ANALYSIS AND MODELLING OF SUSPENDED SEDIMENT CONCENTRATION OF RIVERS IN CATCHMENTS EXPERIENCING LAND COVER DEGRADATION

By

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A thesis submitted to the Department of Civil Engineering, Kwame Nkrumah University of Science and Technology, Kumasi in partial fulfillment of the requirements for the award degree of

DOCTOR OF PHILOSOPHY IN WATER RESOURCES ENGINEERING

OCTOBER 2019

DECLARATION

I hereby declare that this submission is totally an original study that I conducted with regard to PhD degree in Water Resources Engineering. Apart from important literatures which have been accordingly referenced and acknowledged, the work contains no material which has been published or accepted anywhere partly or in total for the award of any degree.

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DEDICATION

This work is specially dedicated to Pastor W. F. Kumuyi.

ABSTRACT

Amongst the issues threatening water security and sustainability is the increasing rate of river sedimentation. Variations in catchment sediment yield results from the variations in its controlling factors such as land use/cover characteristics. Thus, it is crucial that this factor is monitored and managed to ensure sustainability of the resource. However, existing models (statistical) have failed to explore the influence of the land use types. Hence, land cover effect and its associated modifications on the variations in suspended sediment concentration have not been empirically quantified, especially for catchment with heterogeneous land cover classes. In view of this, this research answers the question "To what extent does land use/cover characteristics influence the variations in catchment suspended sediment yield?" The following specific objectives were addressed: (1) to assess the trend and extent of land use /cover changes in the Pra River Basin and their driving forces; (2) to assess the variations in suspended sediment yield of the catchment; (3) to determine the sediment generating areas of the catchment and (4) to assess the relative importance of land use types on the variation of suspended sediment yield and to forecast same. Remote sensing and Geographic Information System techniques, field measurement, data collection and laboratory analysis, and statistical techniques such as Analysis of Variance, multiple regression and correlation analysis were employed for the study. Results reveal that between 1986 and 2018, the Pra River basin had suffered severe land cover degradation resulting from anthropogenic influence. Land use conversion occurred generally from closed and open forest to farmlands, settlement and mining. However, the rate, extent and trend of conversions differed significantly across it sub-basins. Sediment yield of the basin is very high ranging between 13.29 and 215.02 $tkm^{-2}yr^{-1}$, and differs significantly ($p < 0.05$) with respect to the contributing drainage basins. Erosion map showed that about 21.3% of the basin comes under severe and very severe erosion risk category. Soil erosion rate varied with land use types in a decreasing order from Mining to Settlement, Farmland/grassland, Open forest and Closed forest. Lower Ofin, Anum, Birim, Twifu Praso, Upper Ofin and Oda sub-basins were identified to be susceptible to high erosion. Model accuracy increased from 60.2% to 76.7% when land cover types were included as predictor variable in the suspended sediment concentration model. This indicates that land cover characteristics play a significant role in explaining the variations in catchment suspended sediment yield. The study recommends that immediate conservation measures and policy implementation must be put in place to restore the ecological integrity of the degraded sub-basins. The need to form district ecological or environmental task force involving officials of water, environment and security agents can be useful in handling respective sub-basin's environmental threats. This will preserve the water resources for sustainable use.

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LIST OF ABBREVIATIONS

ASTER	Advanced Spaceborne Thermal Emission and Reflection
ADCP	Acoustic Doppler Current Profiler
ANSWERS	Area Non-point Source Watershed Environmental Response Simulation
CREMA	Community Resource and Management Authority
CSIR	Council for Scientific and Industrial Research
CREAMS	Chemicals, Runoff and Erosion from Agricultural Management Systems
DN	Digital Number
DEM	Digital Elevation Model
ETM+	Enhanced Thematic Mapper Plus
EUROSEM	European Soil Erosion Model
FAO	Food and Agricultural Organisation
GIS	Geographic Information System
GWCL	Ghana Water Company Ltd.
IPCC	Intergovernmental Panel on Climate Change
KINEROS	Kinematic Runoff and Erosion model
LULCC	Land Use and Land Cover Change
MFI	Modified Fournier Index
MOLUSCE	Module for Land Use Change Evaluation
MUSLE	Modified Universal Soil Loss Equation
PRB	Pra River Basin
QGIS	Quantum GIS
RUSLE	Revised Universal Soil Loss Equation
SWAT	Soil and Water Assessment Tool
SDR	Sediment Delivery Ratio
SDD	Sediment Distributed and Delivery
TM	Thematic Mapper
UTM	Universal Transverse Mercator
USLE	Universal Soil Loss Equation
WEPP	Water Evaluation Prediction Project
WGS	World Geodetic System
WRC	Water Resources Commission
WRI	Water Research Institute
WRRI	Water Resources Research Institute

ACKNOWLEDGEMENT

I am extremely grateful to the Almighty God for this opportunity to pursue higher degree successfully. I also thank the Government of Ghana, the World Bank and Regional Water and Environmental Sanitation Centre Kumasi (RWESCK) for the scholarship. My appreciation goes to the management and staff of RWESCK. My profound gratitude goes to my supervisors: Dr. F.O.K. Anyemedu, Dr. Emmanuel A. Donkor and Dr. Jonathan A. Quaye-Ballard for their invaluable contribution, encouragement, guidance and correction that has led to successful completion of this research. Their commitment to the supervision is very remarkable.

I am extremely grateful to Mr. Gabriel Appiah of Water Research Institute, CSIR-Accra for his continual support and commitment during data collection and laboratory analysis. Appreciation also goes to Water Research Institute for allowing me to conduct sediment concentration analysis in their lab.

I will like to express my gratitude to my siblings: Seth Danso, Emmanuel Nyarko, and Mrs. Kate Marfo; all friends; PhD colleagues and Pastor's for their consistent support and encouragement. Most importantly, my heartfelt appreciation goes to my wife Mrs. Alice Boakye for her incalculable support, prayer and concern. Without her this story would not have been told. Her endurance, patience and love have brought me this far. And I am happy to inform her that this achievement belongs to the entire family. To my sweet and wonderful children: Asabea, Amankwaa and Nana Boakye, I say thank you for giving me space to concentrate on the programme. I love you so much. You have always been my inspiration and joy. God richly bless you.

LIST OF PUBLICATIONS

PUBLISHED

- Boakye, E. Anornu, G. K. Quaye-Ballard, J. A. and Donkor, E. A. (2018). Land use change and sediment yield studies in Ghana: Review. *Journal of Geography and Regional Planning,* Vol. 11(9):122-133. DOI: 10.5897/JGRP2018.0707

- Boakye, E., Anyemedu, F.O.K., Donkor, E. A and Quaye-Ballard, J. A. (2019). Spatiotemporal analysis of land use/cover changes in the Pra River Basin, Ghana. *Applied Geomatics (Springer), Doi: 10.1007/s12518-019-00278-3. Published online 24July 2019*

UNDER REVIEW

- Boakye, E., Anyemedu, F.O.K., Donkor, E. A and Quaye-Ballard, J. A. (2019). Variability of suspended sediment yield in the Pra River Basin, Ghana. *Environment, Development and sustainability (Springer) (Ref. No: EDS-ENVI-D-1900768)*

- Boakye, E., Anyemedu, F.O.K., Donkor, E. A and Quaye-Ballard, J. A. (2019). Spatial distribution of soil erosion and sediment yield in the Pra River Basin, Ghana. *Geomorphology (Elsevier) (Ref. No: GEOMOR- 8763)*

- Boakye, E., Anyemedu, F.O.K., Donkor, E. A and Quaye-Ballard, J. A. (2019). Statistical modelling of suspended sediment concentration of rivers: The effect of land cover on model accuracy. *Water Resource Management (Springer) (New submission)*

CHAPTER ONE INTRODUCTION

1.1 Background Information

Rivers undisputedly play incomparable role in nature ranging from ecosystem sustainability to domestic, industrial and agricultural uses (Ayivor and Gordon, 2012). "Earth was originally allotted a finite amount of water — we have no more or no less than that original allotment today. It logically follows that, in order to sustain life as we know it, we must do everything we can to preserve and protect our water resource"(Spellman, 2014). Fresh water thrives in environment capable of regenerating itself therefore it is important that river basins are managed to maintain a balance between the availability and the use of the resources (Dunn and Mackay, 1995). Healthy water bodies provide drinking water, fish and wildlife habitats, environmental integrity, recreational opportunities and economic benefits for local communities, protection against flooding etc.

As the population grows and the demand for fresh water increases, natural factors controlling the nurturing of rivers and streams must not be toiled with. It is only through this that sustainability can be assured (Dunn and Mackay 1995). However, human activities associated with population growth continue to impact severely on their catchment leading to land use change and environmental degradation. Throughout the years different land use and land cover researches in Ghana, utilizing various techniques and methods have demonstrated clear event of land use and land cover changes, predominantly from forest/savanna cover to farmlands, settlement and mining (e.g. Aduah *et al.*, 2015; Amoah *et al.*, 2012; Forkuo and Adubofour, 2012; Boakye *et al*., 2008). The changes in land use patterns definitely provide many social and economic benefits, they also come at a cost to the natural environment. Land use change influences natural phenomenon and ecological processes that leads to changes in soil properties, runoff content and soil erosion processes (Kavian *et al*., 2013). On the other hand, vegetative cover protects the soil from eroding by reducing the erosive intensity of impacting precipitation drops and amount of water reaching the soil surface (Nunes *et al*., 2011). Akrasi and Ansa-Asare (2008), and Akrasi (2005) noted that availability of forest reserves, open forest, cocoa, coffee and oil palm plantations of the Pra River catchment accounted for the observed low sediment yield of the rivers. On the other hand, increase in sediment discharge of the Densu River Basin at both low and high discharges by Kusimi (2008) was attributed to reduction in vegetative cover.

Ayivor and Gordon (2012) also intimated that widespread erosion and river sedimentation in the Densu Basin, the Birim River Basin and the Ayensu basin resulted from continuous land use conversions and deforestation in the catchment. Again , Boakye *et al*.(2008) strongly attributed the increasing siltation rate of the Barekese reservoir to changes in land use and land cover resulting from population growth.

One of the major direct environmental impacts of uncontrollable activities is the degradation of water resources both in quantity and quality (USEPA, 2001; Fohrer *et al*., 2001). It may furthermore have an adverse negative effects on the hydrological regime, such that the evapotranspiration, runoff, and river discharge will be altered (Kristian *et al*., 1998). The shift from sub-surface flow to overland storm flows accompanying deforestation may produce dramatic changes in the catchment peak flows and make the catchment more vulnerable to erosion (Kondwani, 2013).The Run-offs entrain sediments especially sand and silt into the river channel from exposed surfaces, resulting in the siltation of the river bed (Kusimi, 2008) thereby causing a range of problems from considerable loss of soil fertility to accelerated river sedimentation and flooding (Bobrovitskaya, 2002).

Sedimentation occurrence results from runoff and soil erosion (Sajikumar and Remya, 2014). The process of soil erosion involves detachment of soil particles, transportation by the flowing water and deposition of sediments (Deferssha and Melesse, 2012; Schob *et al*., 2006). The sediment yield of a catchment describes the total amount of sediment flowing out from a drainage basin within a specified period of time (Jain *et al*., 2005; Verstraeten and Poesen, 2001). Catchment sediment fluxes are obtained through direct field measurement such as determination of suspended sediment concentration and river discharges (Kusimi, 2008; Akrasi, 2005; Amisigo and Akrasi, 1997), measurement of total eroded sediments and deposited sediment in small catchments and measurement of sediment volumes in ponds, lakes or reservoirs (Amegashie *et al*., 2011; Adwubi *et al*., 2009).

Sediment yield varies with the multiplicative effect of rainfall or runoff, topography, vegetation cover density, catchment size and soil type (Morehead *et al*., 2003; Inca, 2009; Milliman *et al*., 1999). Notably among them is changes in land use pattern resulting from human activities such as uncontrollable land use activities; poor agricultural practices, deforestation, illegal mining, urbanization, population growth, industrialization etc. Dunne (1979) argue that cover change is the dominant cause of sedimentation and that the effect of other controlling factors becomes more significant as the density of cover decreases. Also, Ayivor and Gordon (2012) indicated that over the last decade most rivers in Ghana have undergone transformation as a result of land use activities. Thus significant changes in land use in river basins have been accompanied by changes in sediment yield and channel characteristics. However, the relative significance of land use and cover changes in explaining the variation in suspended sediment yield is not fully explored as this also depends on the catchments considered.

1.2 Problem Statement

In recent years there has been seasonal report of water shortages in both urban and peri-urban centers such as Sekondi-Takoradi Metropolis, Kumasi Metropolis, etc. These cities and their surrounding towns and villages solely depends on the Pra River for domestic and industrial water supply. The problem, however, is the increasing rate of sediment transport in the catchment leading to the siltation and pollution of the streams, rivers and reservoirs, generally attributed to changes in land use/cover patterns (Kusimi *et al*., 2014; Ayivor and Gordon, 2012; Forkuo and Adubofour, 2012; Akrasi, 2008; Boakye *et al*., 2008). Eventually two problems are created in relation to water resources management and sustainability; (i) the carrying capacity of the river channels are drastically reduced due to continuous deposition of water borne sediments (Mavima *et al*., 2011) decreasing dry season flows (Plate 1.1) and (ii) deterioration of the water quality (Plate 1.2) and destruction of aquatic life resulting from increased turbidity as well as land surface nutrient and pollutant input (Mensah, 2009).

Plate 1.1. Dredging operations at Daboase intake as a result of siltation.

Plate 1.2. State of the Pra River at Daboase

As a result, water users in the catchment oftentimes suffer a reduction in the quantity of water available. What is worrying is that almost all the streams that used to flow through the urban and peri-urban centres to join major rivers have dried up or turned to ordinary natural channels silted up, which many times results in urban flooding during intense rainfall, because of urbanization and industrialization. Also, rivers of wide channels with relatively high discharge such that people used to swim in it have turned to streams as a result of increasing sediment yield and transport. Besides, Ghana Water Company Limited (GWCL) is faced with high treatment cost in order to bring the water to the acceptable standard limit for human consumption, leading to increases in tariffs. Moreover, in some places the high catchment sediment yield is rapidly deteriorating the filters of their treatment plant. For example, Bentil (2011) reported that treatment plant at Kibi, situated along the Birim River was shut down temporally because the river was too polluted to be treated for domestic use.

Catchment conservation management has been a serious challenge for most governments and institutions in charge of water management especially in developing countries, resulting to high rate of river sedimentation. This is due to lack of accurate data through consistent monitoring of sediment fluxes in the basin. Reliable information on the expected sediment yield and its sensitivity to the controlling factors is therefore crucial for sustainable catchment management and water resources development (Vanmaercke *et al.*, 2014), and critical in dealing with hydrological challenges of river basin's. However, due to the challenges associated with continuous measurement of suspended sediment concentration such as technical difficulties, remoteness of site, and cost (Akrasi, 2005; Edwards and Glyssen, 1999), continuous sediment load data rarely exist. Hence, empirical and physically-based models such as SWAT, MUSLE, ANSWERS, EUROSEM, and WEPP have been developed for soil loss estimations and sediment predictions. These models involve the development of relationships between the factors responsible for the production and delivery of catchment sediment. However, the models require large amount of data sets obtained through complex laboratory analyses and data collection (Silva *et al.*, 2010) for calibration and validation. And since in data-poor zones like developing countries such data rarely exist or very limited it makes it difficult to be appropriated for reliable predictions. As a result, water researchers and hydrologist have commonly adapted statistical (regression) models to predict and estimate suspended loads of rivers (e.g. Wuttichaikitcharoen and Babel, 2014; Akrasi, 2011; Verstraeten and Poesen, 2001; Akrasi and Ansa-Asare, 2008; Tamene *et al.*, 2006; Amisigo and Akrasi, 1997). These models basically relate the sediment concentrations to discharges and basin size, assuming water discharges as the dominant controlling factor in sediment yield rather than sediment supply. Thus, they are likely to over/underestimate the sediment loads (Kusimi *et al*., 2014; Asselman, 2000) especially in catchment's experiencing severe degradation activities.

1.3 Research Objectives

The goal of this research is to model the effect of land use/cover types on the variation in suspended sediment yield of the Pra River and to forecast same.

The specific objectives are:

- To assess the trend and extent of land use /cover changes in the catchment and their driving forces.
- To assess the variations in suspended sediment yield of the catchment.
- To determine the sediment generating areas of the catchment.
- To assess the relative importance of factors controlling sediment yield of the Pra River Basin

1.4 Research Question

The main question leading to the research is: "To what extend does land use/cover characteristics of a basin contributes or influences the variation in the catchment's suspended sediment yield"?

- What are the spatio-temporal trends of land cover changes in the Pra basin and their driving forces?
- What is the spatial sediment yield pattern of the basin?
- What are the critical sediment generating areas that must be given prioritized attention?
- Do land use/cover characteristics significantly influences the variations in the suspended sediment yield of river basins?

1.5 Hypothesis

The hypothesis guiding this study is:

- H_o: There is no significant variation in sediment yield with changes in land use/cover features
- H_a: There is significant variation in sediment yield with changes in land use/cover features.

1.6 Summary of Research Methodology

In order to achieve the objectives of this research the following approaches were employed. The methods are briefly presented here. The details are necessarily presented in the respective chapters.

- For objective one, Remote sensing and Geographic Information System (GIS) techniques were used to process multi-temporal Landsat images covering the basin. The images were taken through the stages of pre-processing, classification and accuracy assessment, and post-classification analysis. Field measurement included sampling or selection of land use/cover classes using Global Positioning System (GPS).
- Objective two involved both field measurement and laboratory analysis. Field measurement included measurement of water discharges and sampling of suspended sediments for nine hydrological stations in PRB. Sediment concentration analysis was conducted in the sediment laboratory at Water Research Institute (WRI) of Centre for Scientific and Industrial Research (CSIR).
- For objective three, the Revised Universal Soil Loss Equation (RUSLE) and the Sediment Delivery Distributed (SEDD) model integrated with GIS was adopted to spatially display the distribution of soil erosion and the sediment generating areas of the catchment.
- For objective four, statistical techniques such as correlation analysis and multiple regression analysis was adopted to develop sediment concentration model involving land cover types for estimation and prediction.

1.7 Relevance and Justification of the Research

Several studies on land use and land cover changes (e.g. Aduah *et al*., 2015; Frimpong, 2015; Forkuo and Adubofour, 2012; Boakye *et al.*, 2008) and suspended sediment yield and transport have been conducted (e.g. Asante-Sasu 2016; Kusimi *et al*.,2015; Kusimi *et al*., 2014; Akrasi 2011; Adwubi *et al*. 2009; Amegashie *et al*., 2011; Kusimi, 2008; Akrasi and Ayibotele, 1984; Ayibotele and Tuffour-Darko, 1979). However, the empirical relation between them have not been fully explored. Land use change studies have generally associated the impact of the observed changes to the occurrence of siltation and pollution of rivers and reservoirs (e.g. Ayivor and Gordon, 2012; Nunes *et al.*, 2011; Scanlon *et al.*, 2005; Jone *et al*., 2002; Fohrer *et al*., 2001; Dale, 1997; Marcelo *et al*., 2005; Kristian *et al*., 1998; Leblanc *et al.*, 1997). On the other hand, sediment yield studies and prediction (statistical) models (e.g. Akrasi, 2011; Tamene *et al*., 2006; Akrasi and Ansa-Asare, 2008; Verstraeten and Poesen, 2001) have strongly related sediment yield of catchments to surface runoff (discharge), topography and catchment area, stipulating that runoff and catchment area accounts largely for the variance in sediment yield, without investigating the significant contribution of land cover categories in explaining the observed variations in catchment sediment fluxes. Despite the fact that the observed variations in catchment sediment yield have often been attributed to land use/cover changes, the model outcome do not demonstrate strong influence of cover classes on sediment yields (e.g. Kusimi *et al*.,2015; Kusimi *et al*., 2014; Akrasi 2011; Adwubi *et al*. 2009; Amegashie *et al*., 2011; Kusimi, 2008). Runoff (discharge), catchment area and topography were more important controls.

The assumption here is that sediment loads of surface water bodies are mostly affected by basin area, topography, geology and the climatic conditions of the local area or region (Inca, 2009; Milliman *et al*.,1999). However Lu *et al*.(2017) indicated that sediment entering stream are not only controlled by climatic factors, geology or topography of the region but also the vegetative cover and human activities. This is also supported by Dunne (1979) that the effect of other sediment controlling variables rather becomes pronounce as the density of cover decreases. There are others such as Wilson (1973) who have opined that in a relatively uniform area the most single control of sediment yield is land cover. Therefore, the assumptions in the predicted models may not be verifiable in regions experiencing changes in land use setting. This is because within the same region with homogenous geological formation, topography and climate, basins or sub-basins can still experience respective anthropogenic threats. Hence, such basins will respond differently to sediment yield and transport, as Wolman (1967) indicated that even in the absence of precipitation, large quantities of suspended sediment may result from construction activities where heavy machinery operates directly in the stream channels. It implies that in developing sediment prediction models the influence of land cover characteristic cannot be down played. Subsequently, it is imperative to explore the influence of LULC characteristic by incorporating it into sediment yield models. In this way, the models estimate and prediction will be as a result of the combined effect of the sediment controlling factors in the basin and hence conform to reality, filling an essential gap.

