which is assumed to be correct (such as an aerial photo).

This task is accomplished by compiling an error matrix. An error matrix is a table of values that compares the value assigned during the classification process to the actual value from an aerial photo. These are compared on a point-by-point basis. A random set of points is generated for the region covered by the area. Then using the aerial photos, the value for each point is identified. Then, these same random points are used to identify each point's known value in the classified image. The error matrix table is completed by comparing these two values.

3.3.4 Generating random points

25 random points were generated on the classified image of the 2013 Landsat image in ArcMap 10.1. These random points were exported to an aerial image of the study area acquired on 18th June, 2013. A point by point comparison was done of the exported points on the aerial image and the results added to the attribute table of the 2013 classified image. The raster values corresponding to the classified image were then extracted (Table 11) and this formed the basis for a point-by-point comparison of the Aerial photo to the raster values (Table 12)

Table 11: Table for performance of Accuracy Analysis

Table

2013 Accuracy Assessment Table

FID	Shape *	Id	Aerial	RASTERVALU
0	Point	0	1	1
1	Point	0	3	2
2	Point	0	3	3
3	Point	0	1	1
4	Point	0	3	2
5	Point	0	3	3
6	Point	0	4	4
7	Point	0	3	3
8	Point	0	3	2
9	Point	0	4	4
10	Point	0	1	1
11	Point	0	1	1
12	Point	0	4	4
13	Point	0	4	1
14	Point	0	3	3
15	Point	0	4	4
16	Point	0	3	3
17	Point	0	1	1
18	Point	0	4	4
19	Point	0	4	4
20	Point	0	4	4
21	Point	0	4	4
22	Point	0	4	4
23	Point	0	4	4
24	Point	0	2	2

From Table 11, the error matrix was compiled thus:

Table 12: Point-by-point matching of classified to aerial image

Aerial / RasterValue	Water (1)	Built-up (2)	Shrubs (3)	Bare-Land (4)	
Water (1)	5	0	0	0	**5**
Built-up (2)	0	1	0	0	**1**
Shrubs (3)	0	3	5	0	**8**
Bare-Land (4)	1	0	0	10	**11**
	6	**3**	**5**	**10**	21

3.3.5 Calculation of overal accuracy

Overall accuracy is the percentage of random points that are the same in both images.

For our matrix above, that is 21 points (5 water, 1 built-up, 5 shrubs and 10 bareland).

We have a total of 25 random points, so our overall accuracy is 21/25 or 84%.

3.3.6 Calculation of Cohen's Kappa

Kappa provides insight into the classification scheme. It helps to establish whether or not we achieved results better than we would have achieved strictly by chance. The formula for kappa is:

$$\text{Kappa} = \frac{Observed - Expected}{1 - Expected} \quad \text{----------------------- [1]}$$

Observed is overall accuracy. Expected is calculated from the rows and column totals (Table 13)

Table 13: Product of Rows and Columns

Aerial / RasterValue	Water Column	Built-up Column	Shrubs Column	Bare-Land Column
Water Row	5 x 6 = 30	5 x 3 = 15	5 x 5 = 25	5 x 10 = 50
Built-up Row	1 x 6 = 6	1 x 3 = 3	1 x 5 = 5	1 x 10 = 10
Shrubs Row	8 x 6 = 48	8 x 3 = 24	8 x 5 = 40	8 x 10 = 80
Bare-Land Row	11 x 6 = 66	11 x 3 = 33	11 x 5 = 55	11 x 10 = 110

The highlighted is used to calculate the product matrix.

What would be expected based on chance is given by the formula:

Expected outcome based on chance =

$$\frac{Product\ Matrix}{Cumulative\ Sum\ of\ Product\ Matrix}$$ ---------------------------------[2]

The product matrix is obtained from the sum of the diagonals as;

Product Matrix =

30 + 3 + 40 + 110 =

183

The cumulative sum of Product Matrix =

30 + 15 + 25 + 50 + 6 + 3 + 5 + 10 + 48 + 24 + 40 + 80 + 66 + 33 + 55 + 110 =

600

So expected outcome based on chance =

$$\frac{183}{600} = 30.5\%$$

Therefore Kappa is;

Kappa = $$\frac{0.84-0.305}{1-0.305} = 77\%$$

This means that the classification done is 77% better than would have occurred strictly by chance.

There were no aerial images to facilitate accuracy assessment on the 1991 and 2005 classified images and so the 2013 results was deemed a sufficient basis for accepting the result of the classification for the 2013 and also the 1991 and 2005.

In view of this, the percent area were computed of all three classified images in ArcMap 10.1 (figures 8, 9, 10)