Water resources development and management cannot be effectively and fully achieved without proper and prior knowledge about the catchment characteristics and morphology, and its associated features that directly or indirectly affects the discharge regime of the resource (Asante-Sasu, 2016). Hence, detail land use studies of basins need to be assessed alongside with sediment analysis in order to ascertain the rate of sediment yield in relation to land cover so as to be in a better position to appreciate the extent, dimension and the key driving forces of erosion within the catchment. Asante-Sasu (2016) empirically demonstrated that two years after the construction of Bui dam, the gross sediment yield of the reservoir had increase by 41.5% over the designed figure. He further cautioned that increase in sediment yield could worsen in the near future if changes in land use are not properly handled. Already Owabi dam, Barekese dam and Birimsu reservoir etc. in the Pra basin has been experiencing reduced capacity resulting from siltation attributed to anthropogenic activities (Boakye *et al*., 2008; Kusimi, 2008).

Therefore, for efficient catchment management and to ensure water sustainability, it is needful to conduct research aimed at explicit understanding of the catchment processes to improve knowledge and quantitative documentation of the impact of changes in land use and management practice on land and water resources (ICWE, 1992), and to provide necessary input to decisions that must balance trade-offs between positive benefits of land use change and negative consequences. Proper understanding of the effect of land use/cover characteristics on the variation in sediment loads, and its inclusion in the predictive models is essential for accurate predictions. It's only through this that water resources managers will be able to predict the changes in sediment yield and delivery in a changing land use and climatic conditions. This will aid in the implementation of sustainable catchment management practices and development of critical sediment generating areas. Eventually, the rate of siltation and pollution of surface water bodies will reduce and thereby restore the ecological integrity of the resource. It is through this that water availability in the right quantity and quality can be assured for mankind.

1.8 Organization of the Thesis

This thesis structured in the manuscript format and has been organized into nine chapters.
Chapter one introduces the research including the problem of sedimentation of rivers, research objectives, relevance, justification and description of the study area.

Chapter two reviews land use/cover change and sediment yield studies in Ghana. It explores the nexus between sediment yield and land use change.

Chapter three describes the study area and the procedures used to achieve the research objectives

Chapter four presents the patterns and trends of land use and land cover changes in the Pra River Basin within the period of study.

Chapter five assesses the sediment yield of PRB and their spatial variability's across the subbasins. In **chapter six**, the RUSLE and SEDD model integrated with GIS was used to display the spatial distribution of soil erosion and the sediment yield of the basin.

Chapter seven models and discusses the contribution of land cover types on the variation of suspended sediment yield of rivers (regression).

Chapter eight summarizes the results of this study whilst **chapter nine** concludes the research and gives recommendations for policy and further research.

CHAPTER TWO

LAND USE CHANGE AND SEDIMENT YIELD STUDIES IN GHANA: REVIEW

This part of the thesis is published in the
Journal of Geography and Regional Planning,
Vol. 11(9):122-133, September 2018 DOI: 10.5897/JGRP2018.0707

CHAPTER TWO LAND USE CHANGE AND SEDIMENT YIELD STUDIES IN GHANA: REVIEW

2.1 Introduction

Amongst the issues threatening water security both in quantity and quality in Ghana is the increasing rate of river basin's sediment yield, transport and deposition (Eswarem *et al*., 2001). Sediment yield is the mass of sediment annually leaving a catchment per unit area (Verstraeten and Poesen, 2001). It is the results of erosion and deposition processes within a catchment. Sediment yield and transport has been noted for altering the hydrological regimes of river basins (Ayivor and Gordon, 2012). High sediment yield usually comes with elevated soil loss within catchment, which compromises soil productivity affecting water quality and quantity as well as flood and control fishing, in addition to reducing reservoir lifespan and modifying river channel morphology (Mensah, 2009; Kusimi, 2008b; Peng *et al*., 2008). Thus, reliable information on the expected sediment yield of river basins is important for water resources management and development (Kusimi *et al*., 2014; Akrasi, 2011).

The sediment yield of a catchment result from the multiplicative effects of land use, climate, basin's size, geology and topography (Inca, 2009; Morehead *et al*., 2003; Milliman *et al*., 1999). The relative importance and sensitivity of these factors in explaining the spatial variation in sediment yield is crucial. Hence, the physical mechanisms responsible for the variation in sediment loads must be explained in order to have proper understanding of the interaction between sediment yield and these related factors responsible for the variability in sediment load. This is fundamental in addressing the hydrological challenges of river basins in order to predict the potential impact of existing practices and trends.

The influence of land use/cover on the sediment yield of a catchment is acknowledged by both land use and sediment researchers. Land use refers to the utilization of land for economic or productive use (IPCC, 2001) whilst land cover refers to the biophysical status of the earth's surface and immediate sub-surface (Campbell, 2002). The status of land use/cover determines the influence of rainfall intensity on erosion rate, transport and deposition (Costa *et al*., 2003). Therefore, changes in land use patterns automatically determine the variations in the catchment sediment yield. Hence, it is important to understand clearly the relative importance of land use/cover changes in explaining the spatial variation in sediment yield. The available evidence regarding the impact of conversion of land use type to another on the sediment loads of rivers must however, be explored. The aim of this study is to review and provide inventory on land use and sediment yield studies in Ghana and to explore their empirical relationship. This will help enhance the understanding of the link between land use, erosion and sediment yield in Ghana, which is fundamental to the development of sustainable land use alternatives as an integral component of river basin and water resources management.

2.2 Land Use and Land Cover Studies in Ghana

Land use and land cover studies are important in water resources development and management as it directly affect the hydrological processes of river basin's (Costa *et al*., 2003 and Fohrer, 2001). Accurate knowledge of existing land use and cover practices and trends represent the foundation for water resources management (Kelarestaghi and Jeloudar, 2011).

Land use has been defined by IPCC (2001); IGBP/IHDP (1999) as the utilization of land for economic or productive use. Hence, land use is based on function, the purpose for which the land is being used or the entire range of direct management activities that affect the nature of the land (Aduah *et al*., 2015; Campbell, 2002) such as agricultural, forestry, industry, as others related. On the other hand, land cover refers to the biophysical status of the earth's surface and immediate sub-surface (Briassoulis, 2006 and FAO, 1997) including vegetation, human constructions, water etc. It must be emphasized that land cover is the visual result of land use at a certain moment in time whilst land use reflects the degree of human activities directly related to land and making use of its resources.

While the earth's land mass remains essentially static with time and space, human demands have changed and increased, impacting heavily on the land as well as its flora and fauna composition in various ways (Ndulue *et al.*, 2015). Consequently, the land use and cover characteristics are being changed from time to time. The conversion or alteration of the natural landscape or changes in structure and function (quantitative) and changes in the areal extent(qualitative) of a given type of land use or cover refers to land use and land cover (LULC) change (Seto *et al*., 2002; Briassoulis, 2006). Thus, land cover change has a unique signature on the topography and soil distribution that gives rise to changes in natural resource.

The first land use map of Ghana using remote sensing was completed in 1998, at a scale of 1: 250,000 under the Ghana Environmental Resource Management Programme (GERMP)

Table 2.1: List of Land Use and Land Cover (LULC) data sources and mapping in Ghana

Research Type	Spatial Coverage	Data Sources	Temporal Coverage	References
LULCC	Owabi Catchment	LandSat & ASTER	1986 &2007	Forkuo & Adubofour,2012
LULCC	Prestea-Huni-Valley District	LandSat, ALOS & OrthoPhotographs	1990 & 2000 2010 2010	Perprah, 2015
LULCC	Barekese catchment	LandSat	1973,1986 &2000	Boakye *et al*., 2008
LULCC	Tarkwa Mining Area	LandSat & ASTER	1986,2002 & 1990, 2007	Kumi-Boateng *et al*., 2012
LULCC	Wassa-West District	LandSat	1986,2002	Kusimi, 2008a
LULCC	Ejisu-Juabeng	LandSat	1986 & 2004	Asubonteng, 2007
LULCC	Weija Catchment	LandSat	1990,2000 & 2011	Antwi-Agyakwa, 2014
LULCC	Nadowli District	LandSat	1990, 2000 & 2014	Basommi & Guan, 2015
LULCC	Wa East District	LandSat	1991, 2000 & 2014	Basommi *et al.*, 2015
LULCC	Birim North	LandSat	2002,2008 & 2015	Mayeem, 2016
LULCC	Densu Basin	LandSat & ASTER DEM	1990 & 2000	Yorke & Margai, 2012

Land use	Okyeman Traditional Area	LandSat	2000	Ayivor & Gordon,2012
LUC(Agric)	Akwapim South District	LandSat & Aerial Photos	1985, 1991 & 1972, 1974	Allotey, 2000
LULCC	Volta Basin of Ghana	LandSat	1984, 1992 & 1999	Braimoh & Vlek,2004
LCC(Urban)	Tema Metropolitant Area	LandSat	1990,2000 & 2007	Amenyo-Xa *et al*., 2010 (unpublished)
LULC	Bawku Municipality	LandSat	1989 & 2009	Adusei, 2014
LULC(Urban)	New Juabeng Municipality	LandSat	1985 & 2003	Attua & Fisher, 2011
LULC(Urban)	Accra	LandSat/GPS Survey	1985 & 2010	Yeboah *et al*., 2017
LULCC	Lake Bosomtwe Basin	LandSat	1986, 2002 & 2008	Adjei *et al*., 2014
LULCC	Southern Ghana	LandSat	2000 & 2010	Coulter *et al*., 2015
LULCC	Ankobra River Basin	LandSat ALOS-AVNIR-2	1986, 1991 & 2002, 2011	Aduah *et al*., 2015
LULC	Mampong Municipality	LandSat	1991, 2001 & 2009	Frimpong, 2015
LULCC	Ejisu-Juabeng	LandSat	1986 & 2007	Amoah *et al*., 2012
LULC	Sekondi-Takoradi Metropolis	LandSat, Topomap & River discharges	1988 & 2008	Aduah & Baffoe, 2013
LULCC	Bosomtwe District	LandSat	1986, 2010 & 2014	Appiah *et al*., 2015

NB: LULCC refers to Land use and land cover change

(Amatekpor, 1999). Since then there have been several applications of remote sensing in land use studies (Table 2.1). Some are published in refereed journals whilst others are unpublished masters' and PhD theses from universities across the globe. Generally, land use and land cover studies have been focused on land use/cover change assessment and prediction (e.g. Basommi *et al*., 2015), land use and climate (e.g. Dale, 1997), land use and water resources (e.g. Ayivor and Gordon, 2012), land use, soil erosion and sediment (e.g. Kavian *et al*., 2014), drivers of land use change (e.g. Braimoh and Vlek, 2005).

Over the years various land use and land cover studies in Ghana, using different methods and techniques have shown obvious occurrence of land use and land cover changes. Results of studies within the tropical forest zones show consistent decline of forest lands (e.g. Forkuo and Adubofour, 2012) whilst those within the savanna belt shows conversion from savanna lands to urban and farm lands (Adusei, 2014). For example, the review of historical document by FAO (2015) showed that between 1975 and 2000, agricultural lands expanded from 13% to 28% and increased rapidly to 32% of Ghana's total land area in 2013. The changing status of the forest area towards farmlands, urban lands and mining areas has been reported in several land use and land cover studies carried out in different areas for different periods (Table 2.1). Besides, there has been the conversion of different classes of land use and land cover classes with different rates and magnitudes.

2.3 Land Use and Land Cover Classification

Land use/cover classification is the process of mapping that is based on either visual or computer aided analysis to categorize all land cover features by their relative spectral patterns or unique similarities (Foody, 2002).

Table 2.2: Land use/cover classification scheme (Anderson *et al*., 1976)

Land Cover	Description
Water	Water courses (streams, rivers), ponds/flooded, lakes, reservoir
Farms/Shrubs	Short tree species and non-tree, Vegetation such as herbs, grasses and farms, commercial and horticulture crops.
Evergreen(deep)Forest	Tall trees including indigenous species and mature rubber located mostly in forest reserves and plantation farms.
Secondary(Open) Forest	Degraded/re-growth forest and tree crops and rubber with open canopy.
Settlement	Urban areas, Villages, Paved/Unpaved roads, bare land, car parks, playing fields.
Mining Areas	Areas where open cast/surface Mining has taken place and mining infrastructures.

Many classification systems are being used throughout the world including the Worlds land use classification, the Canada land inventory and land use classification, the Second land use survey of Britain classification and Canadian land use classification (Scace, 1981). Even though there is not an internationally accepted format, most land use and cover studies especially in Ghana appears to be modelled based on the classification scheme of Anderson *et al*. (1976) (Table 2.2). The application of Remote Sensing (RS) and Geographic Information System (GIS) over the years has greatly enhanced image processing and classification for the production of thematic maps. It provides a map-like representation of the earth's surface that is spatially continuous and highly consistent, as well as available at a range of spatial and temporal scales (Foody, 2002). As a result, research on land use and land cover have demonstrated the full functionality of RS and GIS in (i) classifying past and present land uses (Boakye *et al*., 2008), (ii) predicting future changes (Amoah *et al*., 2012), (iii) evaluating the magnitude and rate at which these changes are occurring (Peprah, 2015) and (iv) spatially characterizing the patterns of change, pinpointing locations at risk (Yorke

and Margai, 2012). This is made possible through the use of remote sensing imageries such as Landsat images (MSS,TM, ETM, ETM^+), Systeme Probatoire D'observation de la Terre-High Resolution Visible Image (SPOT-HRV), IKONOS, Moderateresolution Imaging Spectroradiometer (MODIS), Sentinel, QUICKbird, Advanced Very High Resolution Radiometer-National Oceanic & Atmospheric Administration (AVHRR-NOAA), Light Detection and Ranging(RADAR), GOES, ASTER, Advanced Land Observation Satellites(ALOS), European Remote Sensing Satellite (ERS-1&2), Japanese Earth Resources Satellite(JERS), Meteosat, Scanning Multi-Channel microwave Radiometer(SMMR), Special
Sensor Microwave/Imager (SSM/I) etc. Among these imageries LandSat, ALOS, AVHRRNOAA, SPOT and ASTER have been identified for land cover /land use and vegetation studies. However, review of land cover studies in Ghana shows most researchers prefers LandSat imageries (e.g. Braimoh & Vlek 2004; Yeboah et al., 2017 ; Aduah, *et al*, 2015; Boakye *et al*, 2008) due to the uniqueness of the dataset as the only long-term digital archive with a medium spatial resolution and relatively consistent spectral and radiometric resolution (Yang *e t al*,
2000). It's also easily accessible and can be obtained at low cost.

Images are classified using either the supervised or unsupervised classification technique or sometimes both. The unsupervised classification uses cluster algorithms to automatically classify an image into several spectral classes based on statistical information within the image. The Cluster algorithms iteratively partition the image spectrally by determining statistical groups based on the numerical information (DN values) present in the image. However, supervised classification aims at allocating features based on their spectral peculiarity to a set of pre-defined classes. This method requires familiarity with the study area through field work, aerial photographs, conventional maps or google earth (Chuvieco and Huete, 2010, Jensen, 2005). Supervised classification systems can be grouped as either parametric or non-parametric methods. The parametric methods include maximum likelihood classification (MLC) (Campbell, 2002), fuzzy-set classifiers (Stavrakoudis *et al*., 2011), sub-pixel classifiers, spectral mixture analysis (Nichol *et al*., 2010) and object-oriented classifiers (Platt and Rapoza, 2008). The nonparametric methods include artificial neural networks (ANN) (Laurin et al., 2013; Atkinson and Tatnall, 1997), decision tree and support vector machines (Huang *et al*., 2002). However, available literature indicate that the statistically-based MLC algorithm classification is most preferred and used very often (Yeboah *et al*., 2017; Forkuo and Adubofour, 2012; Boakye *et al*., 2008, Kusimi, 2008a).

To assess the correctness of the classification, accuracy assessment is essentially performed in land use and land cover classification (Foody, 2002). Campbell (1996) defined accuracy in thematic mapping from remotely sensed data as the degree of 'correctness' of a map or classification. A map may be considered accurate if it provides an unbiased representation of the region it portrays. In other words, classification accuracy is the degree to which the derived image agrees with the reality or conforms to the truth (Smits *et al.*, 1999). There are many methods of accuracy assessment in literature but the most widely used is the Error (Confusion) matrix though few challenges have been pointed out by Foody (2002). The confusion matrix provides a basic information of the proportion correctly classified (PCC). It may be useful in refining estimates of the areal extent of classes and also enhance the value of classification for the user (Foody, 2002). It also furnishes the analyst with errors of omission and commission as well as overall, user and producer accuracy (Lilesand and Kiefer, 2000). Most of the literatures reviewed in this study recorded an overall accuracy of 75% and above signifying strong agreement of the classified image and the reality (e.g Yeboah *et al*., 2017; Peprah, 2015; Adjei *et al*., 2014; Forkuo and Adubofour, 2012)

An important tool in monitoring land use and land cover change is the change detection (Mertens and Lambin, 2000). Land use and land cover change detection is the process of identifying differences in the state of land features or phenomenon by mapping it at different times over a period (Coppin *et al*., 2004; IGBP/IHDP, 1999). It involves the use of multi-temporal datasets to identify areas of change between specific dates of imaging. Copping *et al*. (2004) categorized remote sensing techniques used for change detection as algebraic, transformation, classification and visual analysis techniques. Algebraic based technique include normalized difference vegetation index (NDVI) differencing, ,image differencing, image regression and change vector analysis (CVA); the transformation method include multi-date Principal Component Analysis (PCA), Chi-square transformations and Kauth-Thomas (KT); the classification methods consist of post-classification comparison(PCC), multi-date classification, spectral–temporal combined analysis while Visual analysis techniques are primarily based on the visual interpretation of aerial photographs and high resolution images. Algebraic and transformation methods are suitable for detecting continuous changes, while classification methods are effective for categorical changes (Abuelgasim *et al.*, 1999), but depend on the accurate geometric registration and classification of individual images. Continuous changes mean changes in the concentration or amount of an attribute (e.g. biomass and the leaf area index of a forest), while categorical changes are the conversion of one land cover type to another (e.g. Forest to urban area). The reviewed literature indicates that the classification method, specifically the post-classification comparison is commonly used in the land use/cover change analysis, perhaps because of its effectiveness in categorical changes (Aduah *et al.*, 2015; Kumi-Boateng *et al*., 2012). However, a good change detection method should indicate the area and rate of change, spatial distribution of changed features, change trajectories of cover types and accuracy assessment of change detection results (Inca, 2009). Change detection has numerous advantages in land use planning. Amongst them includes i) the provision of the basis for coordinated policies and strategies to guide development at the local level and within the framework of implementing short-term actions, ii) the revelation of the spatial pattern of development in the area whether negative or positive and thereby helping to identify areas where a particular type of change should be encouraged or discouraged (Lamber *et al.*, 2001).

2.4 Driving Forces of Land Use and Land Cover Changes

Land use and land cover changes do not occur in vacuum. It is the resultant effect of human activities within the natural environment. Thence, land use/cover changes are determined by complex interactions of environmental and socioeconomic factors (Kelarestaghi and Jeloudar, 2011). The environmental factors include climate, geomorphology, soil and geology. According to IGBP (1993), possible socio-economic forces behind land use/cover changes can be grouped into six namely population, level of affluence, technology, political structures, attitudes and values of the people. They further argue that land cover modification is mostly driven by human influence rather than natural changes (Ayivor and Gordon, 2012). This is supported by Benneh and Agyepong (1990) that population increase, development policies, urbanization and agriculture contributes greatly to land cover change. Again, some researchers within the country have shown that the rate of land cover changes are the direct results of population, urbanization and agriculture (Appiah *et al*., 2014; Boakye *et al.*, 2008; Braimoh and Vlek, 2005) which are regional in nature as events in one location impact on land use in other locations (McCusker and Carr, 2006; DeHart and Soule, 2000). However, Lambin *et al*. (2001) opines that the utilization of new lands was created by local as well as national markets and policies. Therefore, the driving forces are not only regional or global in scale, but also local (Geist and Lambin, 2002) in that actions at the local level directly affect land use/cover. Of course the combined application of the various land use theories such as Malthusian and Boserupian that relate land use to population growth, the Ricardian paradigm that links land use to intrinsic land quality, and the Von Thu¨nen paradigm that associates land use to location of land parcels (Mortimore, 1993) indicates that the driving forces are not only regional but also local. Hence, it is imperative for land use/cover researchers to dig deep down to the local level to identify specific factors influencing land use/cover change, be it global, regional or local.

2.5 Sediment Yield of River Basins

Sediment yield and loading of river basins present important measure of the hydrology of the drainage basin and the erosion processes (Walling and Fang, 2003). Sediments are particles that can be transported by a fluid flow and deposited as a layer of solid particles on the bed of a body of water. Sediment yield of a catchment is the amount of sediment load passing through the outlet of a drainage basin within a specified period of time (Jain *et al*., 2010; Verstraeten and Poesen, 2001). It involves bed load and suspended load expressed in terms of mass or volume per unit of time. Bed load sediments are those that are transported by saltation and traction e.g. gravels and cobbles whilst suspended load is sediment in suspension by the upward components of turbulent currents (Akrasi, 2011; Nagle, 2000) e.g. silt, clay, and sand. The amount of sediment transported downstream depends on the rate and magnitude of erosion and transporting capacity of the flowing medium viz: soil erodibility, rainfall erosivity, catchment topography, size and vegetative cover (Ndulue *et al*., 2015; Pelletier, 2012). Soil erodibility is defined by Hudson (1995) as the soil's susceptibility to erosion which varies with the soil texture, aggregate stability and shear strength apart from soil infiltrability and organic in addition to chemical content. The rainfall erosivity also defines the potential ability of rain to cause erosion. It is based on the kinetic energy and momentum of the runoff. Therefore, the erosivity index of the storm is a function of rain droplet distribution, frequency, intensity and velocity. Oduro-Afriyie (1996) used the Fournier index to estimate the rainfall erosivity indices for stations in Ghana. His results showed that the erosivity index, c for Ghana ranges between 24.5mm in Sunyani to 180.9mm in Axim. Small flows carry small sediment loads and are essentially ineffective in scour and deposition.