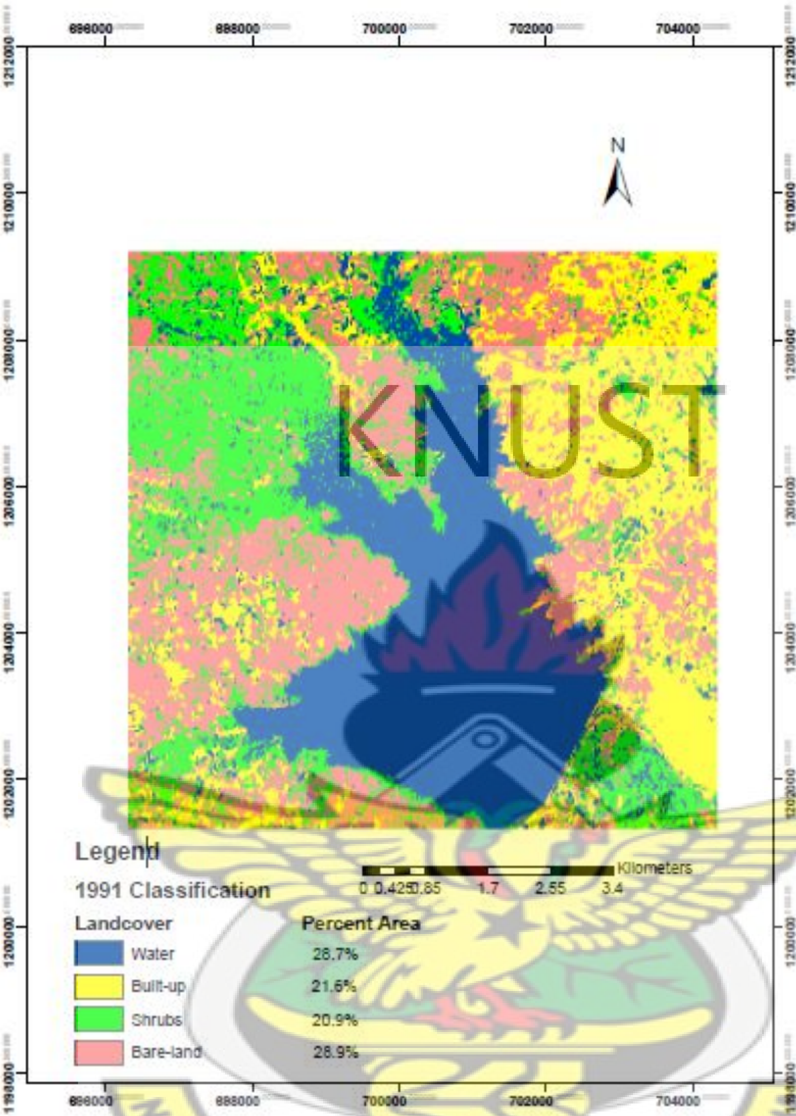


Figure 8:1991 Classified Map based on 1991 Landsat image

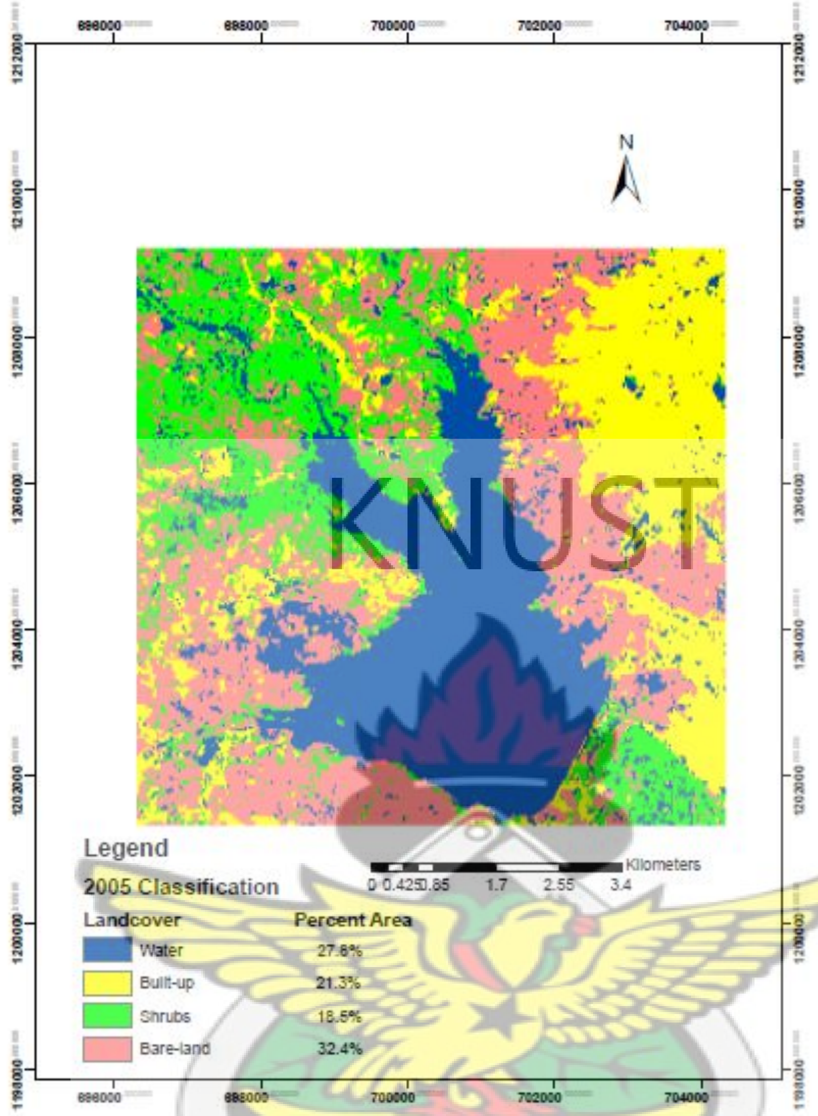


Figure 9:2005 Classified Map based on 2005 Landsat image

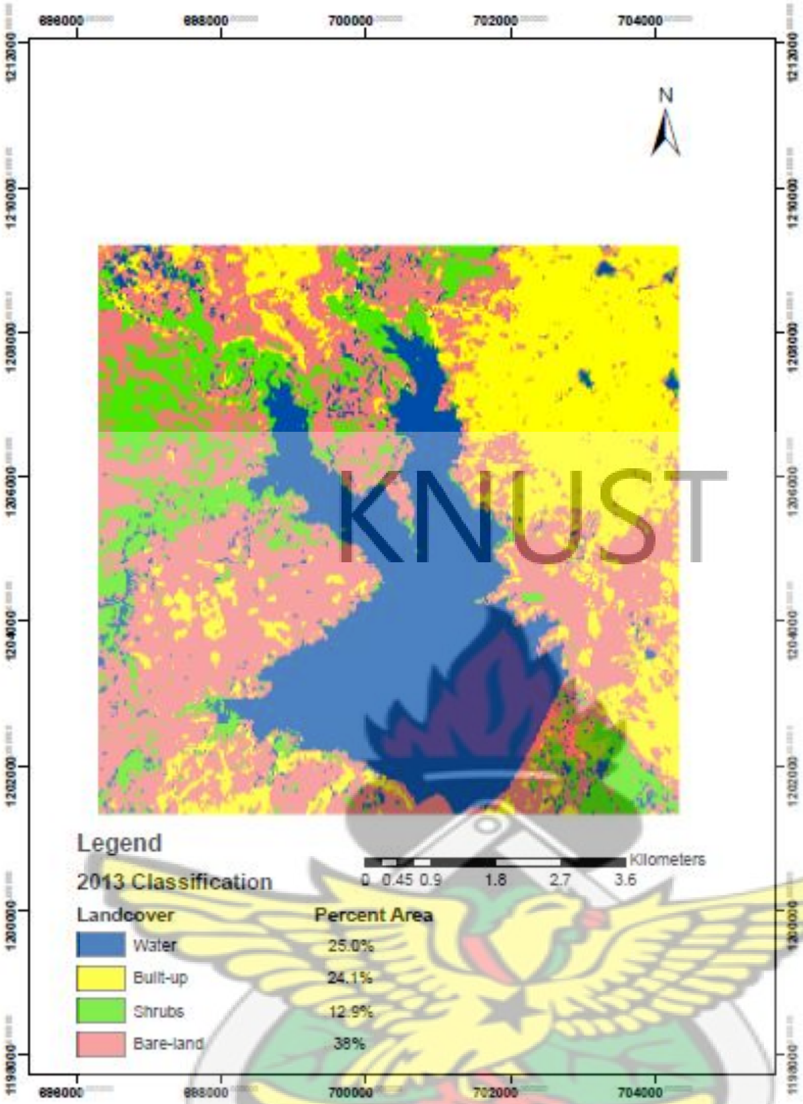


Figure 10:2013 Classified Map based on 2013 Landsat image

3.4 GeoWEPP setup and application

The model used for this study consists of two independent software products; WEPP Model Version 2012.800 and ArcGIS 10.1. These two products are linked via GeoWEPP for ArcGIS 10.x, an ArcView project that is one of the interfaces through which the WEPP model can be used. The GeoWEPP package for ArcGIS 10.x available for free download at the Unversity of Buffallo, Department of Geography website includes two tools that further expand its utility, the Topographic Parameterization tool (TOPAZ) and Topwepp software products developed by the United States Department of Agriculture-Agricultural Research Service (USDA-ARS).

The input files to the GeoWEPP model are;

1. DEM ASCII file

Figure 11: DEM ASCII file for GeoWEPP

2. Soil ASCII file

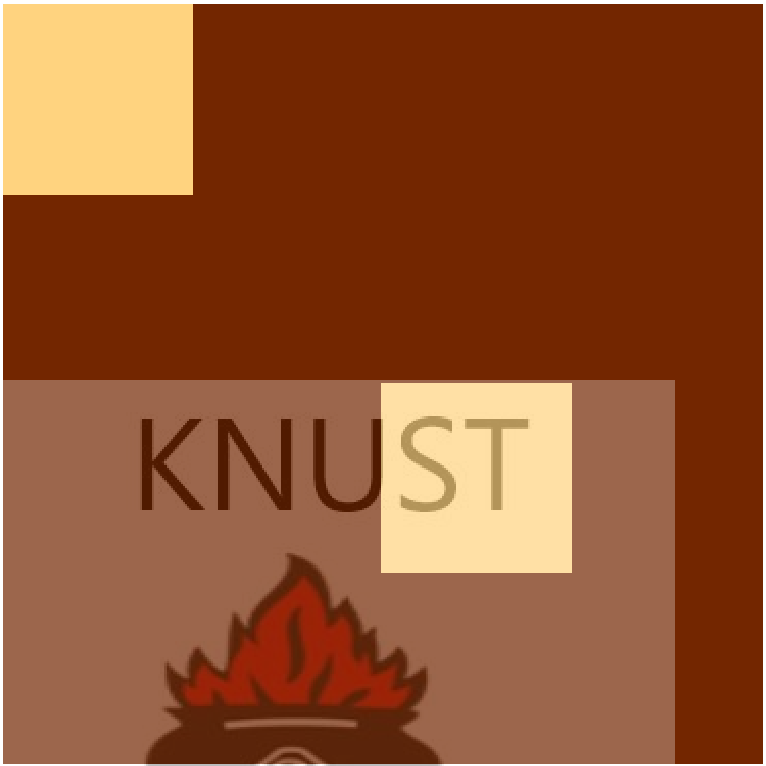


Figure 12: Soil ASCII file for GeoWEPP

3. Landcover ASCII file

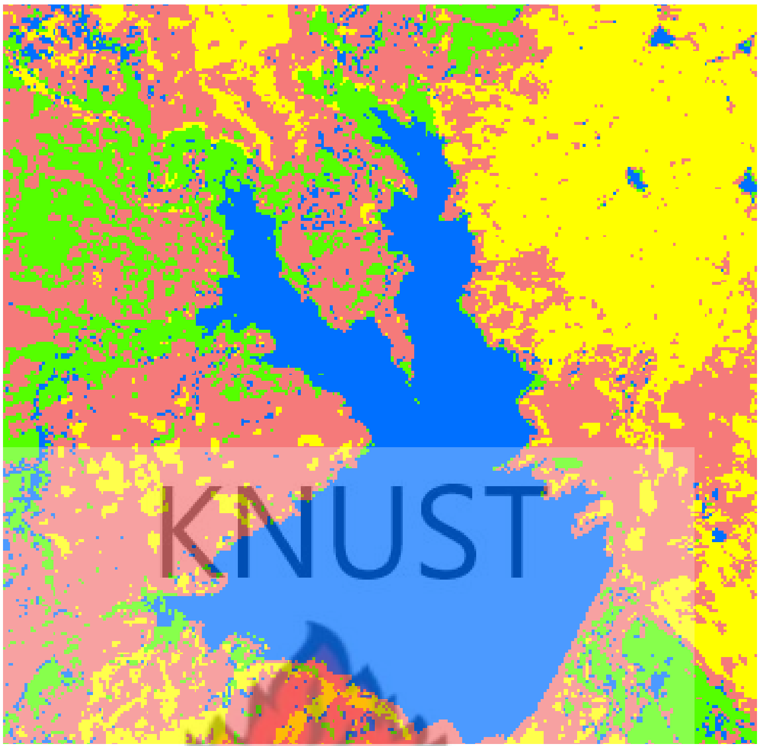
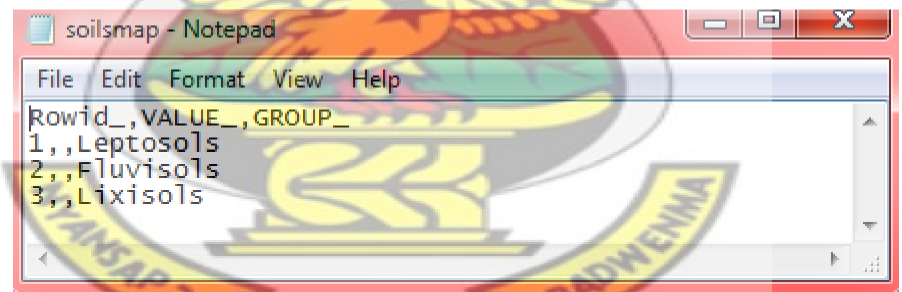