Topographic features that influences erosion are slope; its size and length as well as shape of a watershed and aspect of a mountain. The amount of erosion on an arable land is influenced by the steepness, length and curvature. Thus, the steeper and longer the slope, the more the susceptibility to erosion (Amegashie *et al*., 2011). Vegetative cover serves as the protective layer or buffer between the atmosphere and the soil. It interferes with the amount of rain drops reaching the soil surface. The vegetative cover depending on the canopy will protect the soil from the erosive activity of rainfall that is very high (Akrasi, 2008).

2.6 Sediment Yield Assessment and Modeling

Soil erosion in river basins continues to be a serious problem in the world (Eswaran *et al*., 2001). Accurate determination of suspended sediment loads and its associated fluxes in rivers is of great importance for water resources development and management.

There are two approaches for determining the sediment loads in rivers; direct (field) measurement and modeling (physical and empirical). Field measurement methods usually include measurement of suspended sediment load and discharges (Kusimi, 2008b; Akrasi, 2005; Amisigo and Akrasi, 1997), measurement of total eroded sediments and deposited sediment in small catchments and measurement of sediment volumes in ponds, lakes or reservoirs (Amegashie et al., 2011; Adwubi *et al*., 2009). Measurement of suspended sediment concentration involves sampling and laboratory analysis. Four main types of suspended samplers are available: integrating samplers, instantaneous samplers, pumping samplers and sedimentation traps. The preferred one is the integrating samplers. However, in the absence of depth integrated sampler some researchers such as Akrasi & Ansa-Asare (2008) and Kusimi *et al*. (2014) used the dipping method and applied the necessary correction according to Rooseboom and Annandale (1981) and Demmak (1976). The sampled water was taken to laboratory to determine the suspended sediment concentration through either the evaporation or filtration method. For high concentrations of sediment, the evaporation method is better whilst the filtration method works better for low concentrations of the water-sediment mixture (Ayibotele and Tuffour-Darko, 1979). Another possibility is to make measurement with a field turbidity meter that has been calibrated against natural samples from the site where it's being used (Mawuli and Amisigo 2017; Minella *et al.*, 2008). The suspended sediment concentration obtained can be used to compute for the sediment load in tons per day as well as the specific sediment yield (Akrasi, 2008; Kusimi *et al*., 2014).

As a result of the difficulties associated with obtaining continuous records of concentration through the direct method due to cost, remoteness of site, number of sampling and technical difficulties (Edwards and Glyssen, 1999) water researchers have resorted to the use of empirical models to estimate the suspended loads in rivers that have no direct measurement (Akrasi, 2011; Akrasi and Ansa-Asare, 2008; Syvitski and Milliman, 2007; Amisigo and Akrasi, 1997). These include the erosion rate method, catchment based method, rating curve method and regression method. For instance, in 1974, Ayibotele and Tuffour-Darko established sediment rating curves for suspended and bed loads for the Densu river at Manhyia, Amisigo and Akrasi (2000) also developed sediment yield prediction model for south-western river basins in Ghana, Akrasi (2005) developed the same for the Volta basin system, while Akrasi and Ansa-Asare (2008) developed prediction model for Pra River Basin using runoff and catchment area. Later, Akrasi (2011) developed simple empirical models using multiple regression to predict suspended sediment yield within the south-western and coastal river basin systems in Ghana. The models relate the sediment yield to the catchment area and simple climatological indices such as rainfall and runoff. However, sometimes the results obtained from the curve may be problematic since storm flow hydrographs usually, but not always, are characterized by higher suspended sediment concentrations during the rising limb than the falling limb. For instance, Kusimi (2008b) noticed from his study in the Densu river basin that even during low flows, sediment concentration remains relatively high.

Besides, there are various empirical models to estimate the sediment yield of catchment such as the Universal Soil Loss Equation (USLE) (Wischmeier & Smith, 1978), Modified Universal Soil Loss Equation (MUSLE) (Blaszczynski, 2003) and the Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997). The USLE/RUSLE is a field scale erosion model and cannot be used to estimate the sediment yield directly. This is because it does not account for sediment deposition along the travelling path. To account for this Sediment Delivery Ratio (SDR) is incorporated to estimate the total sediment transported to the basin's outlet (Jain and Kothyari, 2000). However, USLE/RUSLE only predict the amount of soil loss through the sheet and rill erosions but not from gully, channel or bank erosion which may lead to underestimation. Notwithstanding, the RUSLE and its integration with GIS and remote sensing has been widely used by many researchers to display the spatial distribution of soil erosion and estimate the mean annual soil loss of a catchment with good results (Ayalew, 2014; Kayet *et al*., 2018). The uncertainties that normally stem from the availability of long-term reliable data for soil erosion modelling is not unique to RUSLE application. The model is relatively simple, easy to parameterize and requires less data to operate with.

There are also physically-based models developed for hydrologic prediction and for understanding hydrologic processes which are very useful in environmental management. Particular models developed to explore the impact of land use change on hydrological processes includes SWAT (Arnold *et al*., 1998), WEPP (Nearing *et al*., 1989), EUROSEM (Morgan *et al*., 1998), ANSWERS (Beasley *et al*., 1980), CREAMS (Kinsel, 1980), Systeme Hydrologique Europian-TRANsport (SHETRAN) (Ewen *et al*., 2000), KINEROS (Woolhiser *et al*., 1990) etc. These are event based models, continuous, spatially and temporally distributed at catchment scale. However, these models require huge amount of data inputs, and many calibration parameters, that are characterized by complex laboratory analyses or difficult and expensive field data collection (Silva *et al*., 2010). Hence, their application in developing countries where physical sediment data are virtually non-existent is highly limited.

2.7 Sediment Yield Studies in Ghana

Even though sediment yield measurement in Ghana is deficient due to high cost and technical challenges, a number of studies have been conducted. Literature shows that between 1974 and 1976, Water Resources Research Institute (WRRI) measured bed load at eight different gauging stations on some of the large rivers (basin >2000km^2) in southern Ghana (Ayibotele and TuffourDarko, 1979). Also sediment loads of rivers in the south-western river basin systems of Ghana were measured (Amisigo and Akrasi, 2000). Table 2.3 gives an overview of current collected sediment yield data in Ghana and their sources. It must be noted from Table 2.3 that the sediment yield measurement from gauging stations (GS) are generally suspended load and do not include the bed load. This perhaps explains the differences between the sediment yields derived from reservoir sedimentation rate and gauging stations. Nonetheless, the difference may also be attributed to specific catchment characteristics and environmental conditions. For example, sediment observation from reservoirs are mainly for small catchment (<5km^2), while that from gauging stations are for relatively larger catchments (>100km^2). It shows small catchment generate more sediment because it has steeper gradient, less storage capacity, relatively shorter travel distance and less time for entrapment, and greater response to flood (Milliman *et al*., 1999).

Available literatures also indicate that water researchers have developed predictive models to estimate sediment yield for rivers where no measurement is conducted. For example, Akrasi developed simple predictive tool from measured sediment data to estimate the total suspended sediment input to the Volta Lake. His results showed annual suspended sediment input of about 52tkm^{-2}yr^{-1} from the catchment surface (Akrasi, 2005). Also, Akrasi and Ansa-Asare used collected data within the Pra Basin to develop simple empirical model to predict specific suspended sediment yield and nutrient export coefficients within the Pra Basin. The sediment yield of Pra Basin was estimated to be 50.8$tkm^{-2}yr^{-1}$ (Akrasi and Ansa-Asare, 2008). In 2011, Akrasi used measured suspended sediment transport for 21 monitoring stations in southern Ghana to develop simple predictive models for catchment where no measurement had been undertaken. The model results showed that the sediment yield of the south-western and coastal basins ranged between 11 - 50 $tkm^{-2}yr^{-1}$ (Akrasi, 2011). The model indicated that runoff and catchment areas account for a large proportion of the variance of the suspended sediment yield.

Table 2.3: Sediment yield data and sources in Ghana

River/Catchment Name	Measuring Location	A(km^2)	Sediment Yield($tkm^{-2}yr^{-1}$)	Type	Reference
	Dua	0.35	10270	R	Adwubi *et al.*,2009
	Kumpalgogo	0.40	1699	R	Adwubi *et al.*,2009
	Doba	0.70	1850	R	Adwubi *et al.*,2009
	Zebilla	1.1	2668	R	Adwubi *et al.*,2009
Annum	Konongo	681	17.9	GS	Akrasi&Ansa-Asare,2008
Birim	Bunso	150	24.3	GS	Akrasi&Ansa-Asare,2008
Oda	Anwiankwanta	1303	26.9	GS	Akrasi&Ansa-Asare,2008
Offin	Mfensi	1515	24.8	GS	Akrasi&Ansa-Asare,2008
Birim	Oda	3248	40	GS	Akrasi&Ansa-Asare,2008
Offin	Dunkwa	8345	45.1	GS	Akrasi&Ansa-Asare,2008
Pra	Assin-Praso	9793	32.6	GS	Akrasi&Ansa-Asare,2008
Pra	Twifu Praso	20767	44.1	GS	Akrasi&Ansa-Asare,2008
Pra	Beposo	22818	46.9	GS	Akrasi&Ansa-Asare,2008
Afram	Aframso	308	14.8	GS	Akrasi, 2005
Pru	Pruso	1121	9.1	GS	Akrasi, 2005
Daka	Ekumdipe	6586	26.9	GS	Akrasi, 2005
Oti	Saboba	54890	46.6	GS	Akrasi, 2005
White Volta	Pwalugu	57397	21.7	GS	Akrasi, 2005
Black Volta	Lawra	90658	15.2	GS	Akrasi, 2005
White Volta	Nawuni	96957	22.9	GS	Akrasi, 2005
Black Volta	Bamboi	128759	25.7	GS	Akrasi, 2005
	Bugri	2.2	1828	R	Amegashie *et al.*, 2011
Ayensu	Near outlet	1700	88.2	GS	Milliman & Fansworth,2011
Ankobra	Near outlet	6200	290.3	GS	Milliman & Fansworth,2011
Pra	Near outlet	38000	63.2	GS	Milliman & Fansworth,2011
Volta	Near outlet	400000	47.2	GS	Milliman & Fansworth,2011

Bia		10135	25.5	GS	Akrasi, 2011
Tano		16061	24.14	GS	Akrasi, 2011
Ankobra		8366	48.15	GS	Akrasi, 2011
Butre		422	35.34	GS	Akrasi, 2011
Pra		23168	49.17	GS	Akrasi, 2011
Amisah		1298	27.49	GS	Akrasi, 2011
Nakwa		1409	35.85	GS	Akrasi, 2011
Ayensu		1709	16.75	GS	Akrasi, 2011
Tordzie		2916	11.01	GS	Akrasi, 2011
Oda	Anwiankwanta	1288	51	GS	Kusimi *et al*., 2014
Offin	Adiembra	3101	37	GS	Kusimi *et al*., 2014
Birim	Oda	3104	94	GS	Kusimi *et al*., 2014
Pra	Brenase	2168	69	GS	Kusimi *et al*., 2014
Pra	Assin-Praso	9235	24	GS	Kusimi *et al*., 2014
Pra	Twifu-Praso	20625	128	GS	Kusimi *et al*., 2014
Pra	Heman	22758	329	GS	Kusimi *et al*., 2014

NB: 'R' indicates that the sediment yield value was obtained from bathymetric surveys in a reservoir.

'GS' indicates that the value was obtained from measurements at a gauging station.

2.8 Sediment Yield and Land Use/Cover Change

Land use and cover features play significant role in the erosion and sedimentation process of a catchment. They control the intensity of the rain drops reaching the soil surface causing erosion, and the frequency of the overland flow and sediment deposition (Mitchel, 1990; Bryan and Campbell, 1986). Hence, some land use and vegetative types create favorable conditions for runoff and sediment loss than others (Nunes, 2011). For instance, conversion of agricultural, forest, grass, and wetlands to urban areas usually comes with increase in impervious surface, which alter the natural hydrologic conditions such as runoff and sedimentation processes within a watershed. It therefore means that the sediment yield of a basin becomes more sensitive to variations in rainfall intensity and topography as the vegetative cover decreases from forest cover through agricultural crops to rangeland (Vanmaercke *et al*., 2014; Gellis *et al*., 2006; Trimble, 1995; Dunne, 1979; Wilson, 1973).

Rivers where sediment yield have both increased and decreased in recent decade resulting from changes in land use have been reported by several researchers in Africa and beyond (e.g. Kusimi, 2008b). Asante-Sasu (2016) showed that two years after the construction of Bui dam in Ghana, the gross sediment yield of the reservoir had increase by 41.5% over the designed figure resulting from land use activities. Ngo *et al*.(2015) concluded that the increase of agricultural land, expansion of urban area and the removal of forest land dramatically increased runoff and sediment of Da River

Basin of Hoa Binh Province. Again, Huang and Lo (2015) applied SWAT model to assess the impact of land use change on soil and water losses from Yang Ming Shan National Park in Northern Taiwan. Their results showed that 6.9% decrease in forest and 9.5% increase in agricultural land caused sediment yield increase of 0.25tha^{-1}. Thus, Land use change has generally been accepted as influencing factor contributing to the variation in sediment yield of river basins (Ngo *et al*., 2015; Tang *et al*., 2005; Dunne, 1979; Douglas, 1967). However, the evidence for the impact of changing land use on the sediment yield of rivers is still less clear. The empirical relation linking sediment yield to land use features remains unclear. Developed empirical models for the estimation and prediction of sediment yield in river basins in Ghana do not reflect clearly the influence of changes in land use on the sediment yield. Rather, they relate catchment sediment yield to climatological indices: rainfall and runoff, and catchment area only (e.g. Amegashie *et al*., 2011; Akrasi and Ansa-Asare, 2008; Akrasi, 2005). Hence, the contention that land use is the dominant factor to sediment yield of river basins (Kusimi, 2008b; Walling, 1999) and that the influence of other factors becomes more pronounce in a changing land use has been cataloged thoroughly in literatures but without supporting data. Their results and models relate sediment yield to rainfall, runoff and catchment size more than vegetative cover (e.g. Amegashie *et al*., 2011; Akrasi, 2005).

2.9 Conclusions

Sediment yield of river basins poses great threat to the available water resources. It is generally accepted that sediment yield of a basin is influenced by the effect of land use/cover, rainfall and catchment geomorphology. Various land uses and sediment yield studies discuss the sensitivity of catchment sediment yield to land use change. However, the relative importance of land use/cover type in explaining the spatial variation in sediment yield is less clear-cut. Existing sediment studies and regression model results especially in Ghana relate sediment yield of studied catchment to rainfall, runoff and catchment morphology without exploring empirical evidence of land use impact. Though the observed variations in sediment yield have been strongly attributed to land use/cover changes, the results do not show strong influence of cover types on sediment yield. For sustainable water resources management, it is important to empirically explore the link between land use change and the sediment yield of river basins. The study also recommends the use of the RUSLE model to display the spatial distribution of soil erosion for data-deficient basins since it does not require huge amount of data for calibration and validation.

CHAPTER THREE METHODOLOGY

3.1 The Study Area

3.1.1 Background of the Study Area

The Pra River Basin (Fig.3.1) is one of the most significant river basins in Ghana experiencing severe anthropogenic influence ranging from illegal mining, pollution, agriculture and urbanization. It is the largest basin among the three south-western river basins (i.e. Pra, Ankobra and Tano) in Ghana. It is located between Latitudes 5^{o}N and 7^{o} 30' N, and Longitudes 2^{o} 30' W, and 0^{o} 30' W. It consist of four major tributaries namely; Anum, Ofin, Oda and Birim. They take their source from the Mampong-Kwahu ridges and flow southwards for about 240 km before discharging into the Gulf of Guinea at Shama in the Western Region of Ghana. It has a total catchment area of about 23,200 km^2 and spans four regions; Ashanti, Western, Central and Eastern, covering forty-three administrative districts (Water Resources Commission, 2012). The basin has approximately 4.2 million people with a population growth rate of about 2.20% per annum.

The basin is naturally endowed. It has average annual discharge of 4174 Mm^3 and quite high in ground water potential with aquifer transmissivity ranging between 5.7m^2/day and 799 m^2/day (Water Resources Commission, 2012). Besides the river network, is the existence of the only remarkable natural lake (Lake Bosomtwi) occupying land area of 52 km^2. There are nine small dams within the basin constructed to impound water for domestic and industrial uses, serving three regional capitals, forty-one districts and over one thousand three hundred towns. There are three irrigation schemes located in the basin under the management of Ghana Irrigation Development

Authority (GIDA). These include Anum Valley-Bottom irrigation project, Adiembra irrigation project and Gyadam irrigation project.

3.1.2 Topography and Land Use

The terrain is relatively level and undulating with most astounding heights of up to 870 m above mean sea level situated in the northern segments and the edges of the eastern parts.

The principal vegetation of the basin consists of moist semi-deciduous forest type. The basin is heterogeneously covered with closed forest, open forest, farm/grasslands, settlement, mining and water body. It is an agriculturally productive zone and thus has become the hub of agricultural activities. Most of the large cocoa growing areas in Eastern, Ashanti, and Central regions are located in the basin. Subsistence agriculture is largely practiced with production of food crops such as cassava, plantain, cocoyam and maize.

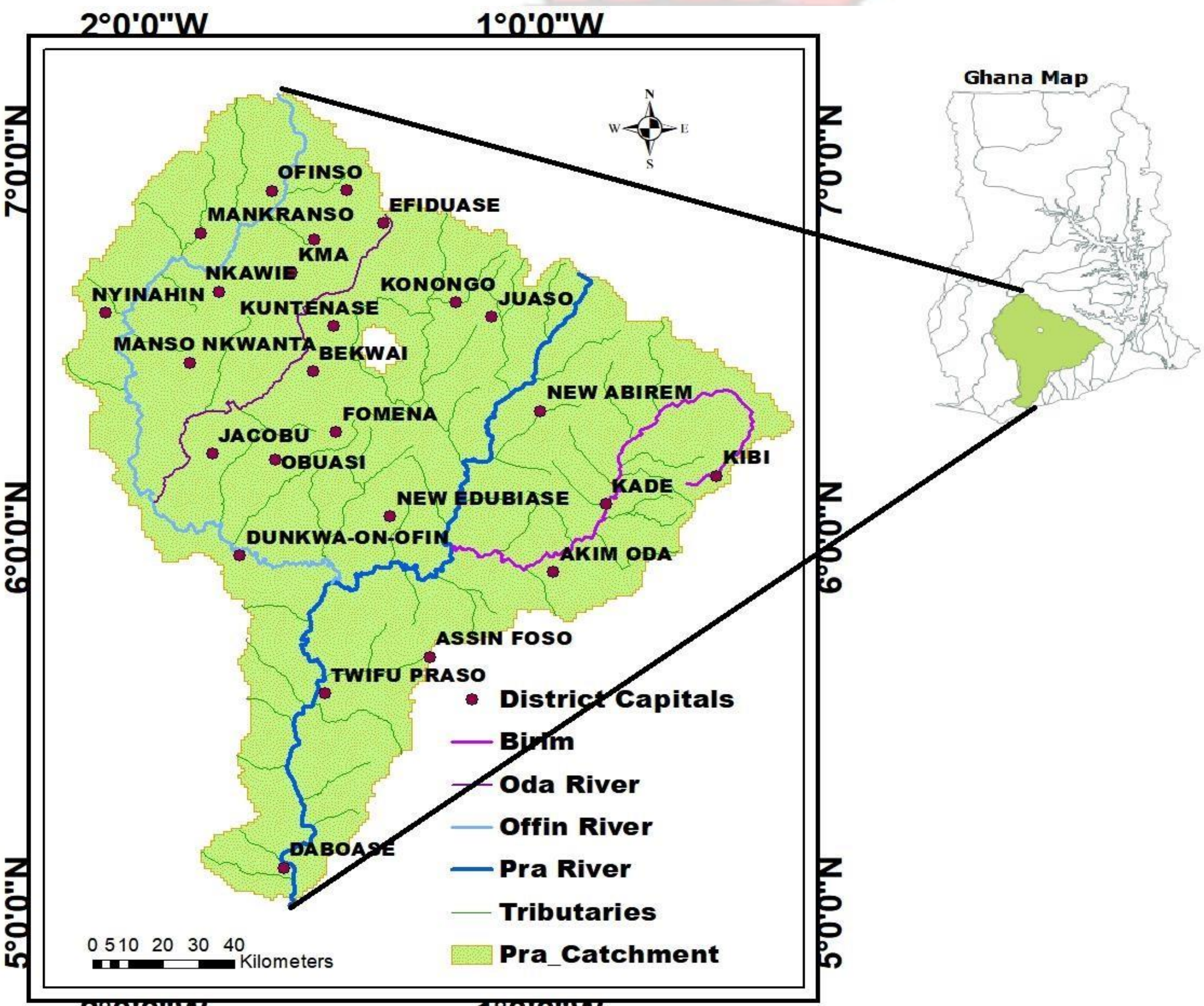


Fig. 3.1. Map of the Pra River Basin

3.1.3 Climate

The basin falls within the sub-tropical wet climatic zone, with double rainfall seasons (May-July and September-November). The mean annual rainfall ranges between 1300 mm and 1900 mm increasing south-westwards. Relative humidity is very high averaging between 70% - 80% throughout the year. The average minimum and maximum temperatures are 26^{o}C in August and 30^{o}C in March respectively. Climate stations used for the development of rainfall erosivity map is shown in Table 3.1.