Figure 13: Land cover ASCII file for GeoWEPP

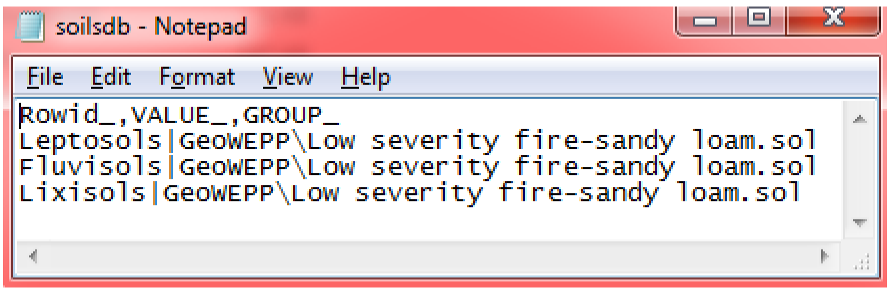
4. Soil description text file




```
Rowid_,VALUE_,GROUP_
1,,Leptosols
2,,Fluvisols
3,,Lixisols
```

Figure 14: Soil description text file for GeoWEPP

5. Soil database text file




```
Rowid_,VALUE_,GROUP_
Leptosols|GeoWEPP\Low severity fire-sandy loam.sol
Fluvisols|GeoWEPP\Low severity fire-sandy loam.sol
Lixisols|GeoWEPP\Low severity fire-sandy loam.sol
```

Figure 15: Soil database text file for GeoWEPP

6. Land cover description text file

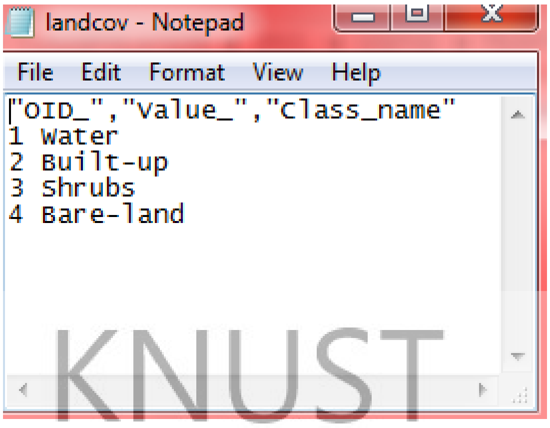


Figure 16: Land cover description text file for GeoWEPP

7. Land cover database text file

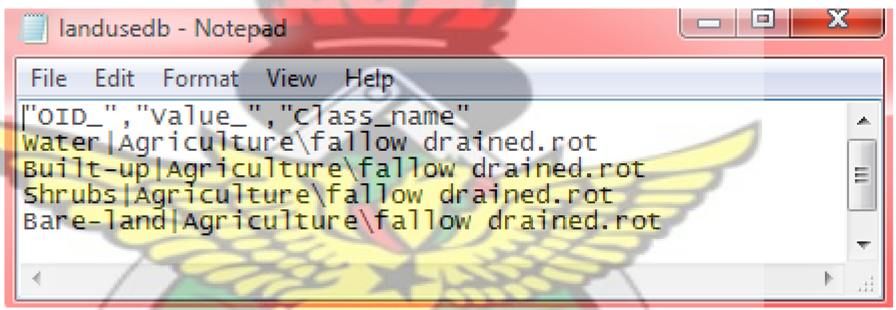


Figure 17: Land cover database text file for GeoWEPP

Core Functions

GeoWEPP combines three different functions to calculate soil erosion.

1. TOPAZ (Topographic Parameterization) for topographic evaluation, drainage identification, watershed identification, watershed segmentation, and subcatchment parameterization
2. PRISM (Parameter-elevation Regressions on Independent Slopes Model) for editing *existing* climate data.
3. WEPP (Water Erosion Prediction Project) for soil erosion calculation

TOPAZ part

1. Defines CSA (Critical Source Area) and MSCL (Minimum Source Channel Length) to delineate streams
2. Specifies the outlet point of watershed

PRISM part

3. Opens PRISM to select/edit existing climate data

WEPP part

4. Obtains the erosion pattern in the watershed
5. Displays reports
6. Saves GeoWEPP project
7. Changes tolerable value of erosion
8. Shows the information of hillslope in the watershed area (click on hillslope)
9. Changes the associated landuse and soil type
10. Returns WEPP after changing hillslope parameter
11. Loads a single hillslope on WEPP
12. Goes to WEPP
13. Saves project and exit