Table 3.1: Climate stations in and around PRB used for the study

No.	Stations ID	Name	Latitude	Longitude	Altitude
1	21020KIB	Kibi	06^0 10'N	00^0 33'W	274.2
2	21043NKA	Nkawkaw	06^0 33'N	00^0 46'W	229
3	19004BOB	Bobiri	06^0 41'N	01_0 21'W	213.3
4	19006JUA	Juaso	06^0 35'N	01_0 07'W	243.8
5	17009KSI	Kumasi Airport	06^0 43'N	01^0 36'W	286.3
6	19017EFF	Efiduase	06^0 51'N	01^0 24'W	335.1
7	17025BEK	Bekwai	06^0 27'N	01^0 34'W	228.6
8	17040AKR	Akrokeri	06^0 18'N	01_0 38'W	243.7
9	23016HAL	Half Assini	05^0 03'N	02^0 53'W	9.1
10	16004ASA	Asankragua	05^0 48'N	02^0 26'W	182.9
11	23003TDI	Takoradi Airport	04^0 53'N	01_0 46'W	4.6
12	23001AXM	Axim	04^0 52'N	02^0 14' W	37.8
13	17015DUN	Dunkwa-On-Ofin	05^0 58'N	01^0 47'W	158.6
14	21088ODA	Akim Oda	05^0 56'N	00_0 59'W	139.4
15	23023TWI	Twifu Praso	05^0 36'N	01_0 33'W	76
16	18026ATI	Atieku	05^0 34'N	01^0 42'W	106.6
17	21049ACH	Achiase	05^0 50'N	00^0 56'W	167.6
18	19036APE	Aperadi	05_0 47'N	01^0 06'W	
19	19050DOM	Dompim	05^0 06'N	01^0 40'W	153

20	19007KON	Konongo	06^0 37’N	01^0 13’W	243
21	18002WAS	Wassa Akropong	05^0 47’N	02^0 05’W	768
22	14004EJU	Ejura	07^0 24’N	01^0 21’W	228.7

3.1.4 Geology and Soil

The basin is underlain with woods ochrosols which are soluble in nature and pre-Cambrian rocks (Birimian and Tarkwaian) (Awotwi *et al*., 2018). Groundwater generally occurs in the Birimian formations, comprising the meta-sediment rocks and meta-volcanic rocks. Soil types of the basin include acrisols, lixisols, leptosols, alisols, luvisols and fluvisols with acrisols covering about 79% of the total landmass. Since the geological setting of the basin’s rock systems is rich in gold and mineral resources, it has become the hub of mining activities (Kesse, 1985). Some mining companies in the basin include AngloGold Ashanti, Newmont Ghana Ltd, Golden Star, Asanko Gold Mines Ltd, Bonte Gold Mines Company Ltd. etc. Besides there are several small scale mining and “galamsey” activities in the towns and villages.

3.1.5 Sampling Stations

For the purposes of this research, nine sub-basins were delineated with nine outlets (Table 3.2). These outlets are existing hydrological stations in the basin. Monthly discharge measurements alongside with sediment sampling were undertaken at the stations from October, 2017 to September, 2018.

Table 3.2: Sampling Stations in PRB

Sub-Basin	Station (River)	Latitude	Longitude
Upper Ofin	Adiembra (Ofin)	06^0 36’N	02_0 02’W
Oda	Anwiankwanta (Oda)	06^0 28’N	01_0 38’W
Anum	Konongo (Anum)	06^0 36’N	01_0 15’W
Birim	Kade (Birim	06^0 05’N	00_0 50’W
Assin Praso	Assin Praso (Pra)	05^0 56’N	01_0 22’W
Upper Pra	Brenase (Pra)	06^0 12’N	01_0 10’W
Lower Ofin	Dunkwa-On-Ofin	05^0 59’N	01_0 49’W
Twifu Praso	Twifu Praso (Pra)	05^0 36’N	01_0 33’W
Lower Pra	Beposo (Pra)	05^0 06’N	01_0 34’W

3.2 Methods

3.2.1 LULC change Analysis

3.2.1.1 Data Acquisition

- Downloading of Landsat 5TM, Landsat 7ETM+ and Landsat 8OLI_TIRS from USGS Earth explorer website (Http://earthexplorer.usgs.gov/).
- Downloading of ASTER Global Digital Elevation Model (ASTGDEMV2_0N07W002).
- Sampling of land cover classes using GPS and Google Earth map.

3.2.1.2 Definition and Delineation of drainage Basins

ASTER DEM projected unto the UTM coordinate system zone 30^0 N in QGIS was processed using the watershed analysis tool to define and delineate the drainage basins (sub-basins) in PRB. The raster layers were then converted into shapefiles.

3.2.1.3 Image Processing and Classification

The Landsat images were processed and classified using ERDAS IMAGINE and QGIS. The processes involved the following:

- Image correction (Geometric and atmospheric correction)
- Stacking of bands to form single images
- Clipping of images using the shapefiles of the respective sub-basins.
- Supervised classification using the spectral angle technique in QGIS.

3.2.1.4 Post-Classification Analysis

- Accuracy assessment using the error (confusion) matrix technique.
- Change detection analysis using post-classification comparison method.

3.2.2 Sediment Yield Assessment

Discharge measurement and suspended sediment sampling were undertaken at nine hydrological stations (Table 3.2) marking the outlet of the sub-basins from October, 2017 to September, 2018. Discharge measurement was conducted using ADCP or current propeller with tape measure and echo sounder. Suspended sediment concentration was determined in the sediment laboratory of CSIR/ WRI using the evaporation method. Data was analyzed using statistical techniques.

3.2.3 Soil Erosion and Sediment Yield Distribution

✓ **Soil Erosion Map**

RUSLE model (eqn. 3.1) was adopted to estimate the annual soil loss of the basin. Its integration with GIS displays the soil loss on pixel by pixel basis.

$A = R\ x\ k\ x\ LS\ x\ C\ x\ P$ (3.1) where

A is the annual soil loss/gross amount of soil erosion (t/ha/yr.); R is the rainfall erosivity factor (MJ mm ha/h/yr.); K is the soil erodibility factor (t ha $MJ^{-1}mm^{-1}$); LS is the slope length and steepness factor (dimensionless); C is the cover management factor (dimensionless) and P is the support practice factor. Rainfall erosivity map was developed from rainfall data of the climate stations (Table 3.1) in and around PRB. Soil erodibility map was developed from soil map obtained from Soil and Crop Research Institute of CSIR. The slope and steepness factor was derived from the ASTER DEM.

✓ **Sediment Yield Map**

Sediment yield (SY) of the basin was estimated from the annual soil (A) and the Sediment Delivery Ratio (SDR) of the basin as

$SY = A_i * SDR_i$ (3.2)

SDR explains the proportion of the gross soil loss from the i^{th} cell that really reaches a stream system (Fernandez *et al*., 2003). It is assessed as a component of movement time given as

$SDR_i = \exp(-\beta\ t_i)$ (3.3)

Where t_i is travel time (hr.) for cell i and β is basin specific parameter

3.2.4 Suspended Sediment Modelling

Correlation matrix and multiple regression analysis were employed to model the relationship between suspended sediment concentration and the controlling factors (i.e. discharge, catchment area, slope, land use types).

CHAPTER FOUR SPATIO-TEMPORAL ANALYSIS OF LAND USE/COVER CHANGES IN THE PRA RIVER BASIN, GHANA

This part of the thesis is accepted and published online in Applied Geomatics (Springer) (Doi: 10.1007/s12518-019-00278-3)

CHAPTER FOUR

SPATIO-TEMPORAL ANALYSIS OF LAND USE/COVER CHANGES IN THE PRA RIVER BASIN, GHANA

4.1 Introduction

Land use/cover features of river basins have great influence on the availability and quality of the basin's water resources (Kondwani *et al.*, 2011; Fohrer *et al*., 2001). It is a key variable of the earth's system that in general has shown a close correlation with human activities and the biophysical environment (Basommi and Guan, 2015). LULC pattern of a basin therefore is a reflection of the natural and socio-economic activities of man in space and time.

Land use/cover changes refers to the quantitative and qualitative changes in the biophysical status of the earth's terrestrial surface (Seto *et al*., 2002; Campbell, 1996). Land use/cover change, therefore, has a unique signature on the topography and soil distribution, that gives rise to natural resource changes (Yeboah *et al*., 2017). Changes in land cover especially conversion from forest to farm/grassland, urban and mining have been shown to have negative impact on stream water quality (e.g. Ayivor and Gordon, 2012; Mensah, 2009; Tang *et al*., 2005), quantity (e.g. Leh *et al*., 2011) and ecosystem health (e.g. Wang *et al*., 2000). It also influences weather patterns (Dale, 1997), generation of stream flow and local flooding (Bronstert *et al*., 2002; Nunes *et al*., 2011). Boakye *et al*. (2008) explained that degradation of forest has impact on the catchment biochemical processes, leads to soil erosion and subsequently water shortage not only in immediate regions but also in distant areas. Kavian *et al*. (2014) concluded that land use /cover changes lead to significant changes in soil properties, runoff content and soil erosion. The rapid occurrence of land use/cover changes especially in developing countries have generally been attributed to anthropogenic activities (Yeboah *et al*., 2017; Amoah *et al*., 2012; Kusimi, 2008). Population growth and movement have resulted in the conversion of natural vegetation to croplands (Braimoh and Vlek, 2004), cropland to residential, industrial and commercial areas (Appiah *et al*., 2015), forest and farmlands to mining (Preprah, 2015; Kumi-Boateng *et al*., 2012), savannah lands to bare ground and settlement (Basommi *et al*., 2015) etc. Therefore, understanding of past and current land use/cover practices is important in pre-empting the future sustainability of existing natural resources (Shao *et al*., 2005).

The use of Geographic Information Systems (GIS) and remote sensing techniques enables accurate analysis of LULC patterns with respect to time. Mapping LULC is the standard approach to monitor changes and identify areas experiencing serious degradation (Forkuo and Adubofour, 2012). Change detection analysis is performed to determine the nature, extent and rate of land cover change over time and space. It also reveals the spatial pattern of development in the basin (Kumi-Boateng *et al*., 2012).

Pra River Basin (Fig.1) falls within the wet semi-equatorial climatic belt and covered by the moist-semi deciduous forest vegetation. Its major tributaries are Ofin, Oda, Anum and Birim rivers, which are respectively located in the Ashanti, Eastern, Central and Western regions of Ghana. The basin serves as the source of water supply for domestic, industrial, mining and agricultural uses for three regional capitals, forty-one districts and over one thousand-three hundred towns with total population of approximately 4.2 million and a growth rate of about 2.20% (Water Resources Commission, 2012). Despite the huge economic importance of the basin, it is reportedly threatened with land degradation resulting from deforestation, agriculture, mining and urbanization. These have impact on the available water resource. Hence, for better and efficient management and development of the water resources, it is important to extract reliable time series information on land use/cover, especially on rivers situated within the tropical rain forest, for monitoring and implementation of conservation measures.

Forkuo and Adubofour (2012) quantified forest cover change patterns in the Owabi area in the Ashanti Region of Ghana and demonstrated the potential of multi-temporal satellite data to map and analyze spatio-temporal changes in land use/cover. Boakye *et al*. (2008) utilized Landsat images to assess land use/cover changes in the Barekese catchment. Yorke and Margai (2007) also explored the use of geospatial approaches in the acquisition and analysis of multi-temporal datasets to evaluate the changes in the Densu River Basin of Ghana. Appiah *et al*. (2015) applied geo-information techniques in land use and land cover change analysis in peri-urban (Bosomtwi) district of Ghana. Their study concluded that land in the district and around the Lake Bosomtwi is put more to the use of residential and commercial purposes than agricultural and forest uses.

Although several studies have been conducted on land use/cover changes less attention has been given to the dynamics of LULC characteristics at sub-basin scale. Often times, basins even larger ones are classified wholly depicting their general trend of conversion, however, this study aims at determining the spatial variation of land use/cover classes across the Pra River sub-basins within the thirty years' period. The study maps, analyze and assess the spatio-temporal pattern of LULC changes in the Pra River Basin using time series of satellite imageries and GIS techniques. Specifically, the study evaluates past and present land use pattern of the basin, spatially characterize the patterns of change and determine the spatial variation of land cover types across the sub-basins, pinpointing areas at risk. For this cause, the entire Pra River Basin was divided into sub-basins. This is important for hotspot analysis of the watershed to enhance coordinated policies and strategies to guide development at the basin and local level, as well as provide solutions for immediate problems (Kumi-Boateng, *et al*., 2012; Sarma, 2005). Thus, nine (9) sub-basins namely; Upper Ofin, Oda, Anum, Lower Ofin, Upper Pra, Birim (kade), Assin Praso, Twifu Praso and Lower Pra were delineated, classified and analyzed.

4.2. Materials and Methods

4.2.1 Data Sets

The study utilized Landsat 5TM (1986 and 1998), Landsat 7ETM+ and Landsat 8OLI_TIRS (Table 4.1). The tiles with path/row 193/55, 194/55 and 194/56 were downloaded from USGS Earth explorer website (Http://earthexplorer.usgs.gov/). ASTER Global Digital Elevation Model (ASTGDEMV2_0N07W002) was also downloaded from same site for catchment delineation. The identified land use/cover classes were sampled in the field using the Global Position System (GPS) and Google Earth map covering the basin. GIS and Remote Sensing packages (ERDAS IMAGINE and QGIS) were used for the analysis.

Table 4.1: Landsat satellite images used in the study

Satellite	Sensor I.D	Resolution	Acquisition Date
Landsat 8	Operational Land Imager (OLI)	30m	27-Jan-18
Landsat7	Enhanced Thematic mapper Plus (ETM+)	30m	15-Nov-08
Landsat 5	Thematic Mapper	30m	1-Mar-98

Landsat 5	Thematic Mapper	30m	27-Jan-86

4.2.2 Methods

4.2.2.1 Catchment Delineation

The ASTER DEM was imported into QGIS and projected unto the UTM WGS 84 coordinate reference system. Then, the watershed analysis program r.watershed and watershed creation program r.water outlet were used to delineate and define the drainage areas contributing to the respective hydrological stations in the basin. Thus, nine sub-basins (Fig. 4.1) were delineated for classification. The choice of this method is because the researcher wants to identify the homogeneity or heterogeneity of land cover classes and their changing rate across the sub-basins. The raster of the sub-basins was converted to their respective vector layers (shapefiles) in QGIS using the r.to. vector tool. The vector layers were used to clip out the respective pre-processed multi-temporal Landsat images for classification.

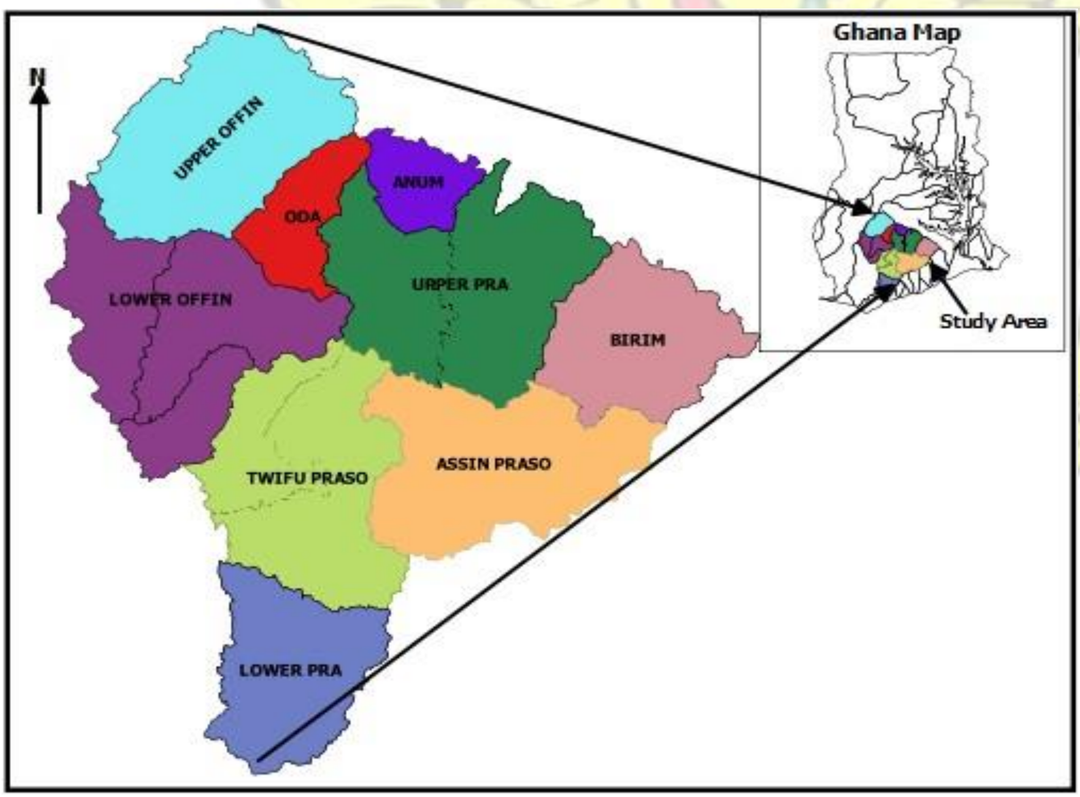


Fig. 4.1. Sub-basins of the Pra river basin

4.2.2.2 Image Pre-processing

Image pre-processing was carried out to correct for radiometric and geometric distortions of the acquired images in order to examine their spatial extent and hence enhance their visual representation (Bektas & Goksel, 2003). The bands of the Landsat 7 ETM+ Scan Line Corrector (SLC) failure errors were gap filled with their respective gap mask to remove the lines. The bands of the images were then stacked into a single image using the layer stack tool in ERDAS IMAGINE software. The images were then geometrically and radiometrically corrected to minimize biases associated with image incompatibility (Yorke and Margai, 2007). The radiometric corrections carried out were haze reduction and atmospheric reduction. The geometric correction included the projection of the images unto the UTM WGS 84 projection system and resampling them to a 30m x 30m pixel resolution. The resampling of the TM images could result in possible radiometric errors (Prakash and Beyer, 1981) which were corrected by radiometric correction in ERDAS IMAGINE. The multi-temporal Landsat images were mosaicked and the sub-basins of the Pra River clipped.

4.2.2.3 Image Classification and Accuracy Assessment

The multi-temporal images of the sub-basins were taken through three stages to generate their respective land cover classes. These include: (i). Definition of imagery bandset and a training shapefile; (ii). Creation of Region of Interest (ROI) and selection of training data (signatures) using the reference data obtained from field survey, google map, field experience as well as familiarity with the site; and (iii). Selection of suitable classification algorithm. For the visual interpretation of the images, three band combination of Red, Green and Blue (RGB) was used to display images in standard colour composite for land use and vegetation mapping. In this study, the Spectral Angle Mapping algorithm (SAM) in the Semi-Automatic Classification Plug-in (SCP) was chosen to characterize the LULC compositions of the sub-basins. The SAM identifies the classes in an image based on their spectral signatures of the pixels and determines the spectral similarity by computing the spectral angle between the spectral image pixels and the training spectral signatures (Congedo, 2015). Using the USGS Anderson Land Use and Land Cover Classification System for use with Remote Sensing Data (Anderson et al., 1976), six land use/cover classes were identified and mapped as Closed forest, Open forest, Farm/Grassland, Settlement, Mining and Water bodies. Afterwards, post processing was done to correct minor misclassifications.

An accuracy assessment of the 2018 classified images was performed using the error (confusion) matrix (Maingi *et al*., 2002), including user's accuracy, producer's accuracy and kappa statistic to assess the correctness of the classification (Foody, 2002). Ground truth data obtained through GPS field surveys, and Google Earth map images were used as reference data. The ground data was based on stratified random sampling using the LULC categories as strata. Different sample sizes were allocated to each stratum depending on the area of the stratum and its proportion in the respective sub-basin (Olofsson *et al*., 2014). Averagely, 1000 points were taken based on the rule of thumb recommended by Congalton (1991) as reference data for each sub-basin to assess the accuracy of the classified map.

4.2.2.4 Post-Classification Analysis

After the image classification, the spatial extent of each land use class within each sub-basin was determined for the 1986, 1998, 2008 and 2018 multi-temporal images using the Modules for Land Use Change Evaluation (MOLUSCE) plug-in in the QGIS software. The MOLUSCE plugin incorporates well known algorithm such as Artificial Neural Networks (ANN), Logistic Regression (LR), Multi-Criteria Evaluation (MCE) and Weights of Evidence (WoE) to (i). Analyze land use/cover changes between different time periods, (ii). Model land use/cover transition potential and (iii). Simulate the future land use/cover changes. A transition matrix illustrating the proportion of land cover conversions between different years was generated using the MOLUSCE plug-in. Finally, the rate of change of land use/cover classes across the subbasins was analyzed. To determine whether the changes in LULC types across the sub-basins differed significantly Analysis of variance (ANOVA) was performed using SPSS statistical package.

4.3 Results and Discussion

4.3.1 Spatial Pattern and Distribution of Land Use/Cover Classes

Nine sub-basins were delineated from the Pra River Basin (PRB) and classified. Four LULC maps were produced for each sub-basin for the years 1986, 1998, 2008 and 2018 (Fig. 4.2 and Fig.4.3). The classification accuracies of all the 2018 classified images (Appendix A) were within the acceptable range of classification (Forkuo and Adubofour, 2012; Congalton and Green, 2009). As already mentioned, six LULC classes were identified and classified: Closed forest, Open forest, Farm/grasslands, Settlement, Mining and Water. Over the period of study, the pattern of LULC classes across the sub-basins vary in their spatial dimension (Fig. 4.4 and Table 4.2). Also their conversion status had different magnitude and rates (Fig. 4.5).

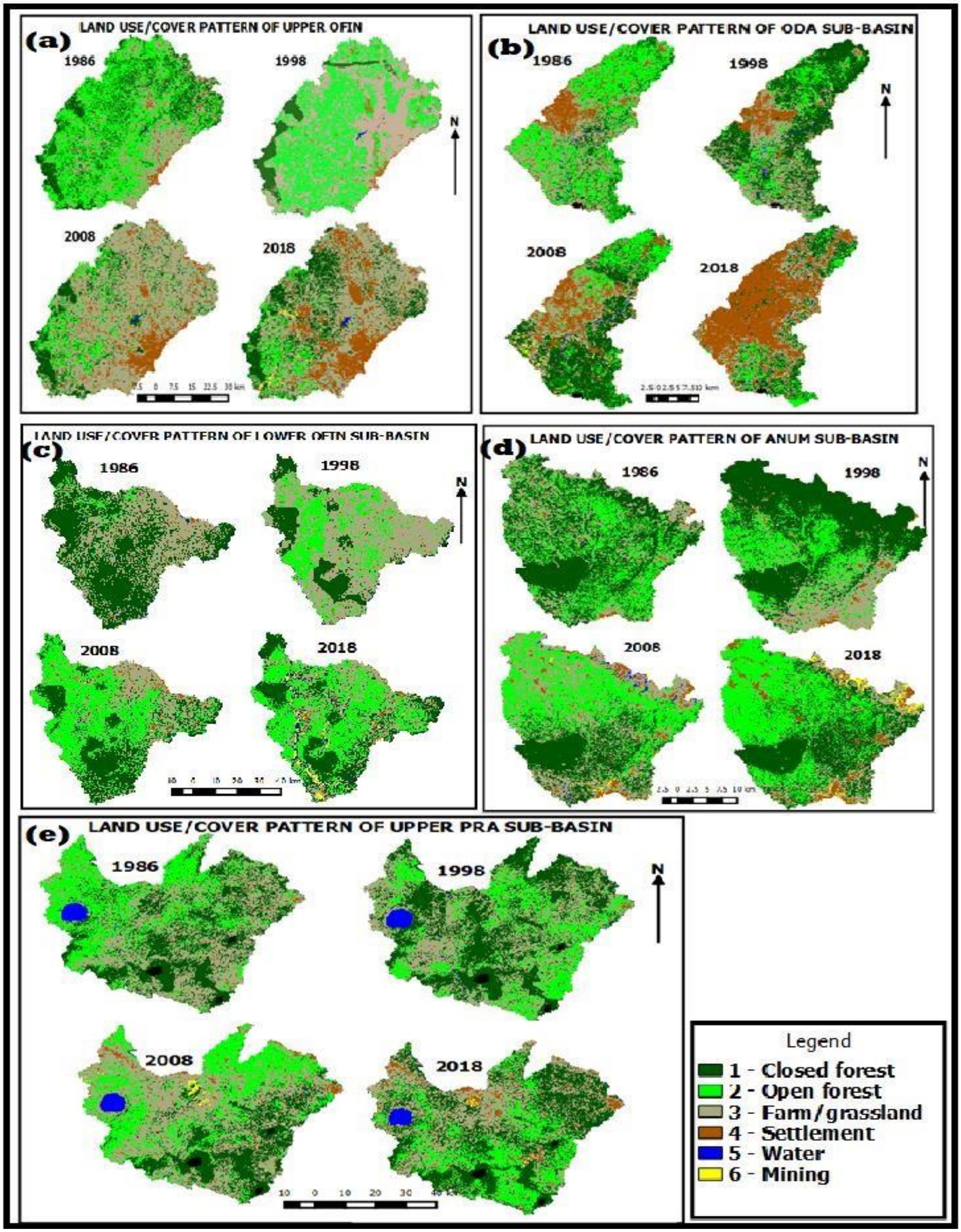

(a)
LAND USE/COVER PATTERN OF UPPER OFIN
1986
1998
2008
2018
N
(b)
LAND USE/COVER PATTERN OF ODA SUB-BASIN
1986
1998
2008
2018
N
(c)
LAND USE/COVER PATTERN OF LOWER OFIN SUB-BASIN
1986
1998
2008
2018
N
(d)
LAND USE/COVER PATTERN OF ANUM SUB-BASIN
1986
1998
2008
2018
N
(e)
LAND USE/COVER PATTERN OF UPPER PRA SUB-BASIN
1986
1998
2008
2018
N
10 0 10 20 30
Legend
1 - Closed forest
2 - Open forest
3 - Farm/grassland
4 - Settlement
5 - Water
6 - Mining

Fig. 4.2. Spatial distribution of land use/cover classes in the Pra river sub-basins (1986 - 2018): (a) Upper Ofin; (b) Oda; (c) Lower Ofin; (d) Anum and (e) Upper Pra

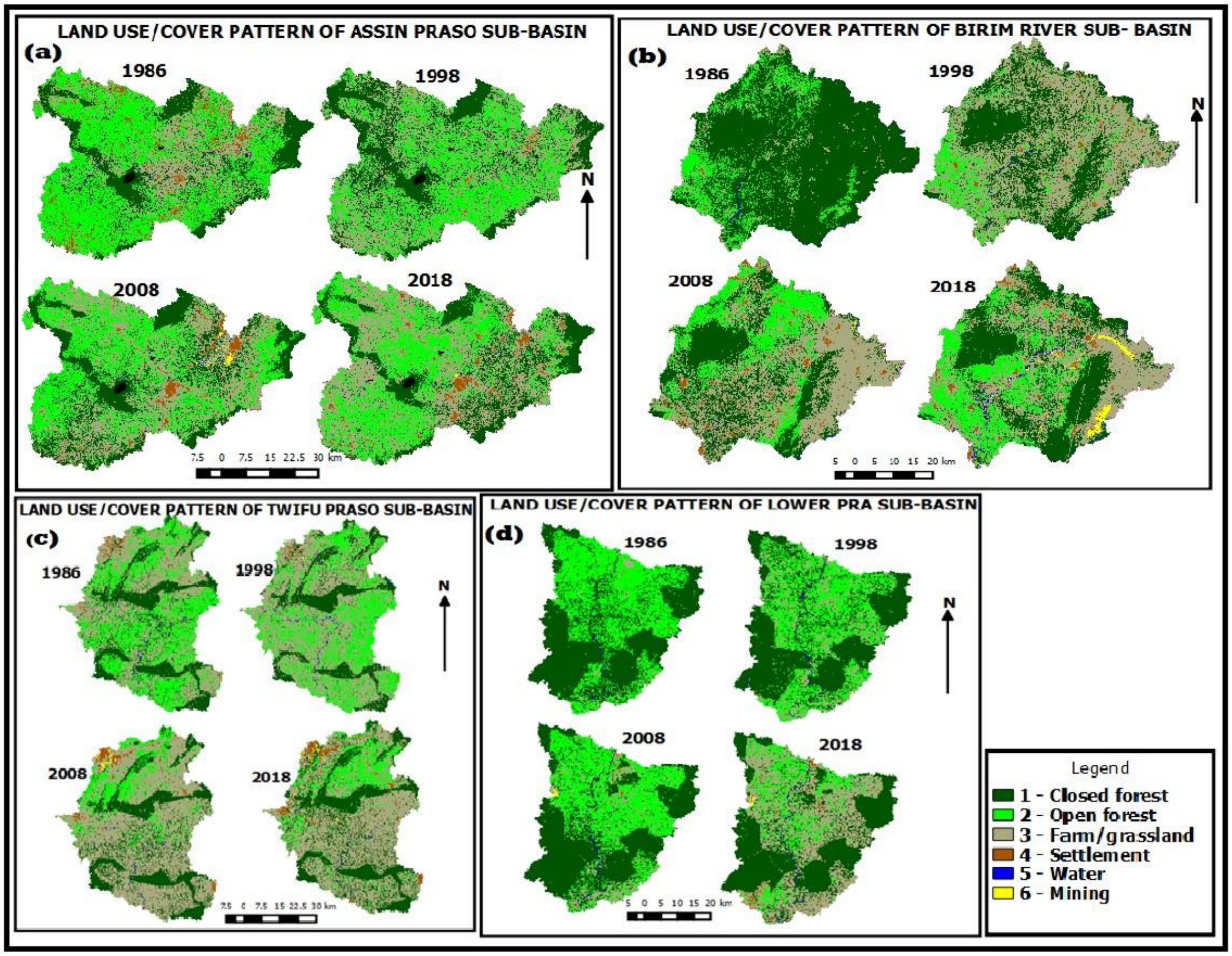


Fig. 4.3. Spatial distribution of land use/cover classes in the Pra river sub-basins (1986 2018): (a) Assin Praso; (b) Birim; (c) Twifu Praso and (e) Lower Pra

There is statistically significant difference ($P<0.05$) in the composition of LULC classes across the sub-basins. Averagely, the results indicate that within the Pra River Basin (PRB), Lower Pra has the highest Closed forest cover followed by Birim sub-basin. With regard to Open forest, Assin Praso has the highest cover followed by lower Pra. Farm/grassland is dominant in the Twifu Praso, Upper Ofin, Upper Pra, Birim, Lower Ofin and Assin Praso sub-basins whilst Settlement is mostly prevalent in the Oda, Upper Ofin and Upper Pra Sub-basins.

Table 4.2: Area of LULC classes of the classification (km^2)

Sub-Basin	Year	Closed forest	Open forest	Farm/grassland	Settlement	Mining	Water
Lower Pra	1986	1083.45	934.63	68.99	4.73	0	8.81
	1998	1012.97	760.86	308.4	8.81	0	9.57
	2008	1021.62	823.28	228.92	14.08	3.15	9.56
	2018	929.15	320.39	795.07	41.88	5.31	8.81
Oda	1986	141.45	388.04	291.7	109.94	0	4.02
	1998	392.77	148.89	272.06	116.37	0	5.06
	2008	375.57	160	233.66	145.91	15.34	4.67
	2018	173.86	72.61	224.14	457.64	5.02	2.24
Anum	1986	323.07	192.6	166.27	7.67	0	0.7
	1998	380.3	154.29	142.25	12.93	0	0.54
	2008	185.36	238.18	229.8	28.59	3.74	4.64
	2018	245.05	288.61	108.46	33.62	14.36	0.21
Upper Pra	1986	1140.52	1042.64	1372.47	49.14	0	55.99
	1998	1441.39	805.33	1305.09	54.1	0	54.86
	2008	1635.02	715.15	1176.37	60.41	24.54	49.29
	2018	1403.76	760.86	1275.52	162.02	9.97	48.62
Assin Praso	1986	869.64	1867.46	318.82	23.49	0	7.04
	1998	972.98	1010.5	1064.09	30.26	0	8.63
	2008	872.78	998.43	1086.77	99.83	1.38	14.81
	2018	75.01	951.64	1269.75	106.46	2.44	5.64
Twifu Praso	1986	833.43	1128.63	1366.52	39.47	0	7.11
	1998	655.93	1045.55	1617.29	40.9	0	15.54
	2008	894.07	391.32	1987.59	79.46	12.92	9.85
	2018	1064.68	441.48	1728.38	109.06	21.52	10.09
Birim	1986	1665.83	320.3	120.61	10.51	0	4.6

	1998	772.37	354.28	952.34	39.8	0	3.06
	2008	705.55	388.56	947.4	75.66	3.85	0.83
	2018	750.44	420.32	841.54	59	37.29	13.26
Lower Ofin	1986	2102.93	14.48	1528.31	55.62	0	7.79
	1998	1250.01	871.96	1656.23	57.79	0	3.14
	2008	1221.81	1529.26	955.82	101.48	7.95	22.75
	2018	1159.48	1500.96	910.9	112.68	88.08	67.03
Upper Ofin	1986	721.16	1450.08	815.36	71.97	0	3.28
	1998	216.71	1407.86	1332.34	96.75	0	8.2
	2008	448.57	296.47	1946.9	366.09	0	3.83
	2018	729.65	206.78	1569.3	533.28	17.95	4.9

From the year 2008 till now, 2018, the PRB began to experience illegal mining referred to as galamsey and alluvial mining. However, the results indicate that the Lower Ofin, Anum, Birim, Twifu Praso, Assin Praso and Oda sub-basins were greatly affected by the illegal mining activities (Snapir *et al*., 2017). This has led to pollution of the Pra River system. Yeboah (2008) observed three main problems of water pollution associated with the mining. These include (i) chemical pollution of ground water and streams, (ii) increased faecal matter and (iii) siltation of water bodies through increased sediment load. The drainage systems in affected areas are destroyed such that the natural river courses are immensely discoursed due to the mining activities carried in and around the river. This is because during their activity the soil is heavily removed and processed for the gold, after which the debris is left any how in and around the river. This increased the turbidity as well as drop in pH, which controls many aquatic reactions such as dissolution of metal oxides as indicated by Boachie-Yiadom (2010). There is also discharge of lubricants and other oils into streams which de-oxygenate the water and therefore threatens aquatic life. Yeboah (2008) reported that there are no fishing activities within the Kwabrafo River (Obuasi) since all species are dead due to toxication. Also improper disposal of tailings causes sedimentation problems and renders streams unusable for both domestic and industrial purposes (Obiri, 2005).

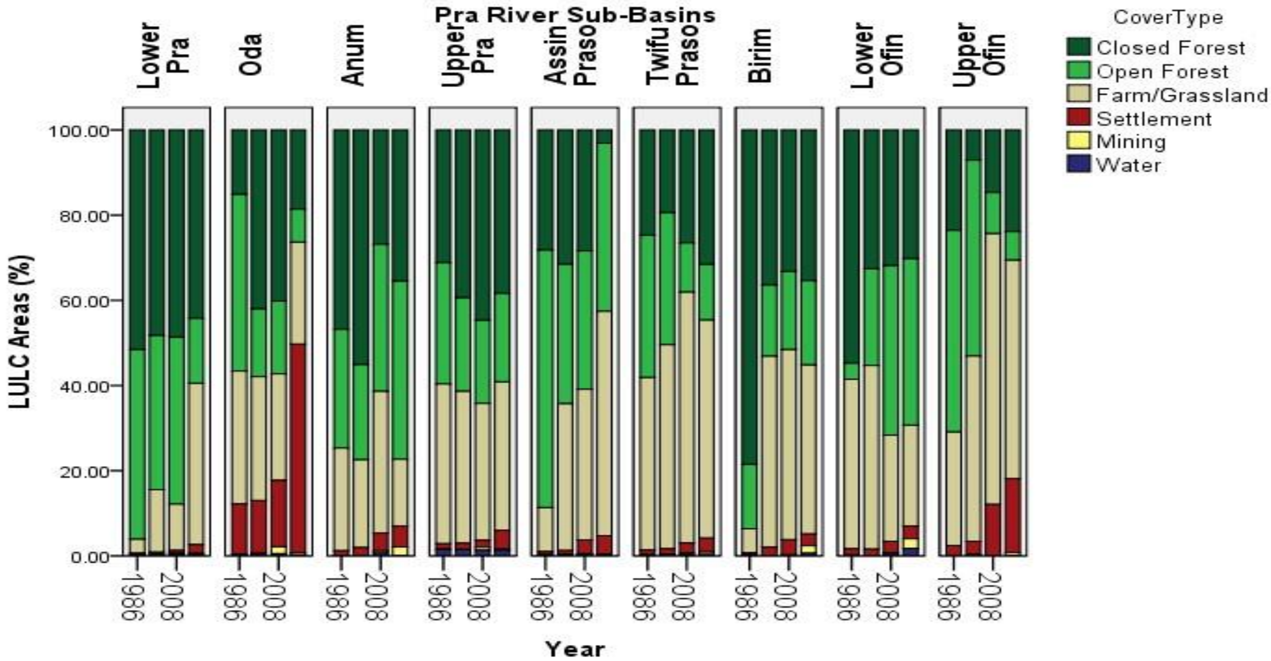


Fig. 4.4. Composition of LULC classes across the sub-basins (1986-2018)

4.3.2 Land Use/Cover Change

The trend analysis of the basin reveals changes in the areal extent of the six LULC classes (Table 4.3) over the thirty (30) year period. It also shows that the trend and rate of land use conversions differ across the sub-basins (Fig. 4.5).

Table 4.3: Composition of LULC Classes (%) of PRB

Year	Closed Forest	Open Forest	Farm/Grassland	Settlement	Mining	Water
1986	39.37	33.62	24.33	2.3	0	0.38
1998	34.63	27.3	34.89	2.7	0	0.48
2008	32.77	24.69	36.53	5.09	0.42	0.5
2018	28.97	22.65	36.76	10.11	0.98	0.53

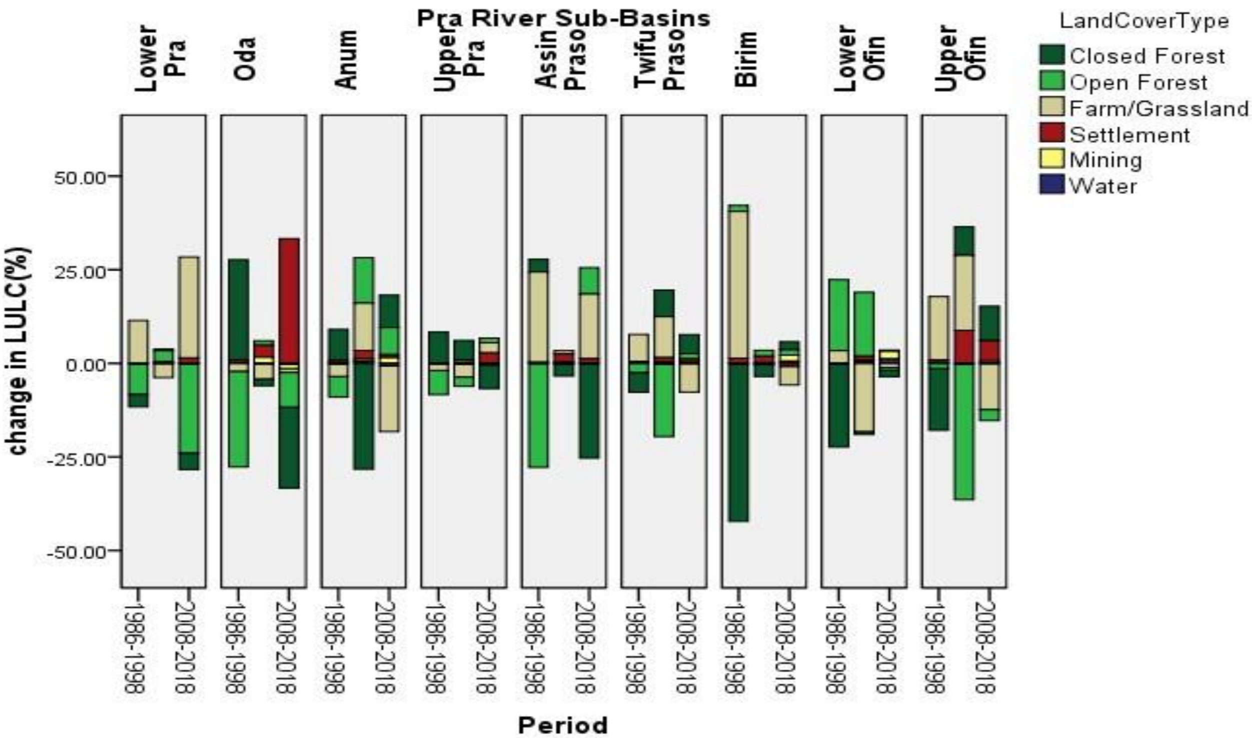


Fig. 4.5. Net change of LULC classes across the Sub- basins (%)

Considering the entire Pra basin, the LULC analysis reveals that Closed forest and Open forest consistently decreased in their spatial dimension while Farm/grassland, Settlement and Mining experienced an increase in their land mass (Table 4.3). However, statistical analysis of the changes in LULC classes across the sub-basins depicts that the changes in the classes differ across the sub-basins even though they are statistically not significant (P>0.05). Between 1986 and 2018, Closed forest experienced slight increase in the Oda, Upper Pra, Twifu Praso and Upper Ofin sub-basins by 3.5%, 7.2%, 6.9% and 0.3% respectively. On the other hand, Closed forest decreased in Lower Pra, Anum, Assin Praso, Birim and Lower Ofin sub-basins by 7.4%, 11.3%, 25.1%, 43.1% and 24.6% respectively. With Open forest, Lower Pra, Oda, Upper Pra, Assin Praso, Twifu Praso and Upper Ofin showed a decreasing trend (range between 7.7% and 40.6%). However, it increased in Anum, Birim and Lower Ofin by 13.9%, 4.7% and 35.3% respectively. Farm/grassland also recorded increases in Lower Pra, Assin Praso, Twifu Praso, Birim and Upper Ofin sub-basins (ranging between 10.7% and 42.3%), whilst it decreased in Oda, Anum, Upper Pra, and Lower Ofin sub-basins (between 2.67% and 16.08). Settlement experienced positive change across all the sub-basins. However, dominant increase of 37.16% and 25.07% occurred in the Oda and Upper

Ofin sub-basins respectively. Similarly, Mining area increased across all the sub-basins. However, Anum, Twifu Praso, Birim and Lower Ofin subbasins recorded high increase with mean of 2.1%, 0.6%, 1.8% and 2.3% respectively.