GeoWEPP Steps

1. A Critical Source Area (CSA) and Minimum Source Channel Length (MSCL) were selected as indicated in the Figure 18

Figure 18: CSA and MSCL left at default values

2. This resulted in the delineation of the channels (Figure 19)

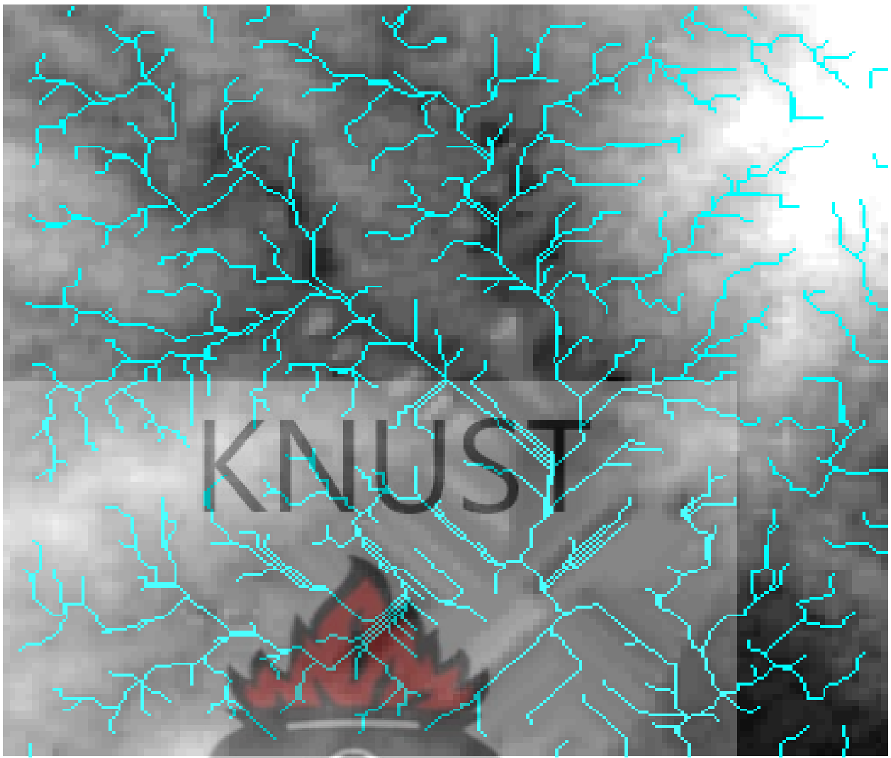


Figure 19: Delineated Channels

3. Pixel of an outlet point was clicked on that enabled the delineation of sub-catchments (Figure 20)

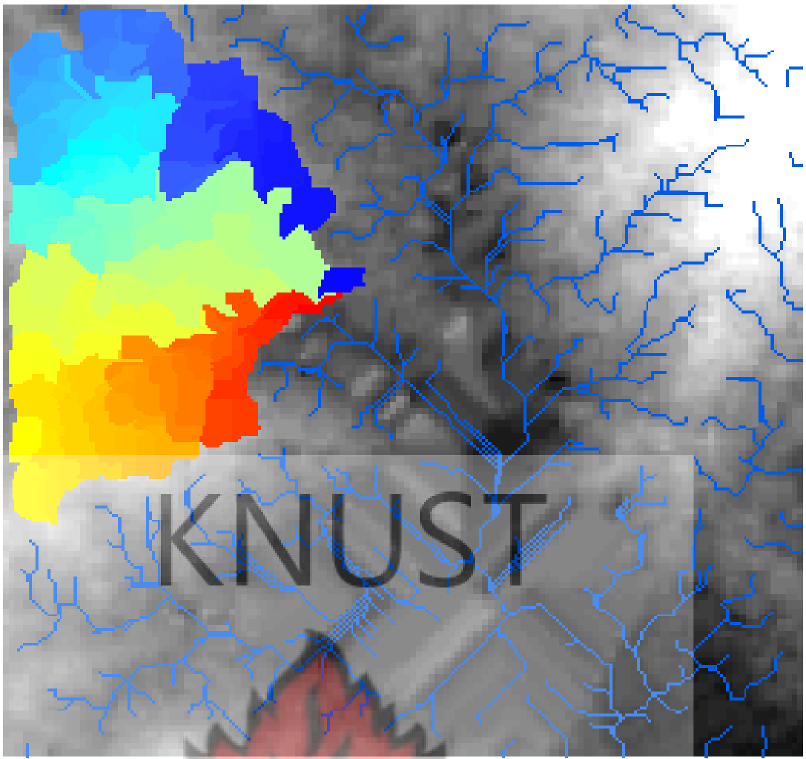


Figure 20: Creation of Subcatchment

4. The climate data that was created via WEPP was selected (Figure 21)

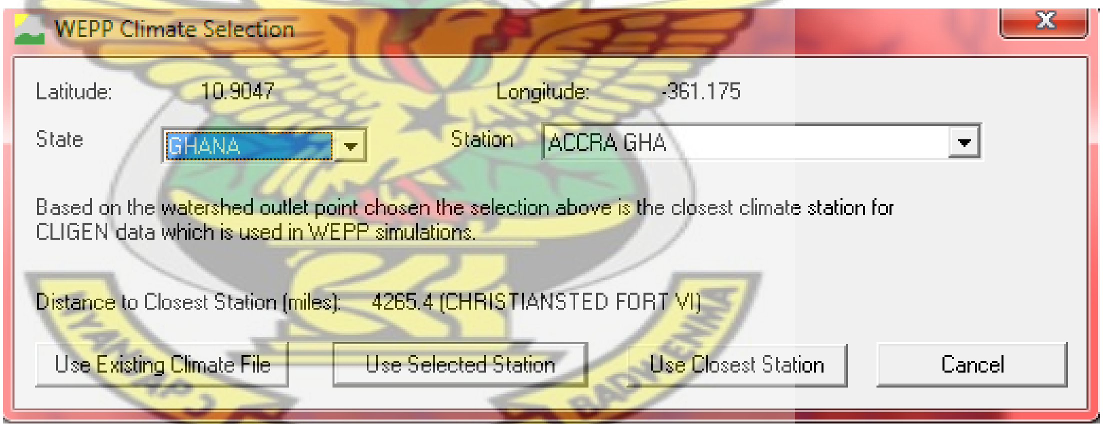


Figure 21: Selection of climate file

5. Parameters were entered to obtain erosion parameters of the Tono Watershed

6. Settings were reviewed. Number of years was set to 29years (Figure 22)

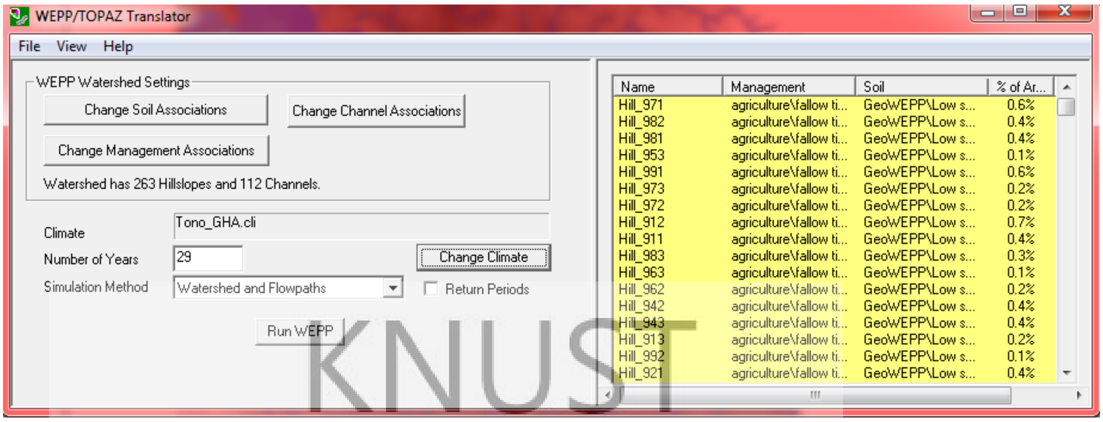


Figure 22: WEPP Management and Soil Lookup window over delineated watersheds. Editing of Landuse, Soils, and Channels types is possible by clicking on the line you want to change.

7. WEPP onsite and offsite output (Figure 23)

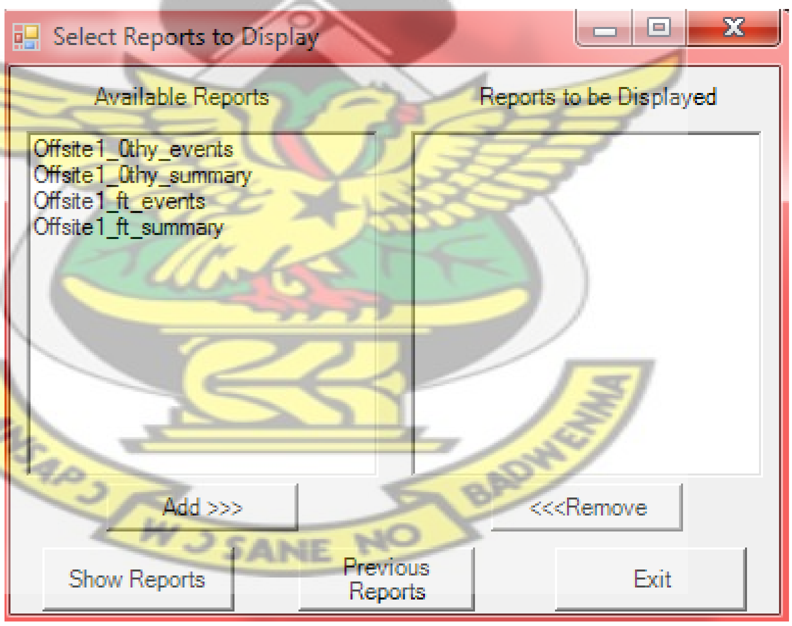
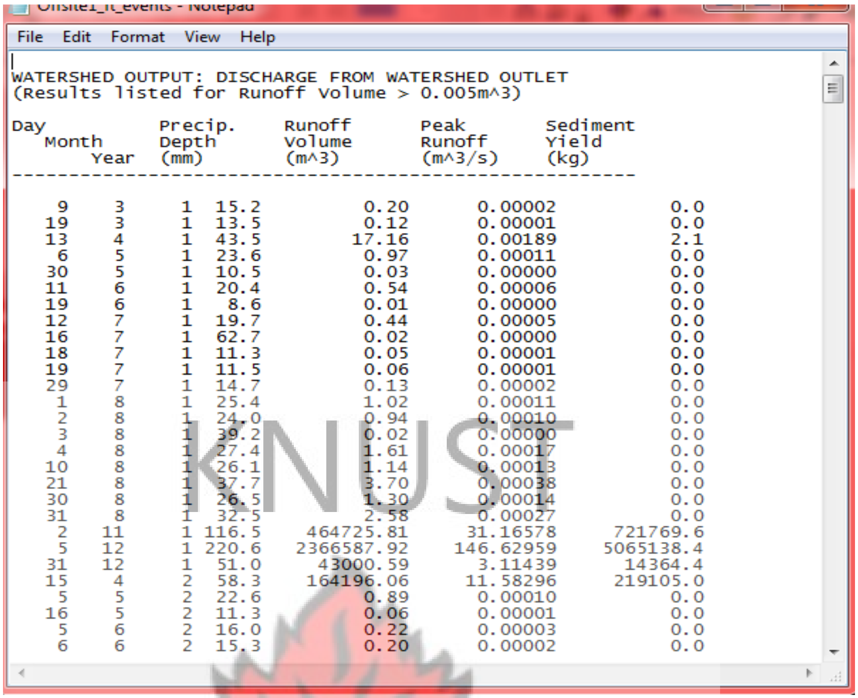


Figure 23: Reports selection interface

8. Sample reports generated after the WEPP run (Figure 24)



WATERSHED OUTPUT: DISCHARGE FROM WATERSHED OUTLET
(Results listed for Runoff Volume > 0.005m^3)

Day	Month	Year	Precip. Depth (mm)	Runoff Volume (m^3)	Peak Runoff (m^3/s)	Sediment Yield (kg)
9	3	1	15.2	0.20	0.00002	0.0
19	3	1	13.5	0.12	0.00001	0.0
13	4	1	43.5	17.16	0.00189	2.1
6	5	1	23.6	0.97	0.00011	0.0
30	5	1	10.5	0.03	0.00000	0.0
11	6	1	20.4	0.54	0.00006	0.0
19	6	1	8.6	0.01	0.00000	0.0
12	7	1	19.7	0.44	0.00005	0.0
16	7	1	62.7	0.02	0.00000	0.0
18	7	1	11.3	0.05	0.00001	0.0
19	7	1	11.5	0.06	0.00001	0.0
29	7	1	14.7	0.13	0.00002	0.0
1	8	1	25.4	1.02	0.00011	0.0
2	8	1	24.0	0.94	0.00010	0.0
3	8	1	39.2	0.02	0.00000	0.0
4	8	1	27.4	1.61	0.00017	0.0
10	8	1	26.1	1.14	0.00013	0.0
21	8	1	37.7	3.70	0.00038	0.0
30	8	1	26.5	1.30	0.00014	0.0
31	8	1	32.5	2.58	0.00027	0.0
2	11	1	116.5	464725.81	31.16578	721769.6
5	12	1	220.6	2366587.92	146.62959	5065138.4
31	12	1	51.0	43000.59	3.11439	14364.4
15	4	2	58.3	164196.06	11.58296	219105.0
5	5	2	22.6	0.89	0.00010	0.0
16	5	2	11.3	0.06	0.00001	0.0
5	6	2	16.0	0.22	0.00003	0.0
6	6	2	15.3	0.20	0.00002	0.0

Figure 24: Text of Report

3.4.1 Climate file

Mean monthly climatic data of precipitation, maximum and minimum temperatures for the period 1980 to 2008 of the Climate stations at the Tono Catchment were collected from the management of the Tono Project. These mean monthly values aided in deriving the climate dataset required by the model.

The climate dataset was built by setting up a CLIGEN par file. To build a CLIGEN input parameter file for the study area, the existing international precipitation and temperature data from Accra, and in GDS file format was downloaded from the hydrology and remote sensing laboratory of the USDA-ARS. This was further used with local data collected from The Tono Irrigation Project to search for a similar US station and also to set up the CLIGEN par file from the local data. The values were then used to generate the needed WEPP climate file using CLIGEN 5.3 to set up a CLIGEN par file for the study area (Flanagan and Livingston, 2007).