4.3.3 Drivers of LULC Change

Analysis of LULC classes over the period reveals changes in their areal extent. The classification showed consistent increase in settlement across the nine sub-basins especially those in and around the District and Regional capitals. This can be attributed to the increasing population and rural migration leading to expansion in residential and commercial land uses as identified by Appiah *et al*. (2015). Population movement towards the districts/municipals/metropolitans is as a result of some level of availability of socio-economic amenities, relatively cheaper rent on land and infrastructural development (roads, factories, accommodation, market etc.) (Braimoh, 2004). Considering the Oda and Upper Ofin basins, it was realized that between the periods 2008-2018, there was large increase in Settlement. These basins include and surround the suburbs of Kumasi, the capital of Ashanti region of Ghana. As a result, the demand for housing for the growing population and higher economic gains (i.e. land for construction of industries and infrastructures) over agriculture returns increased. This in essence affected the productive lands as most of the lands are converted for the purposes of these developments (Appiah *et al*., 2015). Also, farmers are compelled to engage in other economic and commercial activities which attracts immediate livelihood goals as compared to agricultural returns.

Similarly, the Anum, Lower Ofin, Twifu Praso and Birim sub-basins also experienced increase in the illegal mining activities (e.g. Awotwi *et al*., 2018; Awotwi *et al*., 2017; Snapir *et al*., 2017 Basommi *et al*., 2015; Kusimi *et al*., 2014; Kusimi, 2008). These sub-basins realized the conversion from Farmland and Open forest to Mining as a result of the high economic gains in mining over agriculture (Kumi-Boateng *et al*., 2012). Thus people's response to the changing economic opportunities of mining resulted to the change in land use.

Also, rural and agricultural population growth also necessitated forest degradation through land clearance and fuel wood gathering, especially during the period 1986-1998. The increase in farm land across the basins within this period was as a result of the government's structural adjustment/economic recovery programme phase II (1987-1991). The implementation of the policy led to food trade liberalization and importation of fertilizers and other agricultural input. This exposed the food sector to stiff competition with imported food items, however currency devaluation made imported food relatively more expensive than domestic food, giving domestic food producers a competitive edge (Braimoh, 2004; Awudu and Huffman, 2000). Hence, there was a substantial migration of labour back into agriculture in Ghana. Also Ghana's dependence on fuel wood within this period contributed to the deforestation of our lands (Nketia *et al*., 1988).

The slight increase of Closed forest in the Oda, Upper Pra, Twifu Praso and Upper Ofin subbasins may be due to the government's reforestation and forest reserve protection program as well as the intervention of NGO's. For instance, Community Resource and Environmental Management Association (CREMA) was formed to see to the protection of the forest species around the Lake Bosomtwi and the Barekese reservoir located in the upper Pra and Upper Ofin sub-basins. Besides, the proliferation of the media and their involvement supported the effort of the Forestry commission.

4.4 Conclusions and Recommendations

LULC analysis of the Pra river basin was performed to characterize the land use/cover patterns and determine the spatial variation of LULC classes across it sub-basins. The main LULC classes identified in the basin are closed forest, open forest, farm/grassland, settlement, mining and water. The results indicate that within the study period the basin has been experiencing changes in the spatial patterns and distribution of LULC classes. Generally, PRB lost 10.4% and 11% of its land mass occupied by closed forest and open forest respectively towards settlement, farm/grassland, mining and water which gained 7.8%, 12.4%, 0.95% and 0.2% of the basin's total land mass respectively. Generally, PRB lost 10.4% and 11% of it land mass covered with closed forest and open forest respectively, towards settlement, farm/grassland, mining and water which increased by 7.8%, 12.4%, 0.95% and 0.2% respectively. Change detection analysis showed that the change in land use classes varied across the sub-basins. Settlement increased consistently in all the sub-basins, however Oda and Upper Ofin changed greatly towards periurban residential and commercial land uses. Similarly, illegal mining activities increased across the sub-basins, however, Anum, Birim, Lower Ofin and Twifu Praso recorded severe increase. Open forest showed decreasing trend in Lower Ofin, Twifu Praso and Assin Praso sub-basins whilst closed forest declined in Anum, Birim and Upper Ofin sub-basins. The main drivers identified in the study include population growth and movement in response to economic conditions and policies, availability of natural resources and dependency on fuel wood.

The variations in the changing rate of LULC classes across the sub-basins require that different intervention and management strategies must be applied. For instance, in the Upper ofin, Oda and Anum sub-basins, there is the need for efficient land use planning and utilization. Adherence to the building code and buffer zone policy will help reduce the extensification of residential and commercial land uses. In the lower Ofin, Birim, and Twifu Praso sub-basins, the illegal mining (galamsey) activities must be stopped as the government has embarked on, whilst small scale mining must be effectively regulated. Moreover, farmers must be educated consistently on how to have good yield and agricultural productivity so as to encourage agricultural intensification instead of extensification. This will help reduce the deforestation rate in the respective basins. This is important for effective catchment management and sustainability of the ecosystem. There is also the need for proper economic planning and implementation of natural resources conservation measures. The ban on illegal mining by the government and the formation of the "Operation Vanguard" to flush out illegal miners is a good step and must be encouraged. Besides, the buffer zone policy should strictly be enforced. However, local level committees such as Community Resource and Environmental Management Association (CREMA) should be set up to formulate by-laws regarding the protection of the natural resource and serve as whistle blowers in the event of encroachment.

CHAPTER FIVE VARIABILITY OF SUSPENDED SEDIMENT YIELD IN THE PRA RIVER BASIN, GHANA

This part of the thesis is under review for publication in Environment, Development and sustainability (Springer) (Ref. No: EDS-ENVI-D-19-00768) **CHAPTER FIVE**

VARIABILITY OF SUSPENDED SEDIMENT YIELD IN THE PRA RIVER BASIN, GHANA

5.1 Introduction

One key limitation to achieving sustainable water resources management is the growing rate of soil erosion and sediment yield from river basins (Wuttichaikitcharoen and Babel, 2014). Sediment in rivers does not only distort the river's morphology and chemistry but also affect the storage capacity and the operations of existing reservoirs (Kusimi, 2008). Hence the determination of catchment sediment yield is very important for efficient water resources management and development, and also essential for addressing the hydrological difficulties in river basins (Cooper *et al*, 2018; Vanmaercke *et al*., 2014). The sediment yield of a river basin represents the volume of sediment load passing through the outlet of the catchment within a specified time period (Kusimi *et al*., 2014; Jain *et al*., 2010; Akrasi and Ansa-Asare, 2008). It is the reflection of the catchment's erosion and deposition process (Amegashie *et al*., 2011).

Sedimentation of rivers result from the multiplicative effect of climate (runoffs), land use and catchment properties (area, topography and geology) (e.g. kuksina and Alexeevsky, 2014; Dunne, 1979). Variations in these contributory factors result in variations in suspended sediment yield (Vestraeten and Poesen, 2001). Various statistical models relate the sediment yields to discharges and catchment properties pinpointing that climate, area and topography are the important controlling factors (e.g. Amegashie *et al*., 2011; Akrasi, 2011). However, Vanmaercke (2014) and

Dunne (1979) explained that the effect of climate and catchment properties on sediment yields becomes evident, only in a changing land use.

Anthropogenic activities related to the utilization of land, mineral and water resources either increase or decrease catchment sediment yield (Chakrapani, 2005; Walling and Fang, 2003). Intensification of land use activities in the Black Volta Basin two years after the construction of the Bui dam resulted to 41.5% increase in the reservoirs sediment yield (Asante-Sasu, 2016). According to Kusimi (2008), the Weija Lake in Ghana is under serious threat of siltation from various anthropogenic activities such as agricultural, indiscriminate waste disposal as well as building and construction. For some years now, the Pra River Basin (PRB) has been besieged with increasing anthropogenic activities such as urbanization, uncontrollable farming activities, indiscriminate waste disposal and illegal mining(galamsey) activities including alluvia gold mining within the river bed (Water Resources Commission, 2012). These activities, especially the galamsey and the alluvial gold mining, have increased the injection of sediments into the water bodies increasing the pollution and siltation levels. In 2012, Kusimi's study on suspended sediment yield at some selected stations within the PRB revealed that the observed sediment yields were higher than those obtained for major rivers in Ghana such as the Black Volta, White Volta, Oti as well as major rivers in Africa and South America (e.g. Kusimi *et al*, 2014). These are due to anthropogenic influence.

According to an official in Ghana Water Company at Daboase treatment plant, the increase in the sedimentation of the Pra River has resulted to the increase in treatment cost such that more chemicals need to be applied to bring the water to the acceptable consumption level. Besides, communities that used to directly depend on the rivers in the basin, have now shifted their attention to other sources of water for domestic activities as a result of the over-deterioration of the quality of the river. This has attracted huge public outcry and government attention. As such the government of the day in their effort to deal with environmental menace, on Monday 31st July 2017 commissioned a 400-member Police and Military Joint Task Force (JTF) called "Operation Vanguard" to combat illegal mining and alluvial mining across the three most galamsey ravaged zones in the country (Ashanti, Eastern and Western) with the hope of restoring the ecological integrity of the river system to ensure efficient and equitable utilization without compromising its sustainability (Price, 2011).

Based on the above, it is therefore important to have up-to-date information on the sediment loads of the Pra River and its tributaries. The measurement of sediments in rivers can better improve the understanding of the effects of land use or climate changes. The aim of this research is to assess the spatial variations in suspended sediment yields of the PRB. Thus, the study (i) assesses the current levels of sediment yield in the Pra River Basin; (ii) explores the variations in the observed sediment yield with respect to their respective contributing drainage areas; and (iii) analyzes the variations with respect to the river discharges. The study also reveals the impact of the activities of "Operation Vanguard" on the catchment's sediment yield.

5.2 Materials and Methods

5.2.1 Methods

The determination of the sediment yield of the Pra River Basin involved both field work and laboratory analysis. In the field, river discharge measurement and suspended sediment sampling were undertaken for nine hydrological stations (Fig. 5.1). The choice of the stations was as a result of the fact that they serve as outlet for sub-drainage basins within the PRB and therefore, the results could be a reflection of activities characterizing the respective drainage areas. Sampling and measurement were undertaken from October 2017 to September 2018 in order to cover both low and high flows.

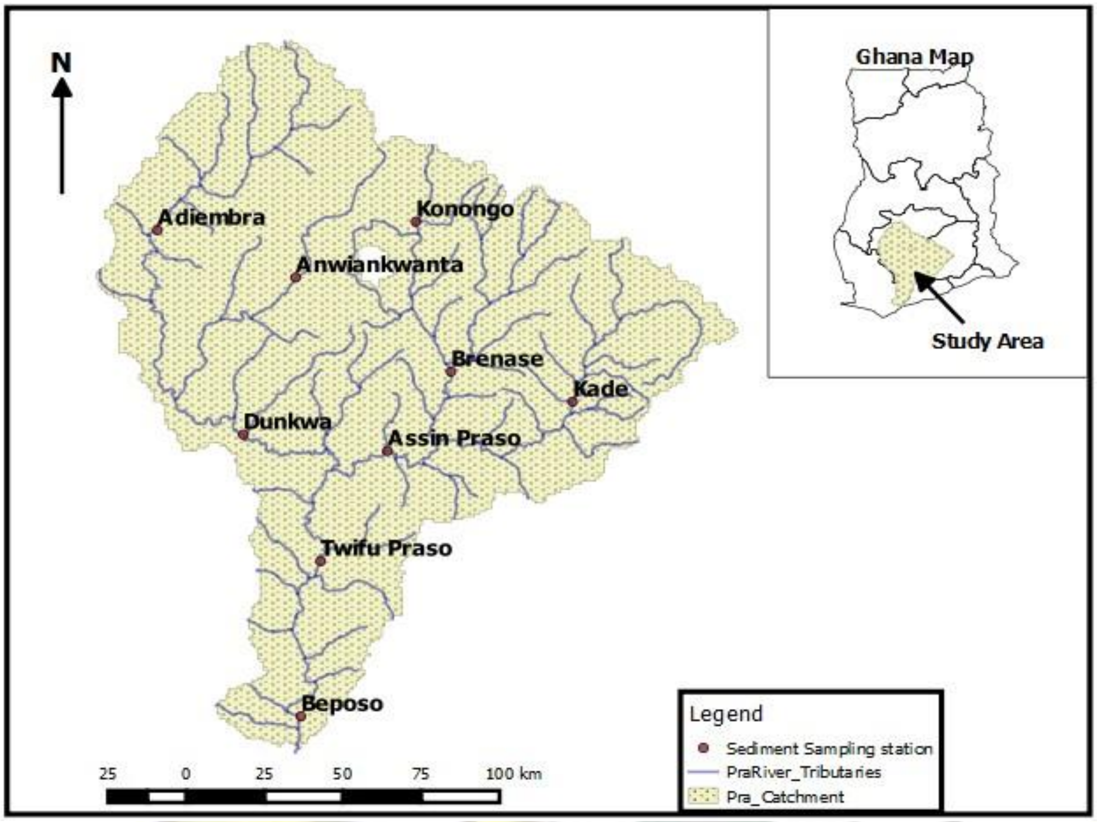


Fig. 5.1. Pra River Basin showing sediment sampling stations

The water discharges were measured using the Acoustic Doppler Current Profiler (ADCP). The ADCP measures instantaneously the water discharge (top, bottom, total) and shows the profile of the river cross-section (Figs. 5.2 & 5.3). In the absence of the ADCP or stations where there was no access to canoe, the current propeller/meter was used to measure the flow velocity, whilst the echo sounder and measuring tape measured the river depth and width respectively. The discharge was then computed using the discharge equation,

$$Q=VA, \tag{5.1}$$

Where V is Velocity, A is Cross-sectional area

In using the echo sounder and tape measure, the river cross-section was divided into sections at intervals of 5m or 3m depending on the total width of the river.

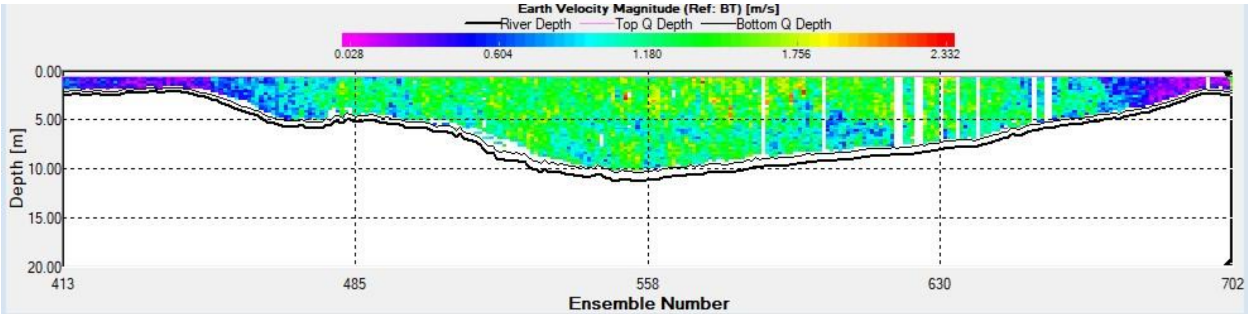


Fig. 5.2. Cross-sectional Profile of Pra River at Beposo hydrological station shown by the ADCP, 16th July 2018

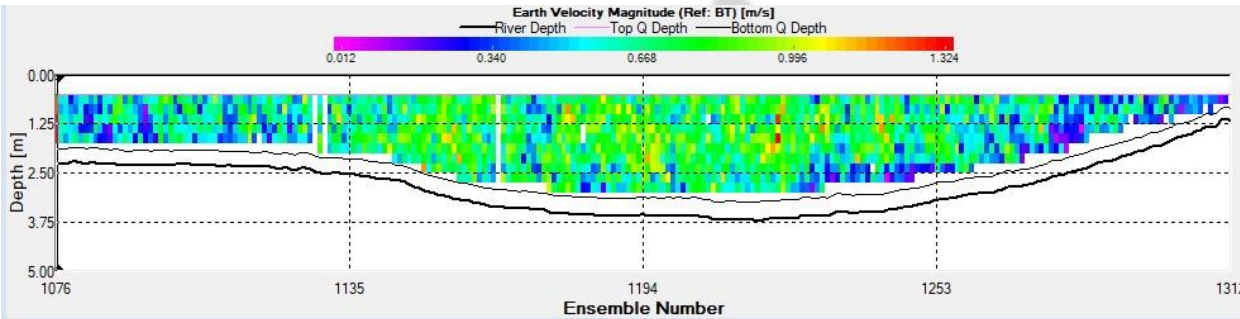


Fig. 5.3. Cross-sectional Profile of Birim River at Kade hydrological station shown by the ADCP, 14th July 2018

Suspended sediments were collected using the Integrated Sampler and kept in clear plastic bottles. To account for variability in sediment concentration (Kusimi, 2014; Edwards and Glyson, 1999), sampling was cross-sectional (i.e. Equal-Width- Increment). The cross-section was divided into at least three sections and then sampling was done to form composite sample for the cross-section.

Sediment concentration analysis was performed in the sediment laboratory at Water Research Institute (WRI) of Council for Scientific and Industrial Research (CSIR), Accra using the evaporation method. The samples were kept undisturbed for a period not less than 14days (Guy, 1969) to allow the sediment to coagulate. Afterwards, the gross weight of each sample (i.e. bottle + content) was measured. Then the water in each sample was decanted and the sediments at the bottom of the sampling bottle was shaken thoroughly and emptied into glass dishes of known tare weight and measured. The weight of the sample (water + sediment) was determined by deducting the tare weight of the sampling bottles from the gross weight. The sample in the glass dishes were oven dried at a temperature of 105^{o}c (Guy, 1969). The gross weight of the glass dishes with the sediment were measured after cooling in a desiccator. Then the sediment weight of each sample was obtained by deducting the tare weight of glass dishes from the gross weight. The weight of each sediment was divided by the weight of the sediment-water mixture. To obtain sediment concentration of the sample, the results was multiplied by one million, converting it to parts per million. The daily suspended sediment discharge was calculated using the instantaneous concentration and flow equation

$$Q_s = Q_w * C_s * K \qquad (5.2)$$

Where Q_s - Suspended sediment discharge/load in tons per day

Q_w - Water discharge in cubic meters per second

C_s - Mean concentration of suspended sediment in the cross-section in milligram per litre K - Coefficient based on the unit of measurement of water discharge that assumes a specific weight of 2.65 for sediment, and equals 0.0864 in SI units.

Sediment rating curves were then developed using equation 3 from plots of daily sediment loads and water discharges.

$$Q_s = kQ_{wb} \qquad (5.3)$$

where K is a constant and b is rating curve exponent.

The daily suspended sediment discharge obtained for the sampling stations was used to compute the annual suspended sediment ($t.yr^{-1}$) and specific suspended sediment yield ($t.km^{-2}.yr^{-1}$.) for the period.

5.3 Results and Discussions

The daily mean suspended sediment concentration was correlated with the daily discharges

(Figs. 5.4 - 5.12). Spearman and Kendall's correlation analysis shows very weak correlation between the suspended sediment concentrations and the river discharges with r being 0.13 and 0.24 respectively. Similarly, Syvitski and Milliman (2007) recorded weak relation between river discharges and sediment concentration of rivers at global scale. At Adiembra (Fig. 5.4) lowest concentration of 15.92mg/l at a discharge of 90.6 m^3s^{-1} in August 2018 and highest concentration of 62.73 mg/l at the discharge of 36.82 m^3s^{-1} in May 2018 was observed.