3.4.2 Topography and land cover

WEPP also utilizes topography and land cover information to generate run-off as well as sediment yield and soil loss estimation (Maalim *et al*., 2013). The 30-m digital elevation model (DEM) was downloaded from the CGIAR consortium for Spatial Information (CGIAR-CSI) website while the land cover data for the study area was acquired from the Earth Resources Observation and Science Centre (EROSC) website of the USGS Global Visualization Viewer (USGS-Glovis). The DEM was reprojected into WGS84-UTM zone 30 coordinate system in ArcGIS 10.1. The reprojected DEM was clipped to size for the study of the watershed. The clipped DEM was resampled using bilinear resampling technique into a 30m resolution. The resampled DEM was converted into ASCII (Figure 11) format as input into the GeoWEPP model.

The slope of the catchment area under consideration is

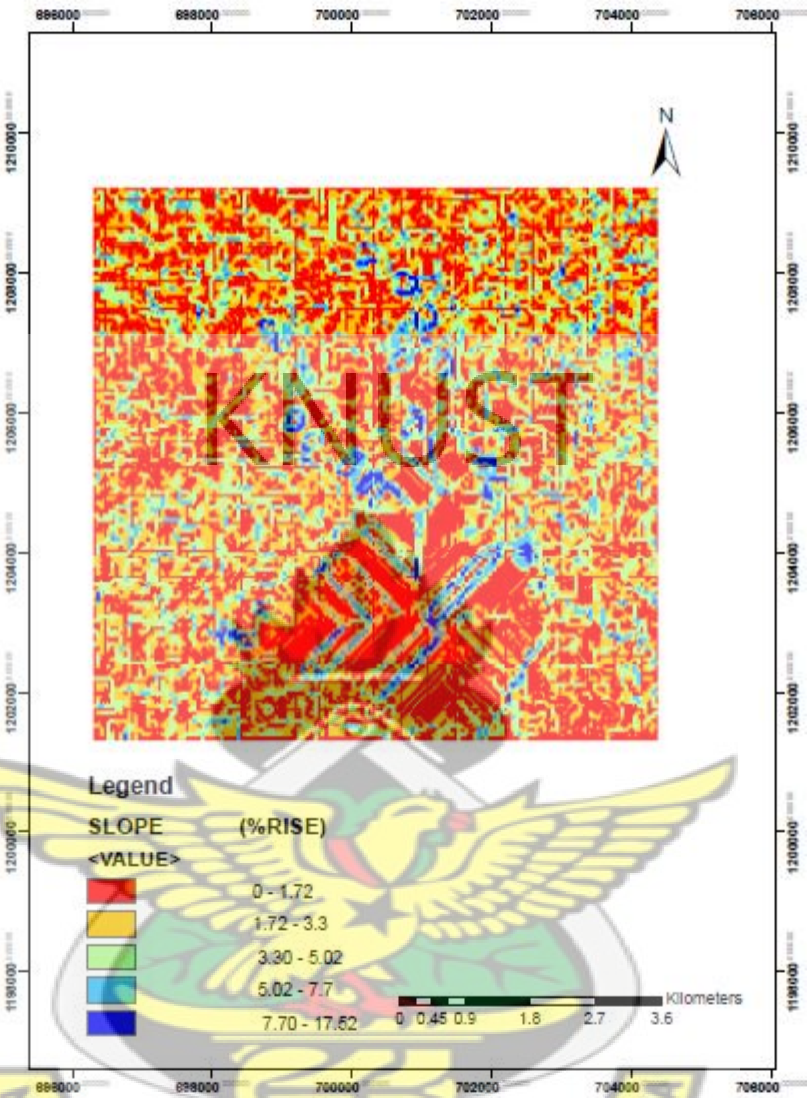


Figure 25: Range of percentage rise in slope at the study site

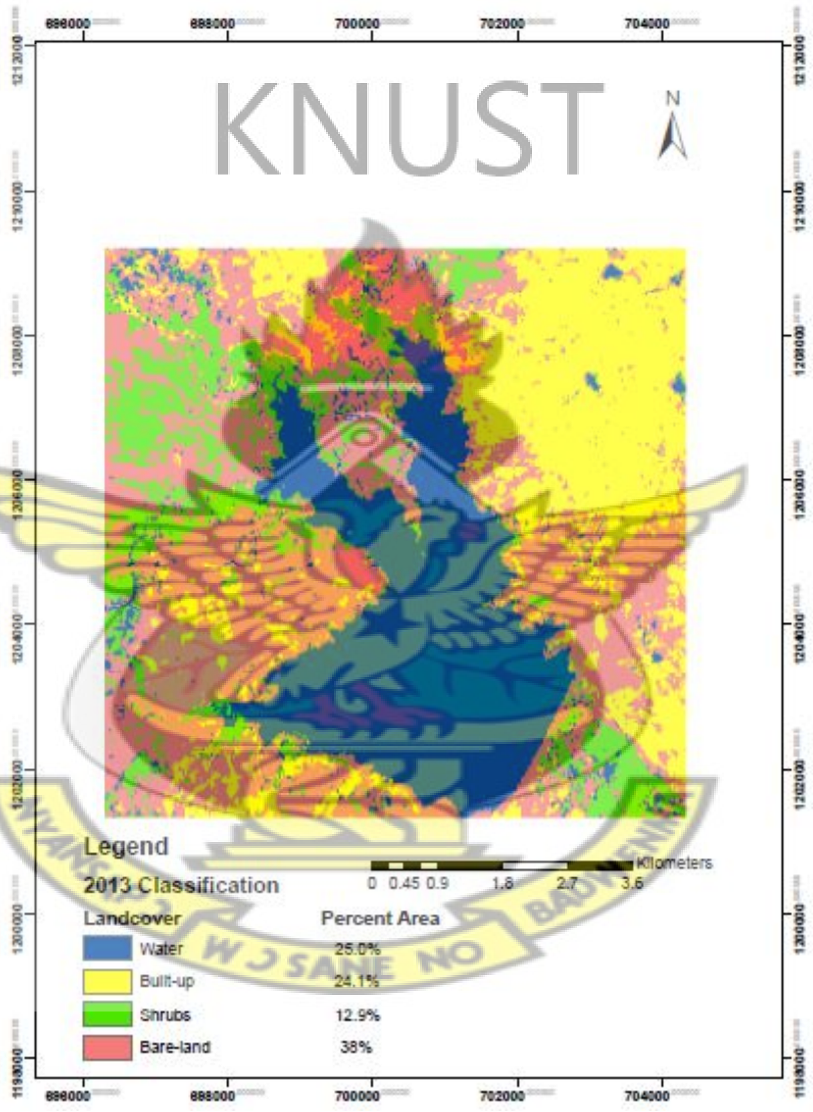


Figure 26: Land cover for GeoWEPP simulation

3.4.3 Soil data

The soil map was in shapefile and this was not in the format required by GeoWEPP.

GeoWEPP requires that all input files be in ASCII format. To do this the soil shapefile was therefore converted into raster format first. Before converting the soil shapefile into raster, the .dbf file containing the soil attributes was opened in exel and resaved as .csv file. This file was used to join the soil attribute table in ArcGIS. This new attribute table was then exported into a .txt file which was then reformatted for the soilsmap.txt (Figure 14) file, an optional input for GeoWEPP. The soil shapefile was then converted into a raster, resampled by bilinear resampling technique, and then converted to soilsmap.asc (Figure 12) (the ASCII for the soil) file as input for the GeoWEPP . The soilsmap.txt file was copied and the copied file was edited to form the soilsdb.txt (Figure 15)

From the soil map it was noticed that Fluvisols and Lixisols dominated in the study area. These soils are not included in the WEPP soil database. They however have some characteristics (Table 15) that is similar to soils in the WEPP soil database.

Table 14: Soil data Characteristics

Local Classification	**FAO-UNESCO Classification**	**Main Characteristics**
Savanna Gleisols and Alluvisols	Fluvisols	Very deep, grey, strongly mottled, non gravelly, imperfectly to poorly drained
Grey earths	Lixisols	Grey to brown, deep, porous, sandy and sandy loam, hardpans in subsoil

Source: Agyare *et al*; (2008).

From the soil characteristics, the sandy loam grey soil characteristic dominates and also the Tono watershed is characterised by annual bushfires and so the low severity fire sandy loam (LSFSL)(Table 16) soil property was selected from the WEPP soil database for the simulations.

Table 15: WEPP input soil parameter for the Tono Watershed.

Soil file name	Low severity fire sandy loam
Soil texture	Sandy loam
Interrill Erodibility	4.001e+005 kgs/m^4
Rill Erodibility	0.0001 s/m
Critical Shear	1Pa
Effective Hydrolic Conductivity	25 mm/h
Sand	55%
Clay	10%
Organic	5%
Cation Exchange Capacity (CEC)	15meq 100/g
Rock	20%

3.4.4 Management parameters

Land use/land cover maps for the study area were obtained for 1991, 2005 and 2013 LANDSAT images. Relevant information is summarized in Table 17.

Table 16:Percentage coverage of the land use/land cover types

LandUse/LandCover Type	Area (%) for 1991	Area (%) for 2005	Area (%) for 2013
Water	28.7	27.8	25.0
Built-up	21.6	21.3	24.1
Shrubs	20.9	18.5	12.9
Bareland	28.9	32.4	38.0

The 2013 landcover map was used in this study for the modeling. Prior to using the landcover map, it was also prepared through the same procedure as indicated for the soil map, except that this map was already in raster format because it was used in the landcover change detection studies previously in this study. The landcover map was loaded in ArcGIS, its attribute table was exported to form the landcov.txt (Figure 16) file. The raster landcover map was then converted into an ASCII format, the landcov.asc file. The landcov.txt file was copied and edited to form the landusedb.txt (Figure 17) file conforming in turn to the land management types outlined in Table 18 with reference to the WEPP management database.