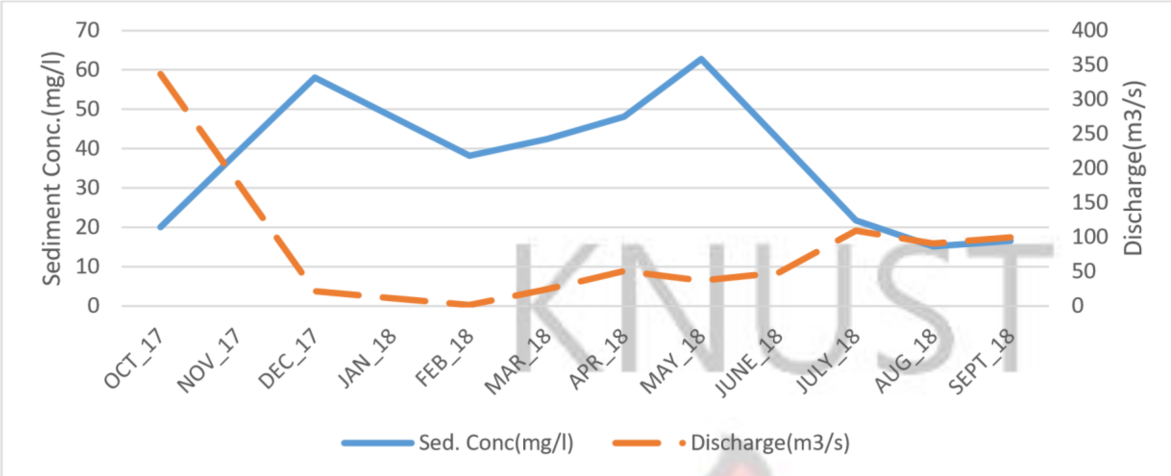


Fig. 5.4. Mean sediment concentration and discharge at Adiembra

At Dunkwa-on-Ofin station, the lowest sediment concentration of 96.85mg/l at a discharge rate of 281.89 m^3s^{-1} was observed in October 2017 whilst highest concentration of 858.80 mg/l occurred at the discharge of 29.53m^3s^{-1} in March 2018 (Fig.5.5). The sediment concentration recorded shows that whilst river discharge decreased continuously from October to March, sediment concentrations increased from 96.85mg/l to 858.80mg/l. This trend indicate that the variations in rivers sediment concentration is highly influenced by other sediment contributory factors more than the changes in the discharge regime.

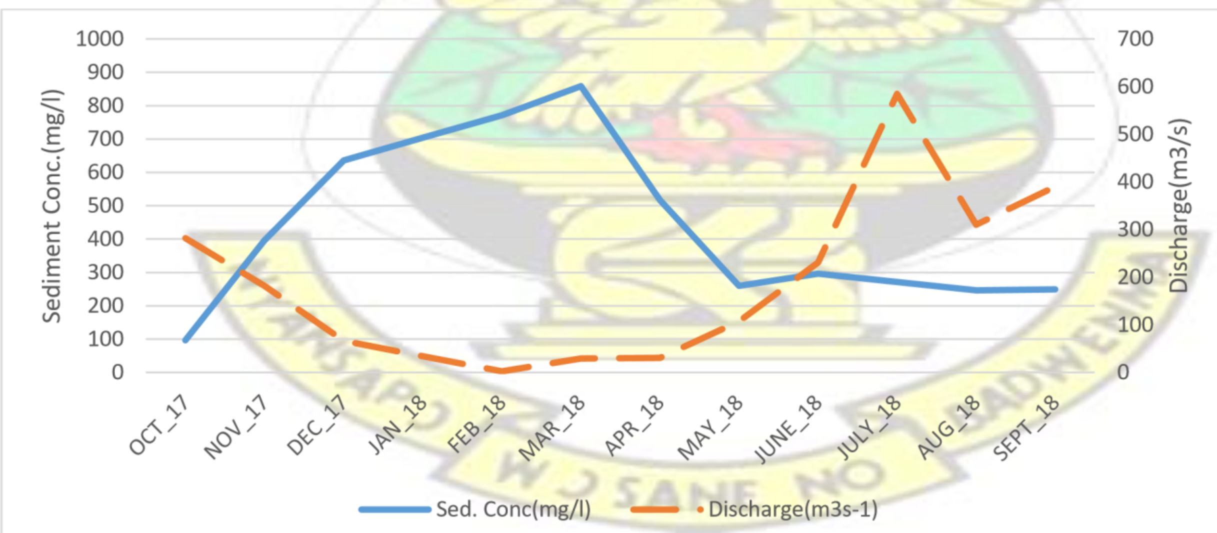


Fig. 5.5. Mean sediment concentration and discharge at Dunkwa-on-Ofin

LULC classification results (Fig.4.2c) shows that the immediate drainage basin (Lower Ofin) of this station is highly a gold mining area characterized with illegal mining (galamsey) both on land and river banks as well as within the river bed. These activities generate large amount of sediments injecting them into the river system (Chakrapani, 2005). The drainage systems in affected areas are destroyed such that the natural course of the rivers are immensely disturbed (Plate 5.1). Besides, improper disposal of tailings also causes sedimentation problems. Hence, the rise in the human activities resulted to proportionate increase in the sediment concentration of the river.

Plate 5.1. Illegal mining within a)water body and b) on land

Then again, it was expected that sediment concentration would be relatively higher toward and during the raining season when discharges increased (Akrasi, 2011). However, the observed concentration levels declined (Fig.5.5), indicating possible decline in the intensity of the sediment generating activities which might be due to the reduction in the galamsey activities resulting from the intervention of the “Operation Vanguard”. At this time, their effort might have been able to calm down some of the galamsey activities resulting to the reduction of sediment concentration. This observation is an indication that increases in water discharges alone do not necessarily result to proportionate increase in sediment concentration (Mawuli and Amisigo, 2016; Dedkov, 2004).

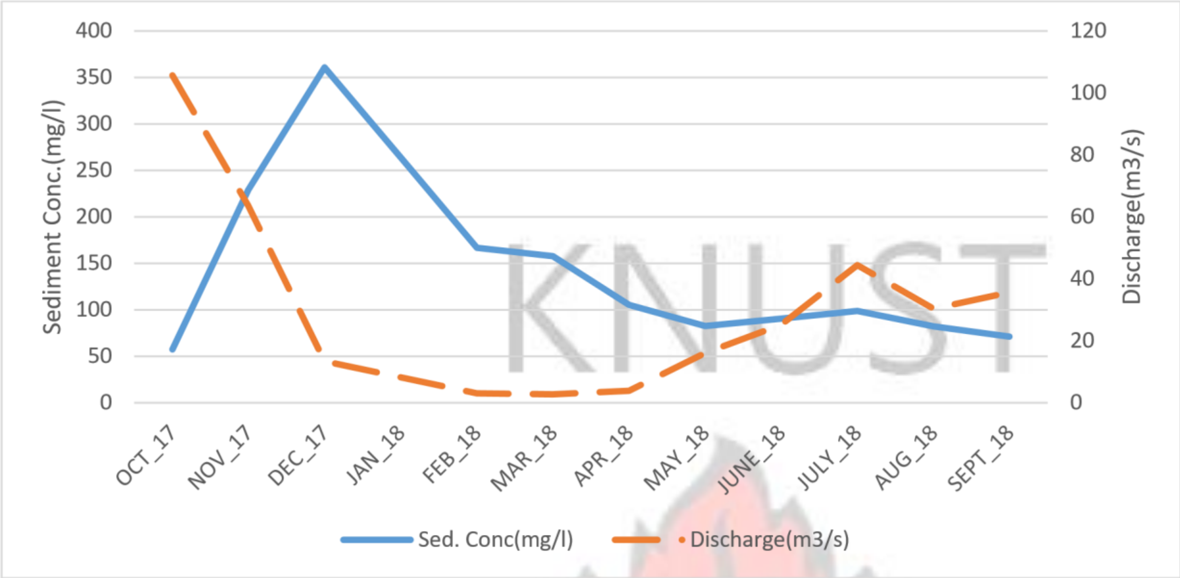


Fig. 5.6. Mean sediment concentration and discharge at Kade

At Kade, lower concentration of 57.30mg/l at a flow rate of 105.68 m^3s^{-1} in October and highest concentration of 360.84mg/l at a discharge of 13.32 m^3s^{-1} in December (Fig.5.6) was observed. The drainage (Birim) contributing to the Kade station is also besieged with galamsey and agricultural activities. Hence, the rise in sediment concentration even at decreasing discharges. However, After December 2017, the sediment concentration at Kade exhibited decreasing trend at varying discharges. This may also be due to the intervention of the “Operation Vanguard”.

Actually, the “Operation Vanguard” started their operation around August 2017 in the Eastern Region where the Birim sub-basin is located. The decline might perhaps be as a result of their effort.

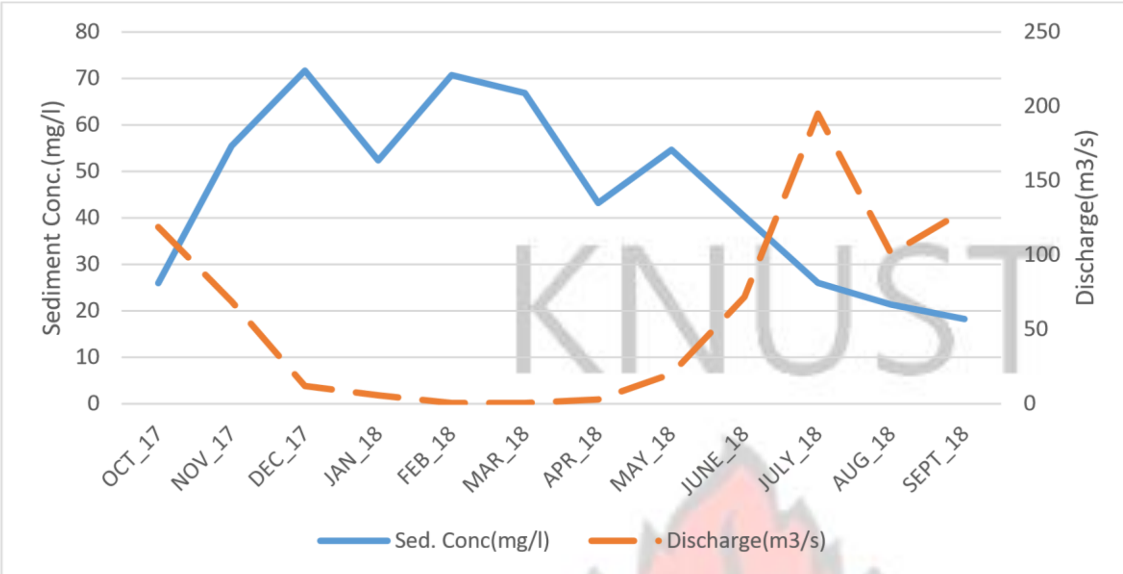


Fig. 5.7. Mean sediment concentration and discharge at Brenase

The Brenase station marks the outlet of the Upper Pra drainage basin before the Birim River joins it and flows downstream. The sediment concentrations fluctuate with varying discharges.

Highest sediment concentration of 70.71mg/l occurred at the discharge of 0.54 m^3s^{-1} in February 2018 whilst the lowest concentration of 25.99mg/l occurred at the discharge of 195.02 m^3s^{-1} in July 2018 (Fig.5.7). Relatively, this station exhibits low sediment concentration. The immediate drainage basin is characterized with forest and crop cover with farmlands and few sand winning activities.

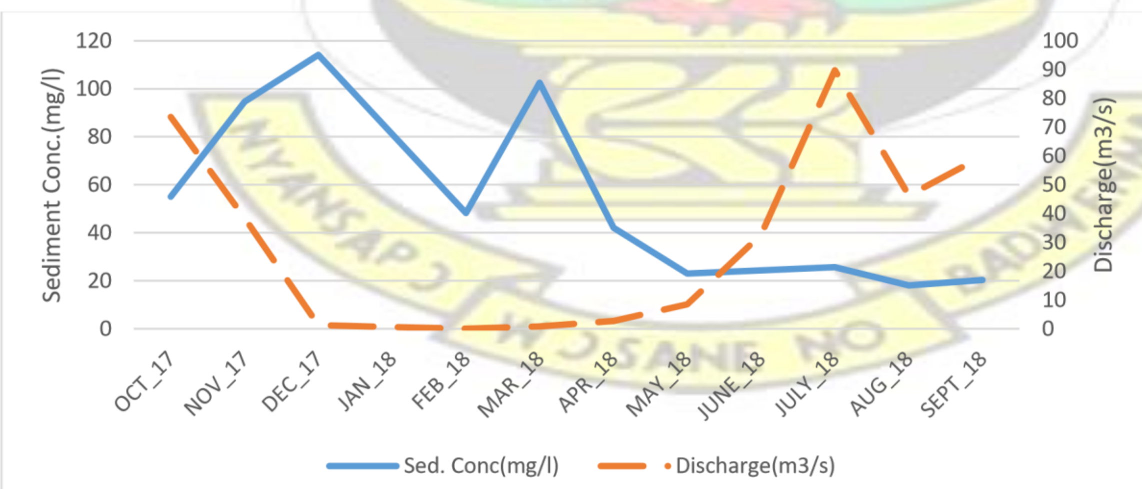


Fig. 5.8. Mean sediment concentration and discharge at Konongo

The sediment concentrations observed at Konongo (Fig. 5.8) on the Anum River also fluctuates with varying discharges. Even at seemingly low discharges, the sediment concentrations vary. The lowest concentration of 18.10mg/l at the discharge of 46.33 m^3s^{-1} in August 2018 and highest concentration of 114.19mg/l at the discharge of 1.250 m^3s^{-1} in December 2017. In the event of high sediment concentration at low discharges, there is an indication of anthropogenic influence. The Anum sub-basin is characterized with spots of galamsey activities besides extensive agriculture and urbanization. Again, the decreasing trend after December 2017 signal the impact the "Operation Vanguard" activities, might have had in calming down the galamsey activities, such that even at peak discharge in July, the sediment was as low as 26.65mg/l showing some level of cleansing. The sudden rise in sediment concentration in March 2018 may be due to the sudden increase in discharge associated with the early rainfall and thunderstorm, when most solute is flushed into the river channel (Kusimi, 2008; Nabegu, 2005).

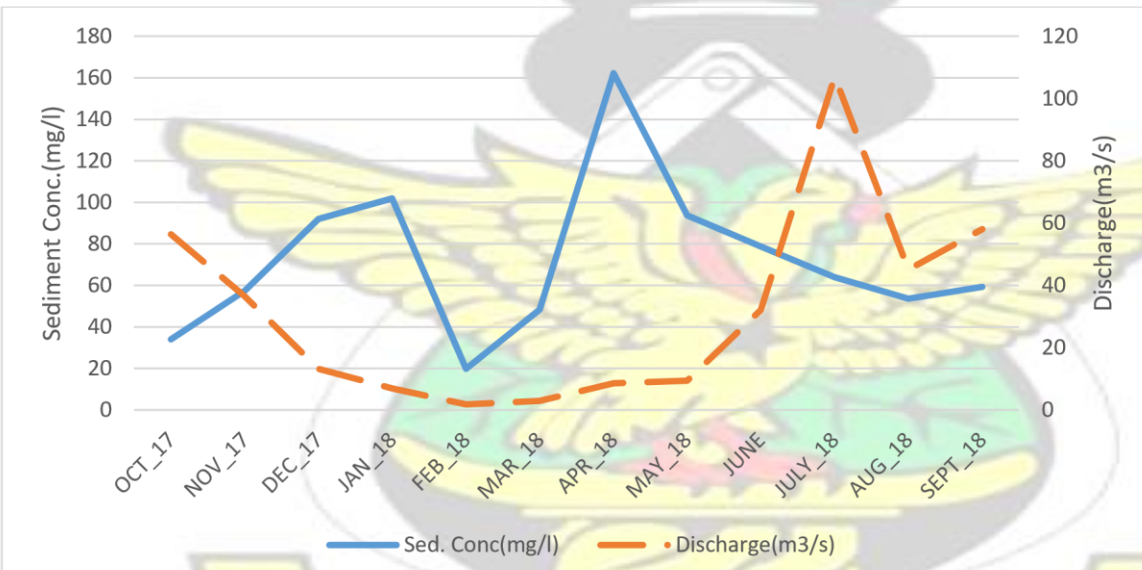


Fig. 5.9. Mean sediment concentration and discharge at Anwiankwanta

The Anwiankwanta station is on the Oda River. The drainage basin is dominantly characterized extensively with settlement and farming activities. There are also some pockets of sand winning activities in the basin and within the river bed which promote sediment generation. Lowest sediment concentration of 19.79 mg/l at the discharge of 1.75 m^3s^{-1} in February and highest concentration of 162.27mg/l at the discharge of 8.57 m^3s^{-1} in April 2018 (Fig. 5.9) was observed.

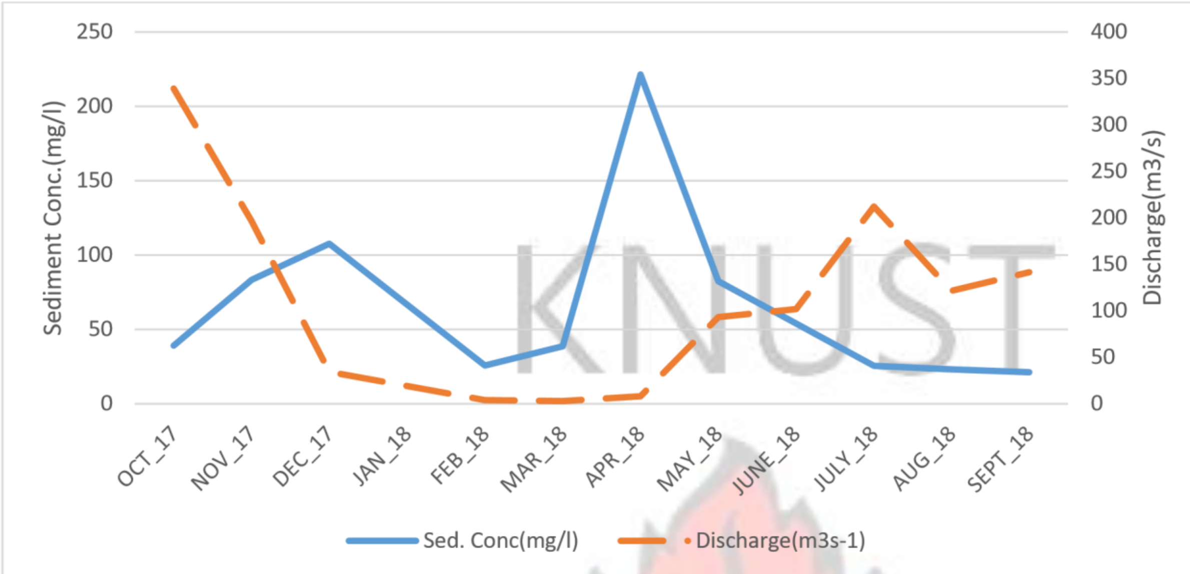


Fig. 5.10. Mean sediment concentration and discharge at Assin Praso

At Assin Praso lowest sediment concentration of 21.22mg/l at the discharge of 141.30 m^3s^{-1} and the highest of 221.39mg/l at the discharge of 7.90m^3s^{-1} was observed (Fig. 5.10). The immediate drainage basin is dominantly characterized with farmlands and pockets of galamsey, and sand winning activities. Besides, this station receives the upstream sediment from Birim, Anum and upper Pra that could not settle along the path of travel.

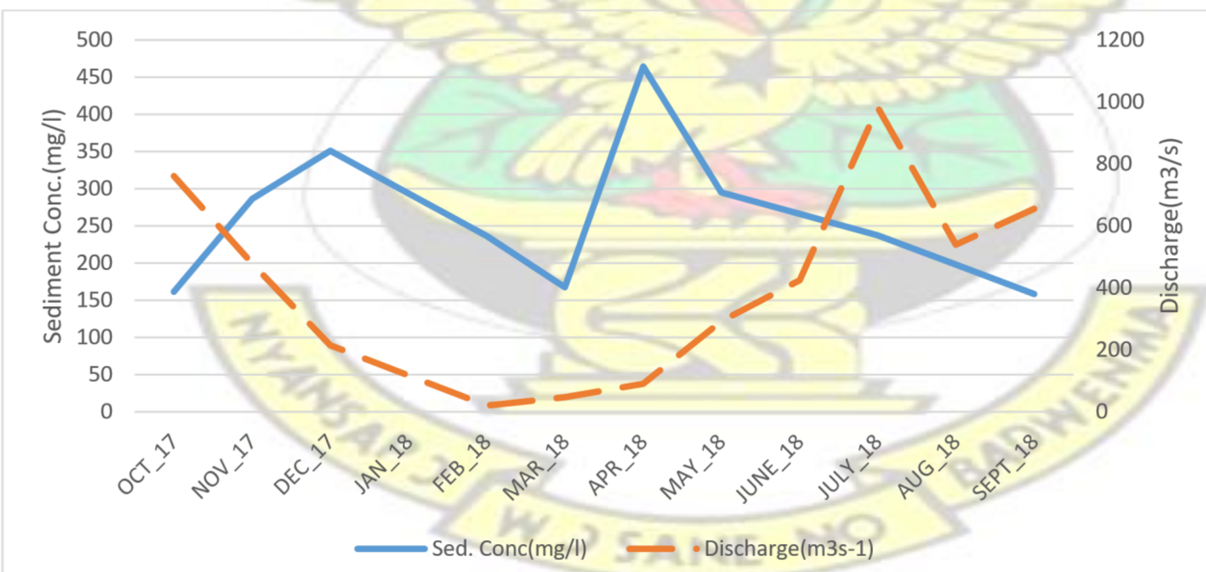


Fig. 5.11. Mean sediment concentration and discharge at Twifu Praso

At Twifu Praso, the suspended sediment concentration ranged between 158.22mg/l and

464.39mg/l (Fig. 5.11). The discharge at Twifu Praso station is a combination of discharges from all the tributaries of the Pra River. The immediate drainage basin is also characterized with intense illegal mining (galamsey) activities on land and in the river bed coupled with agricultural activities which has resulted to high sediment concentration.