Table 17:Land use change scenarios

Land Cover	Land Management Types	Scenarios
(2013)	Agriculture- fallow tilled	1
(2013)	Agricultural- corn, soybean no till	2
(2013)	Non-agricultural shrub perennial	3

3.4.5 Model run

The DEM, soilsmap.asc, soilsmap.txt, soilsdb.txt, landcov.asc, landcov.txt, landusedb.txt and a topographical map were loaded into the GeoWEPP model. Channel deliniation was done by maintaining both the Channel Source Area (CSA) and Minimum Source Channel Length (MSCL) at the default values. After channel deliniation was completed, an outlet point was selected, which made it possible to define the requisite watershed area for determining the sediment yield and runoff on the watershed and flowpath method of the Tono Irrigation dam. Model simulations were run using the watershed option for each of the three scenarios described inTable 17. The three environmental scenarios considered in this study are 2013 land-use/land-cover with agricultural lands under fallow-tilled management (Scenario 1); 2013 land-use/land-cover with agricultural lands under corn, soybean no till management (Scenario 2); and 2013 land-use/land-cover with non-agricultural land use (Scenario 3). WEPP reports the total runoff, soil loss, soil deposition and sediment yield of each hill-slope in the sub-catchment.

A 29-year simulation run in WEPP using the climatefile discussed above generated estimates of annual runoff, soil loss, and sediment yield. The Topwepp component of GeoWEPP mapped the 29-year mean sediment yield outputs using a Tolerable Soil Loss scheme. To identify the areas with the highest sediment yields, the upper soil loss tolerance limit of 11 tons/hectare/year (Hall *et al*., 1985 cited in Maalim *et al*; 2013) (Figure 26)was applied uniformly across the watershed even though soil loss tolerance as a parameter is not uniform for the different soils of a watershed or even for the same soil under different management practices (Maalim *et al*; 2013).

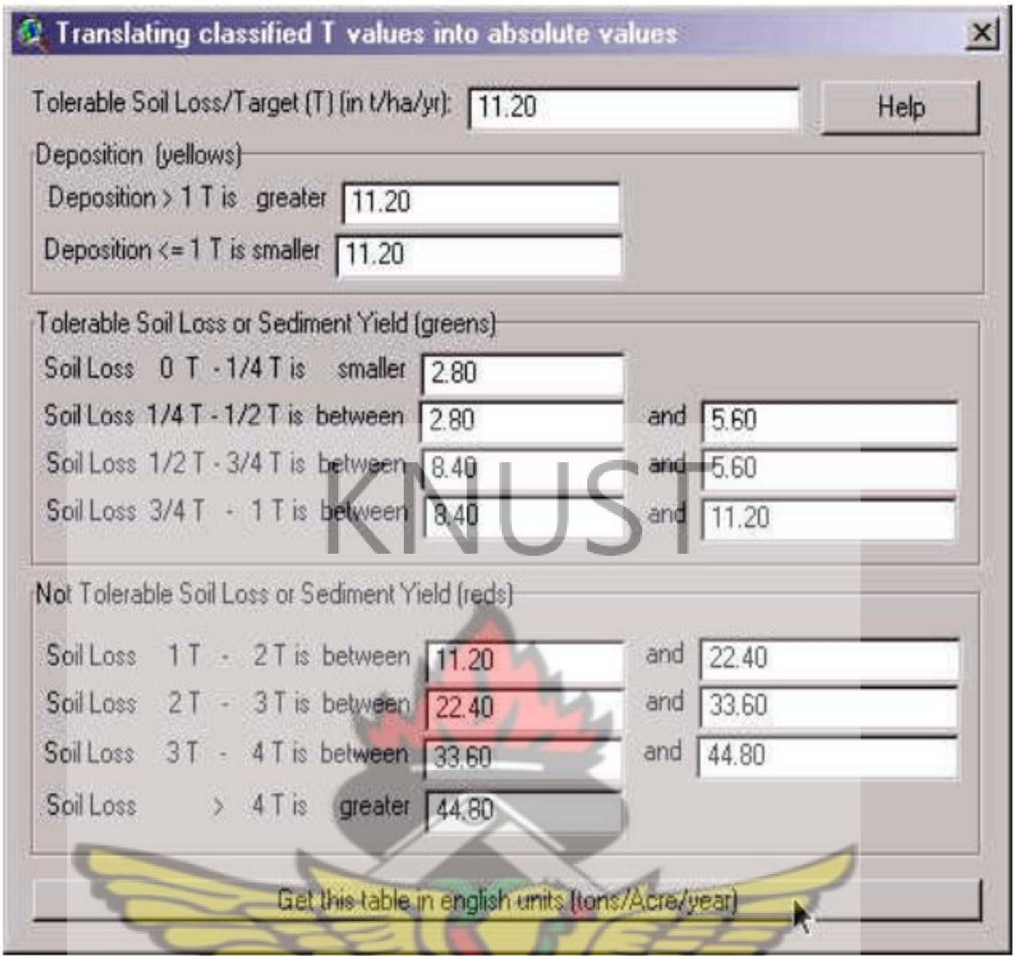


Figure 27: Tolerable Soil Loss scheme

CHAPTER 4: RESULTS AND DISCUSSION

The results and discussion section is organized as follows. The first part discusses results of the Bathymetric survey. In the second section results of the land use change detection studies done with the Remote Sensing data are discussed. In the third, the results of the modeling with GeoWEPP are discussed. Finally limitations of this study are discussed.

4.1 The Bathymetric Survey Results and Discussion

As the sediments accumulate in the reservoir, so the dam gradually loses its ability to store water for the purposes for which it was built. Every reservoir loses storage to sedimentation although the rate at which this happens varies widely. The rate of reservoir sedimentation depends mainly on the size of a reservoir relative to the amount of sediment flowing into it: a small reservoir on an extremely muddy river will rapidly lose capacity; a large reservoir on a very clear river may take centuries to lose an appreciable amount of storage.

The capacity of the Tono reservoir is 9.3×10^{7} cubic meters (WRRI, 1996). The total area of the reservoir surveyed was 1139.44hectares, out of the about 1800hectares. Digitized existing DEM (Figure 28) was used together with surveyed DEM (Figure 29) to extract silt thickness (Figure 30) that aided in the volume computation. The volume of silt accumulated from 1991 to 2013 is approximately 3.56×10^{6} cubic meters which corresponds to 4.27×10^{6} tonnes.

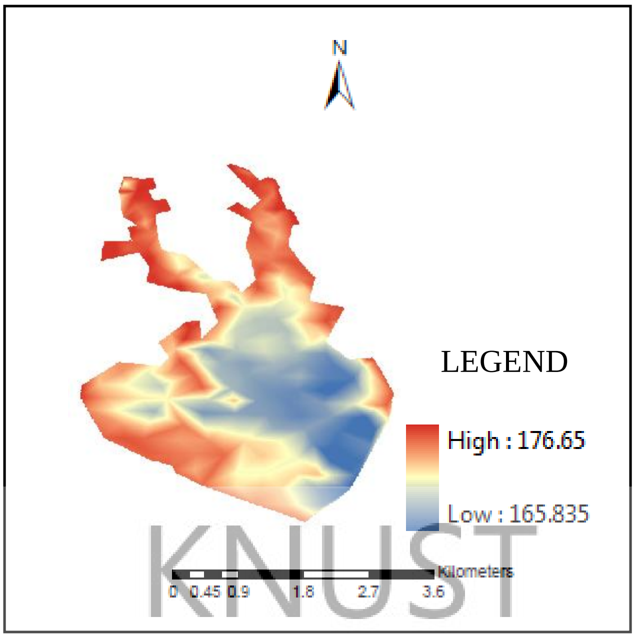


Figure 28: DEM of Existing Bathymetric Survey

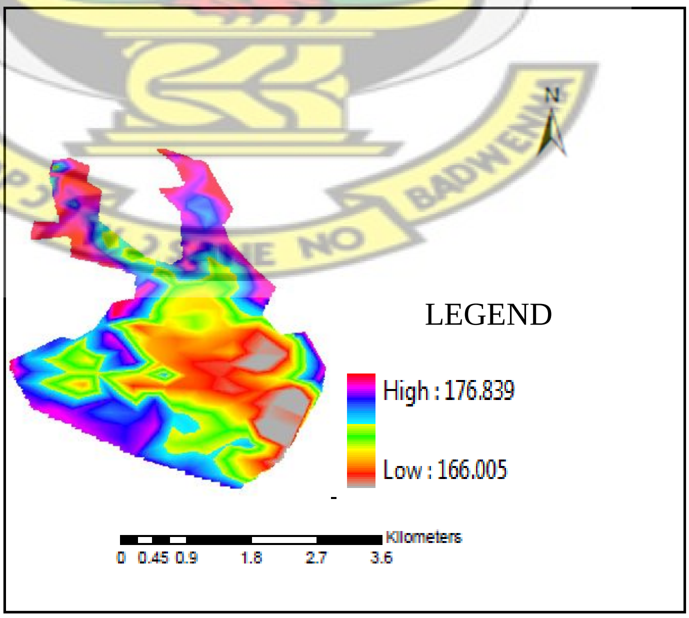


Figure 29: DEM of New Bathymetric Survey

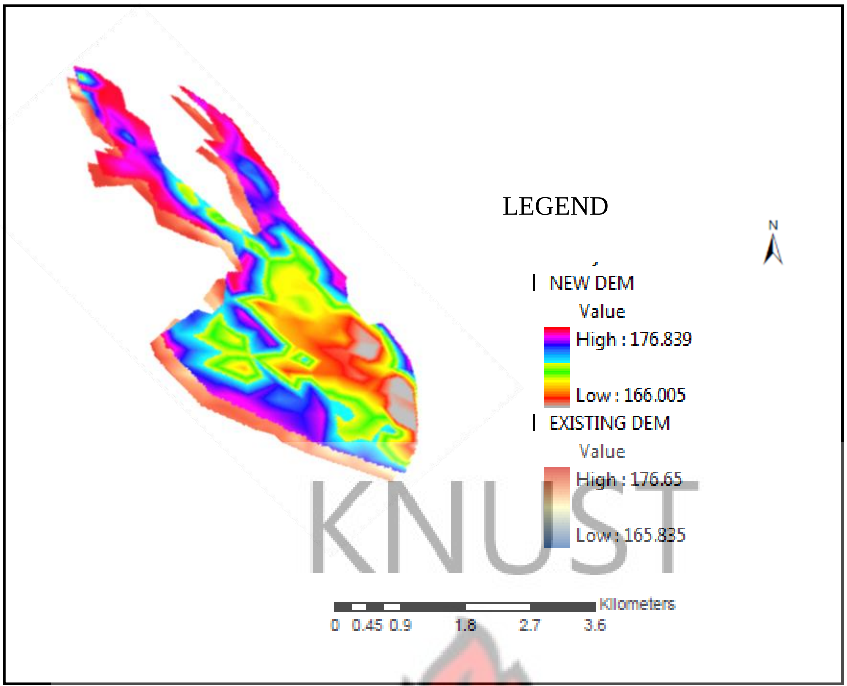


Figure 30: New DEM superimposed on existing DEM

This translates into 1.62 X 10^{5} cubic meters of silt per year which is about 1.74% reduction in reservoir capacity on annual basis. This amount of silt could be attributed partly to the land use and land use changes that have occurred within the watershed. In order to save themselves the extra economic implication of irrigating farmlands far away from the bank, most farmers farm very close to the reservoir. These areas are also watercourses, so not only the irrigation return flow to the reservoir carries sediment but also during rain events, lose soil is also transported into the reservoir. Another reason could be the loss of vegetation as a result of grazing by cattle and other livestock along water courses. Wave wash also erodes material from the bank to topple the silt amount in the reservoir. This can be accelerated by recreational boating and navigation by tourists and fishermen alike.

4.2 Land cover Change Results and Discussion

The three Landsat images, 1991, 2005 and 2013 were classified into four land cover classes (Table 18). The classification was based on the Land use Land cover classification scheme of 1995 by the National Remote Sensing Agency (NRSA-1995) (Table 10).

Table 18:Area (Percentage) coverage of the land use/land cover types

LandUse/LandCover Type	Area (%) for 1991	Area (%) for 2005	Area (%) for 2013
Water	28.7	27.8	25.0
Built-up	21.6	21.3	24.1
Shrubs	20.9	18.5	12.9
Bareland	28.9	32.4	38.0

From Table 18, shrub land has decreased by 2.4% from 1991 to 2005 and 5.6% from 2005 to 2013 respectively. This contributes to a total of 8% decrease in shrubs area from 1991 to 2013. This possibly accounts for the astronomical increase in the bare-land area of 9.1% for the 22years span. A section of the reservoir has become bare and this accounts for the reduction in the reservoir area by 3.7%. These changes have had a significant impact on the amount of silt that has accumulated in the reservoir as revealed by the bathymetric survey.

It is not much of a surprising revelation because the catchment area of the Tono Irrigation watershed is characterized with annual “traditional” bushfires and logging of trees for burning into charcoal on regular basis. In this situation, the infiltration capacity of the soil is reduced and runoff increases substantially due to accelerated overland flow rates and mass soil movement (Kerr, 2000). During a logging operation, not only the ground where the tree was logged gets affected, but the ground preparation for burning the tree to form charcoal. These, coupled with the environmental impact of the burning of the charcoal, subject at least a 10m radius of ground area from the ground point where the charcoal is burnt to become ineffective to support plant growth. This is because the soil organisms and nutrients that support plant growth have all been denatured. In this respect, the amount of bare land will be on the ascendancy and subsequently runoff events will accelerate and thereby augmenting the silt accumulation in the reservoir as these areas are within the watershed.

4.3 The Modeling Results and Discussion

The results and discussion section is organized as follows. The first section discusses results of the runoff simulation under the three scenarios, including the effect of land use and tillage management on runoff. In the second part, soil loss and sediment yield for the three scenarios, and the effects of land cover and field management settings are discussed. Finally, a discussion of limitations of the GeoWEPP model for this study is outlined.

4.3.1 Runoff

Average annual runoff depth for the watershed under scenario 1 is 118.41mm (Table 19). Estimated runoff depth varies in time and space depending on the individual slope profile, soil type, and land use/land cover of each hillslope. A summary of the average annual runoff depths for the other scenarios are shown in Table 19.

Table 19: Variations in runoff, mean annual soil loss rate, sediment yield, and sediment delivery ratio for the three scenarios.

	SCENARIOS		
Result description	**1-FT**	**2-CSNT**	**3-SP**
Mean annual runoff depth (mm)	118.41	94.61	57.70
Reduction in runoff depth (%) as compared to scenario 1	0.00	20.10	51.27
Mean annual soil loss (Tonnes)	27025.70	3299.90	716.30
Mean annual soil loss rate (Tonnes/hectare)	22.83	2.79	0.61
Reduction in soil loss rate (%) as compared to scenario 1	0.00	87.78	97.33
Mean annual sediment yield (Tonnes)	18236.90	1018.80	660.30
Sediment delivery ratio (%)	0.68	0.31	0.92
Mean annual sediment yield rate (Tonnes/hectare)	15.40	0.90	0.60
Reduction in sediment yield rate (%) as compared to scenario 1	0.00	94.16	96.10

1-FT => Scenario 1, implementing fallow tilled management

2-CSNT=> Scenario 2, implementing corn soybean no till management

3-SP=>Scenario 3, implementing shrub perennial management

4.3.2 Effects of land use/ land cover on runoff

Mean annual runoff depths (Table 19) for the watershed under the three scenarios are 118.41mm, 91.61mm and 57.70mm respectively. A comparison of the annual mean runoff reveals that there is 20.10% and 51.27% reduction in annual mean runoff under scenarios 2 and 3 compared to scenario 1. This translates to 87.78% and 97.33% reduction when it comes to soil loss (Table 19), highlighting the effect land use change has had on the watershed. Since there are no observed field data, the comparison was made to understand the impacts of land use changes.

4.3.3 Effect of tillage practices on runoff

As shown in Table 19, runoff under scenario 1 is predicted to be higher than in scenario 3. The annual average of 118.41mm under scenario 1 is 51.27% higher than the 57.70mm depth reported for scenario 3. The presence of surface residue has an impact on the amount of runoff. Residue has an impact on the amount of time it will take for rainfall to seep into the soil as it alters infiltration. The tillage practice adopted for scenario 1 and 2 are each such that they have less surface residue than the scenario 3. This accounts for why the runoff in scenarios 1 and 2 are higher than that for scenario 3.

4.3.4 Soil Loss

According to Maalim *et al* (2013), soil loss is the amount of onsite detachment of soil material from a location by the action of an eroding agent. Average annual soil loss for the watershed under scenario 1 is 27025.7t, approximately 22.83t/ha. Soil loss (Figure 31) is generally highest in areas with greater slopes in close proximity to major streams. The soil loss trend across different land use/land covers is very similar to the one predicted for runoff depths.

4.3.5 Effect of tillage practices on soil loss

Watershed soil loss under the FT management system is predicted to be higher than in the CSNT and SP systems (Table 19 and Figure 31). The annual average watershed soil loss rate of 2.79t/ha and 0.61t/ha under the CSNT and SP which are 87.78% and 97.33% less than the FT watershed soil loss rate of 22.83t/ha. Soil loss rate is influenced by the degree of surface soil disturbances. The degree of surface soil disturbance is influced by the tillage system adopted. In this study, the tillage practices considered were SP, CSNT and FT. The tillage practice that disturbs the soil most is FT, followed by, CSNT and then SP. Mathematically, the degree of surface soil disturbance for the three tillage practices adopted in this study can be represented as

SP < CSNT < FT.

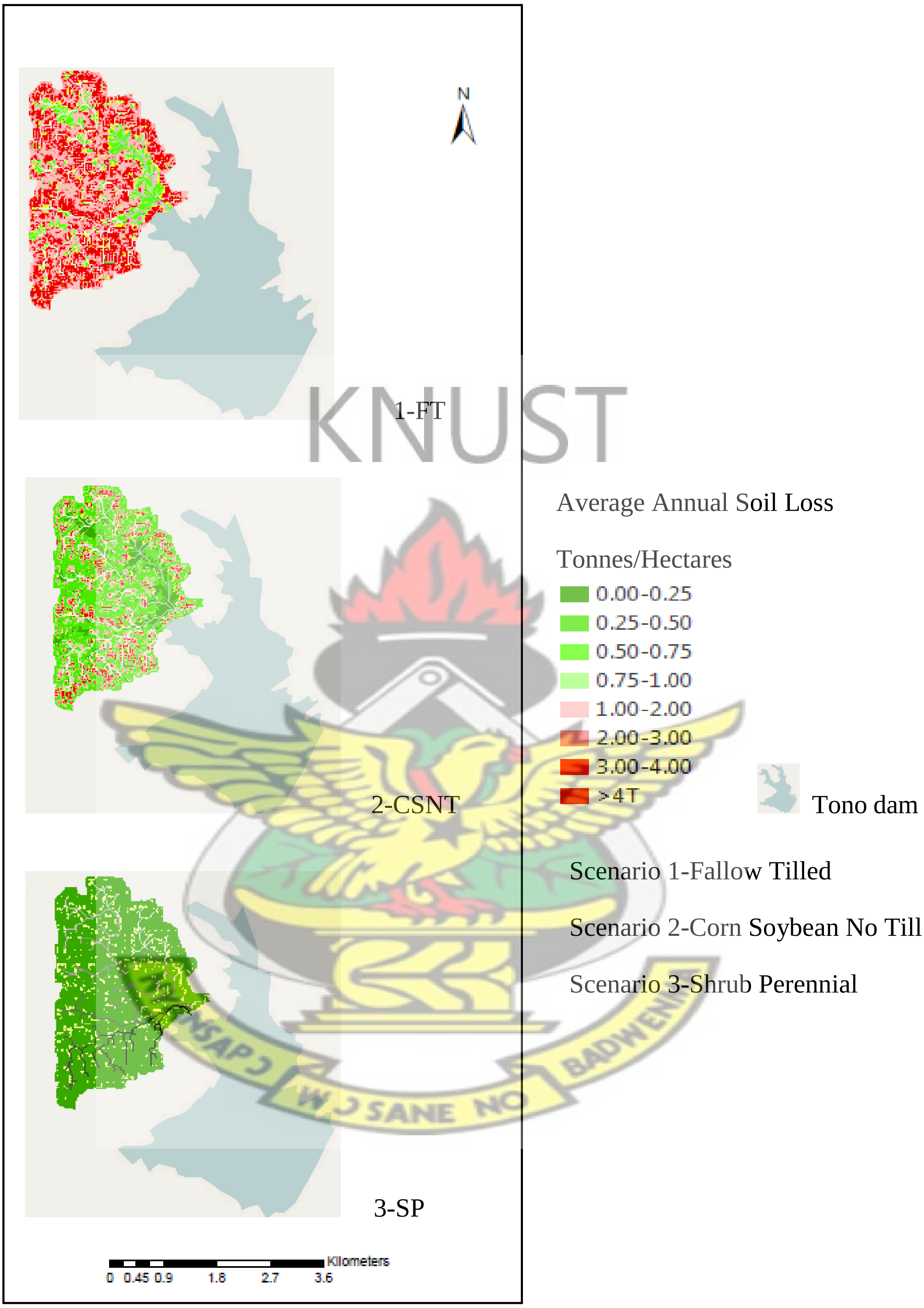


Figure 31: Map of average annual soil loss (tonnes/ha) for scenarios 1, 2, and 3 respectively.

4.3.5 Sediment yield

Sediment yield from an area (mass of eroded sediment delivered to an off-site location) is always less than the mass of local soil loss and the actual amount varies with topography, land use/ land cover and presence or absence of conservation structures. (Maalim *et al*; 2013).

The spatial pattern of sediment yield for different land use/land covers is very similar to the one predicted for runoff depths. Figure 32 shows the patterns in sediment yield among hill slopes/OLFEs under each of the three scenarios while Table 19 summarizes the mean sediment yields and sediment delivery ratios for the entire watershed under these scenarios.

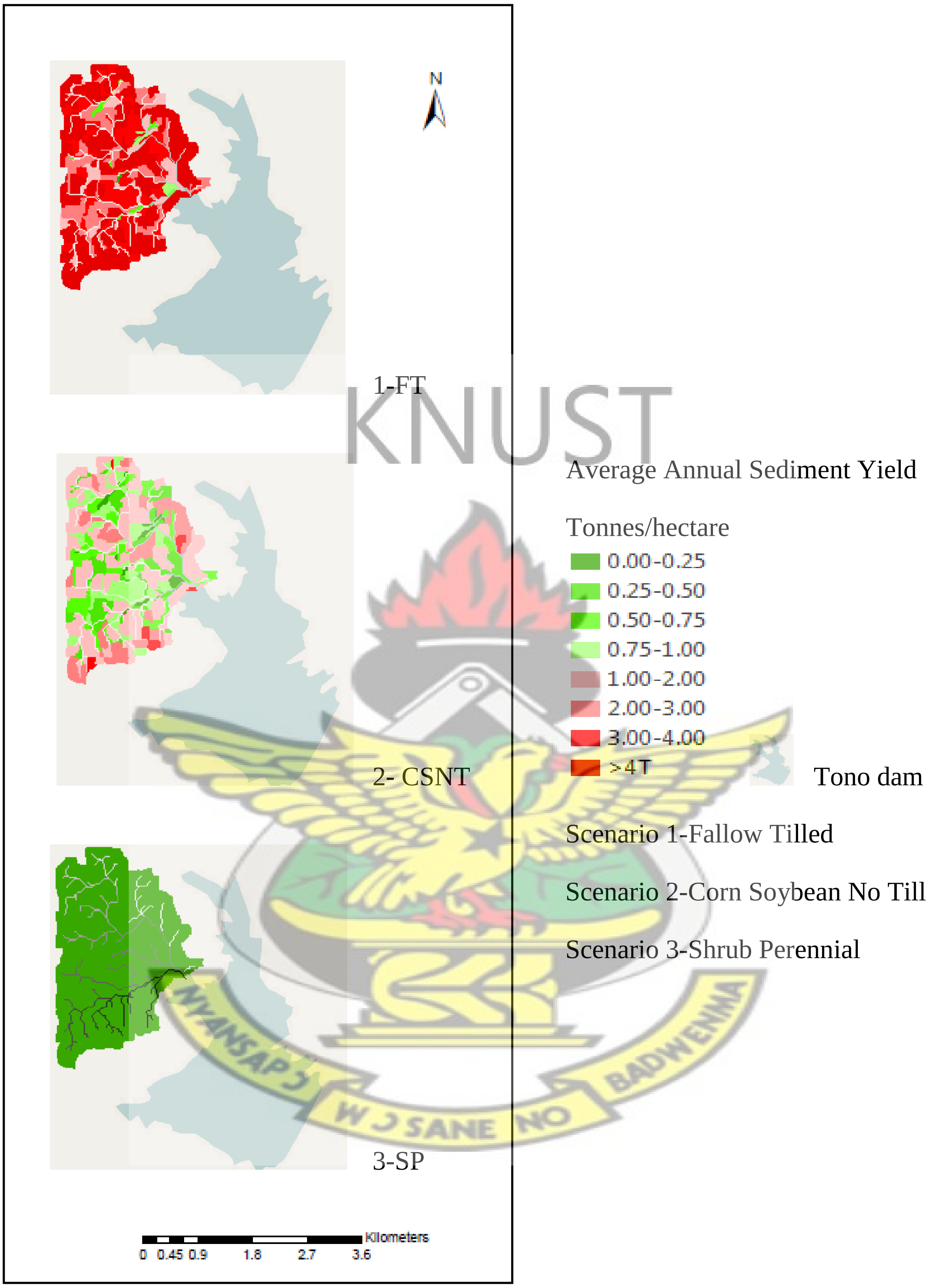


Figure 32: Average annual sediment yield (Tonnes/ha) for scenarios 1, 2, 3

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

The bathymetric survey results indicated that on annual basis the reservoir capacity reduces by 1.74%. The land use change analysis indicated that a significant transformation has taken place in the landscape of the watershed since 1991. Shrub coverage had reduced by 8.0% giving way to additional bare land by 9.1%.

Using GeoWEPP, the study identified erosion susceptible areas and depositions within the watershed, which can be used for targeted interventions to implement soil and water conservation measures. The percent rise in slope ranged from 0%-18%. Knowledge of how much runoff and sediment to expect from the watershed during a rainstorm are also known. The study predicted that, management practices influenced both runoff and sediment amounts. For instance, in a fallow tilled management, the runoff and sediment amounts are respectively 118.41mm and 18236.90t/ha, while with shrub perennial management, they are respectively 57.70mm and 660.30t/ha.

The results from the model indicated that land use/land cover change has significant impact on land degradation and hydrology of the Tono reservoir. The sediment budget results show high sediment detachment in the upstream agricultural areas are deposited in the lower relatively flatter areas. The results obtained through this study show that runoff fluxes, soil loss, and sediment yield vary with land use/land cover.

This study recommends that:

1. A sound watershed planning and management action that counter the trend of increased soil erosion must be adopted;
2. The participation of the local population in water resource management is an important requirement to establish equilibrium between the upstream and

downstream areas of the reservoir. It is recommended that the land users be made aware of the negative consequences of some land use practices on erosion and its attendant impact on the water resource through siltation;

3. It is important to develop multi-criteria economic analysis for assessing the economic impacts of erosion problems (and sedimentation) on environmental and social conditions;

4. There is the need to increase the frequency of bathymetric measurements, to 5-year intervals in order to provide more exact information on the magnitude of annual sedimentation;

5. A special investigation of theoretical and practical aspects of sediment measurements should be established;

6. There is the need to implement sedimentation models to forecast reservoir silting and

7. Indiscriminate slashing, cutting and burning of natural vegetation should be stopped.

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