The Beposo stations marks the last hydrological station, after which the Pra River flows into the Atlantic Ocean. Its sediment concentration record ranged between 149.24mg/l and 324.77mg/l (Fig. 5.12). The levels show that even at relatively low flows the concentrations are high.

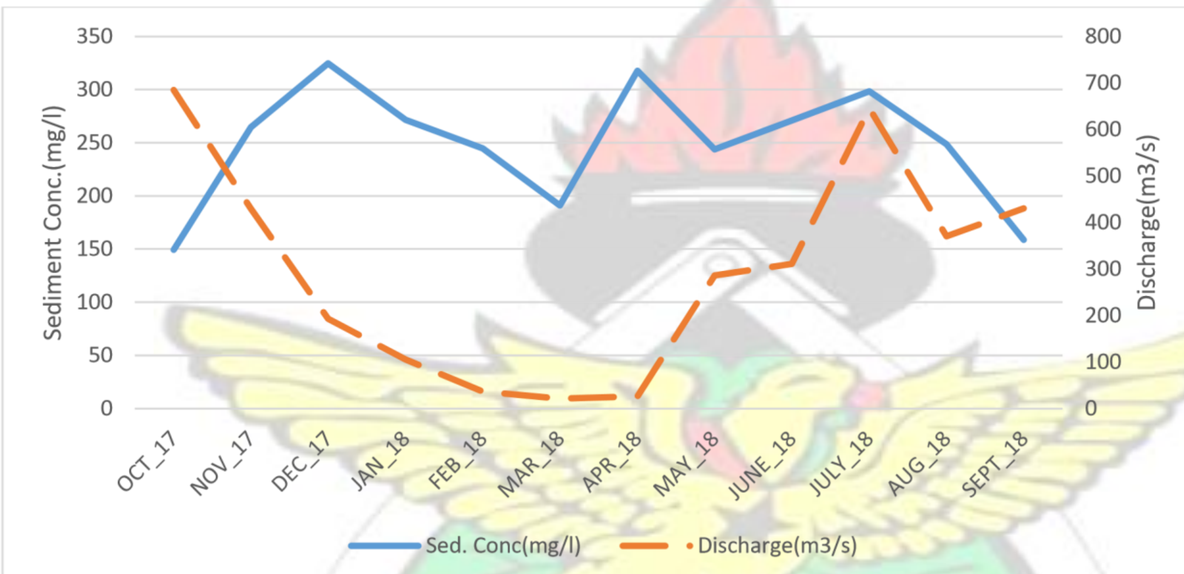


Fig. 5.12. Mean sediment concentration and discharge at Beposo

F-Test of significance of the concentrations and the water discharges indicate that the relationship between the concentration and the discharges is statistically insignificant (P = 0.385).The correlation analysis as well as the F-Test of significance results show that for the observed data, discharges do not statistically explain the variance in sediment concentration and that changes in the discharge regime do not correspond to proportionate variation in the sediment concentration of the river (Chakrapani, 2005).

Again, Unlike Kusimi *et al*. (2014) findings, levels of suspended sediment concentration did not increase proportionally from upstream of the rivers downstream as naturally expected. The variations can be explained by the differences in the intensity of land use activities within the immediate contributing drainage areas. The occurrence of highest concentrations at relatively low flows in most stations signals that the patterns in suspended sediment concentration in the Pra River tributaries is greatly influenced by the activities directly executed in and around the water bodies (Tamene *et al*., 2006; Dunne, 1979) rather than the variations in the water discharges. One Assemblyman echoed that "it's during the low flows that people intensify the alluvial mining and sand winning activities". Higher sediment concentrations observed at Dunkwa-on -Ofin, Twifu Praso, Beposo and Kade, where sediment generating activities (Illegal mining, sand winning and farming) is intense also establishes the fact that sediment concentration levels is a reflection of the intensity of land use/anthropogenic activities characterizing the immediate drainage basin (Vestraeten and Poesen, 2001).

The concentration levels at some stations which are relatively lower than that of their immediate upstream station indicates probably that i.) there is much deposition of sediments along the travel path, ii.) there is less bank or channel erosion even at large discharges within the travel length and iii.) The immediate sub-basin may not be generating much sediment which may be due to good vegetative cover coupled with low gradient of the catchment (Chakrapani, 2005).

Fig.5.13 shows the trends in the daily suspended sediment loads of the sampling stations. Sediment discharges correlated with the bimodal rainfall pattern of the basin (i.e. April – July and September – November).There is statistically significant difference ($P < 0.05$) in the suspended sediment load of the stations controlled by their respective drainage areas in the PRB.

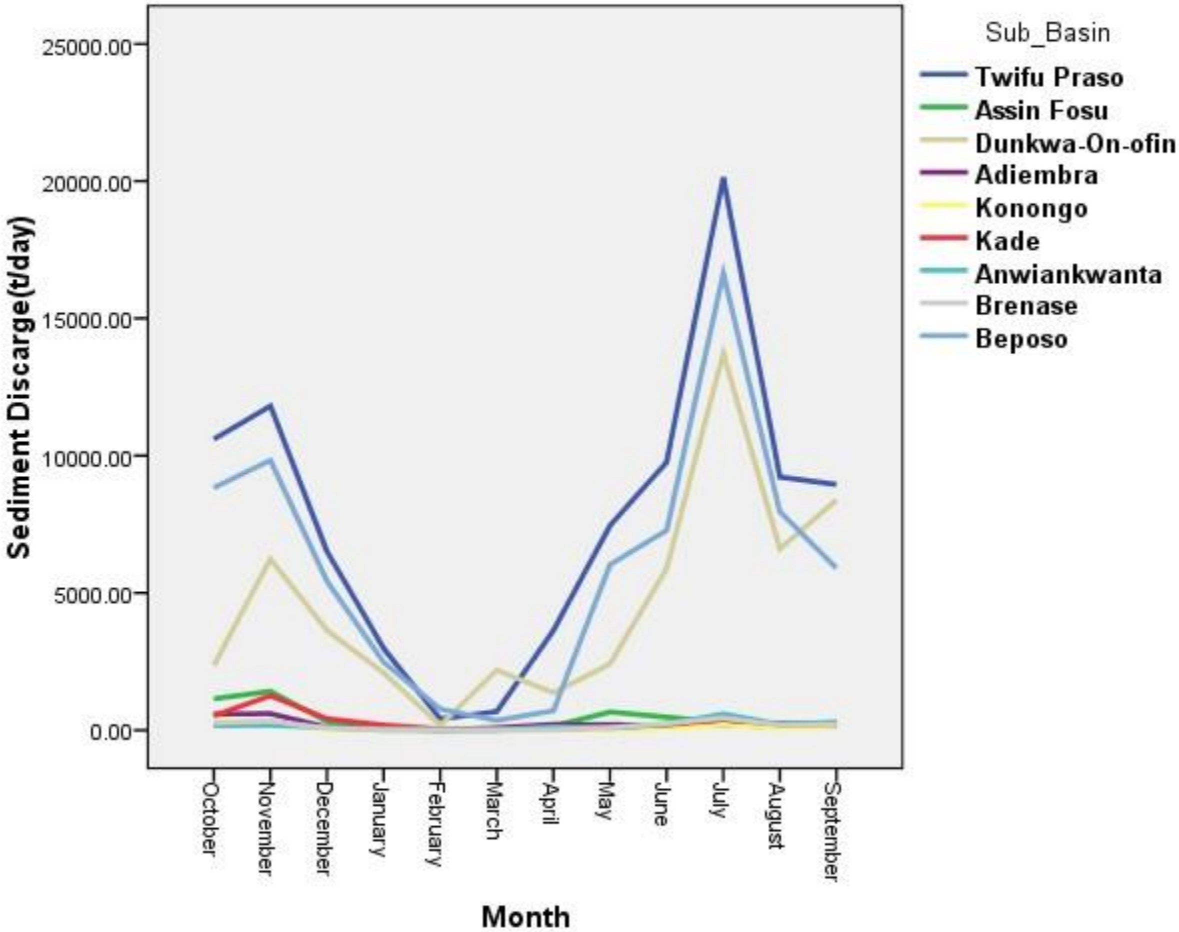


Fig. 5.13. Sediment discharges at the sampled hydrological stations

At Adiembra on the Ofin River and Anwiankwanta on the Oda River, where the catchments are dominant with settlement and farming activities coupled with spots of sand winning, sediment discharge increased from 4.7tday^{-1} and 2.99 tday^{-1} to 604.32 tday^{-1} and 591.26 tday^{-1} respectively (Figs. 5.13 and 5.14). At Konongo on Anum river and Brenase on Pra river, the lowest sediment load was 0.53 tday^{-1} and 2.29 tday^{-1} whilst the highest was 350.31 tday^{-1} and 437.85 tday^{-1} (Figs. 5.15 and 5.16) respectively. On the other hand, highest sediment transport of 1256tday^{-1}, 1414.46tday^{-1}, 13730.65tday^{-1}, 20131.61tday^{-1} and 16642.35tday^{-1} were observed at Kade, Assin Praso, Dunkwa-on-Ofin, Twifu Praso and Beposo stations (Figs. 5.17 to 5.21) which have been besieged with illegal mining and alluvial gold mining in addition to other anthropogenic influences.

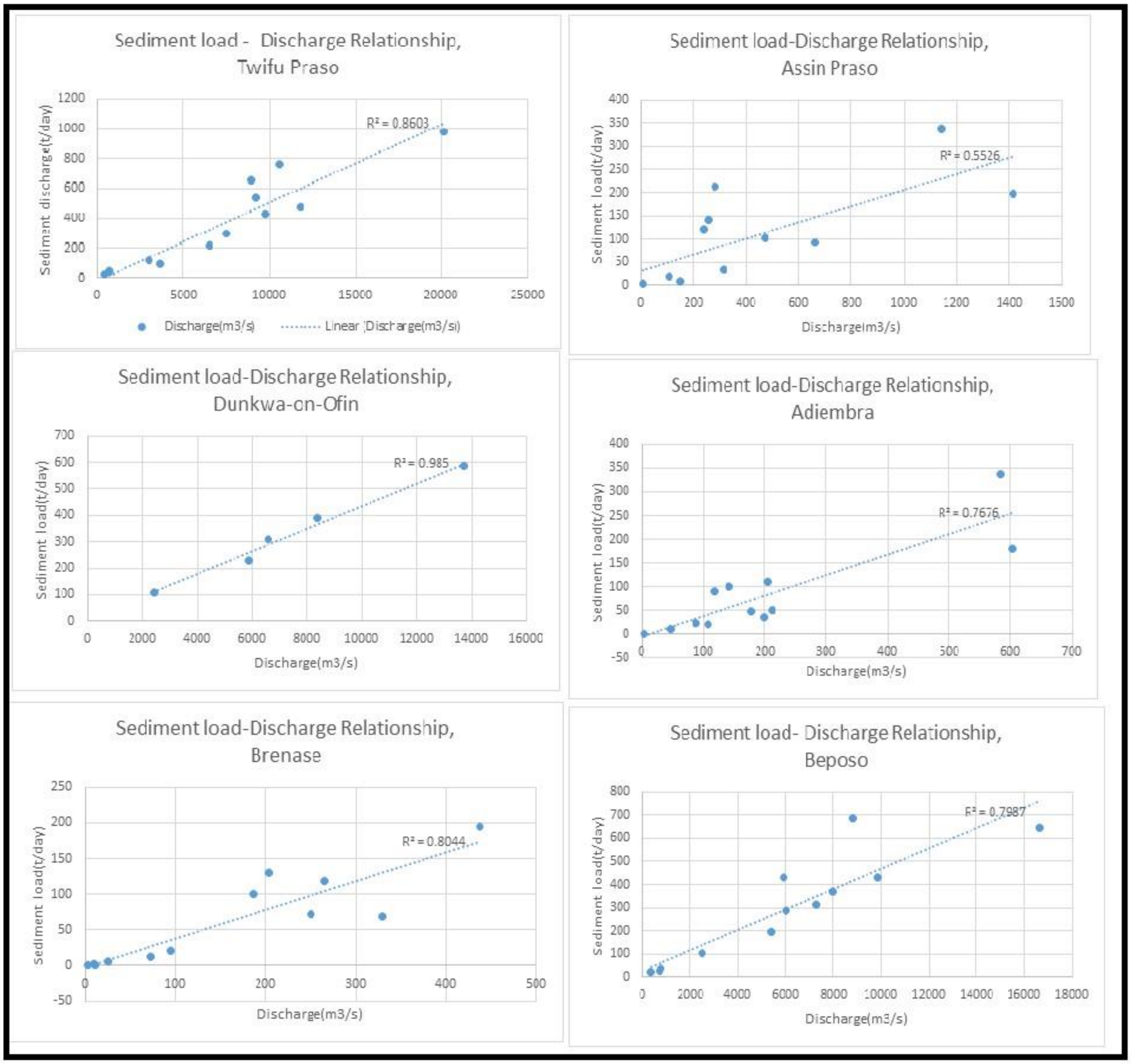


Fig. 5.14. Plots of sediment discharges against water discharges

Unlike the sediment concentrations, the suspended sediment discharges correlated positively and strongly with the water discharges (Fig. 5.14). Kendall's and Spearman correlation of 0.722 and 0.89 respectively was recorded and the correlation was statistically significant at 1% level. This means greater proportion of the suspended sediment discharge is explained by the water discharge. This however is not surprising. Because sediment loads (eqn. 5.2) are product of river discharge and sediment concentration, and the former covers much larger range than the latter.

Therefore their relatively large value will contribute to a greater percentage.

Rating curves were developed (Table 5.1) to determine the relationship between the sediment loads and the river discharges. Coefficients of determination R^2 of the stations ranged between 0.78 and

0.96, and were statistically significant at 5% level. However, the rating exponents ranged between 0.69 and 1.13, which are far below 2.0 and 3.0 (Akrasi, 2011), indicating that the concentrations are relatively insensitive to the discharge increase and that the rivers possibly remain turbid over a wide range of flows. Similar findings have been reported in literatures (e.g. Kusimi, 2008; Syvitski and Milliman, 2007; Gregory and Walling, 1973).

Table 5.1. Suspended sediment rating curve equation for sampled stations

Station	River	Equation	R^2
Adiembra	Ofin	$Q_s = 5.645Q_w^{0.83}$	0.93
Anwiankwanta	Oda	$Q_s = 3.329Q_w^{1.13}$	0.86
Konongo	Anum	$Q_s = 5.339Q_w^{0.84}$	0.91
Kade	Birim	$Q_s = 18.484Q_w^{0.81}$	0.78
Brenase	Pra	$Q_s = 8.198Q_w^{0.75}$	0.93
Assin Praso	Pra	$Q_s = 6.588Q_w^{0.88}$	0.79
Dunkwa-On-Ofin	Ofin	$Q_s = 135.220Q_w^{0.69}$	0.86
Twifu Praso	Pra	$Q_s = 30.221Q_w^{0.94}$	0.93
Beposo	Pra	$Q_s = 25.587Q_w^{0.96}$	0.96

These findings then suggest that in catchment experiencing severe land cover changes, the use of sediment rating curves for sediment predictions may not be realistic and does not truly reflect the sediment levels in rivers as it has previously been reported (e.g. Kusimi *et al*., 2014; Akrasi, 2011; Akrasi and Ansa-Asare, 2008; Kusimi, 2008). This is because the equation does not reflect the influence of other factors controlling sediment supply into the water resources other than the runoffs (Yan and Tun Lee, 2018; Dunne, 1979).

Table 5.2: Catchment area, annual suspended sediment and specific suspended sediment yield for the sampled stations in the PRB

Station(River)	Catchment Area(km^2)x10^3	Annual Suspended Sediment Yield(tyr^{-1})x10^4	Specific Suspended Sediment Yield(tkm^{-2}yr^{-1})
Adiembra (Ofin)	3.062	7.6054	24.84
Konongo (Anum)	0.690	3.5551	51.50
Anwiankwanta (Oda)	0.935	6.0892	65.11
Brenase (Pra)	4.351	5.7834	13.29
Kade (Birim)	2.122	11.0405	52.03
Assin Praso (Pra)	9.559	154,767	16.19
Dunkwa-On-Ofin (Ofin)	7.836	168.4910	215.02
Twifu Praso(Pra)	20.770	282.1133	135.82
Beposo (Pra)	22.871	221.2764	96.75

The specific suspended sediment yield of the basin ranged between 13.29 tkm^{-2}yr^{-1} and 215.02 tkm^{-2} yr^{-1} (Table 5.2). Upper Pra sub-basin recorded the least specific suspended sediment yield of 13.29 tkm^{-2} yr^{-1} whilst Lower Ofin observed the highest specific suspended sediment yield.

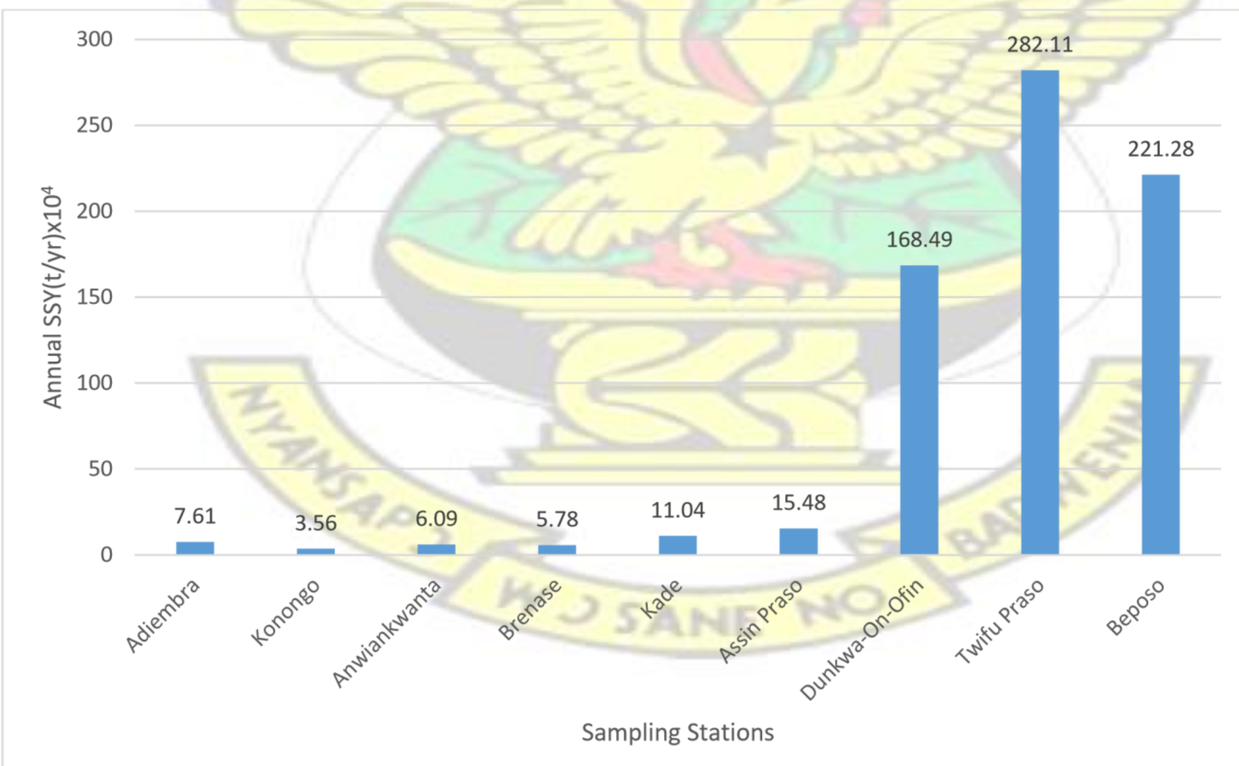


Fig. 5.15. Annual Suspended Sediment yield of sampled stations in PRB

These levels of sediment load (Fig.5.15) have posed serious threat to the basins water resource such as the pollution of ground water and streams, increase in faecal matter and siltation of water bodies. It also threatens the sustainability of the Water Company's hydraulic structures as a result of continuous intake obstruction and accelerated abrasion. The level of deterioration has also rendered the raw water unusable. Communities situated along the rivers have shifted their dependency from the surface water to boreholes for their domestic activities. Besides, the discharge of lubricants and other oils from mining spillage into the streams de-oxygenate the water and therefore threatens aquatic life. According to Yeboah (2008) fishing activities within the Kwabrafo River (Obuasi) have cease since all species are dead due to intoxication from sediment load.

5.3.1 Effect of the "Anti-galamsey" Intervention Measures

As already alluded to, government's ban on illegal mining as well as the formation of "Operation Van Guard", an anti-galamsey team is expected to flush out all illegal miners in the country towards environmental sustainability and the restoration of ecological integrity. To assess their impact, this study could only be compared with Kusimi' sediment analysis for some selected hydrological stations in the basin conducted in 2012 as a result of lack of previous reliable data (Table 5.3).

Table 5.3: Comparison of Annual suspended Sediment Yield between pre and Post antigalamsey intervention

	Annual Suspended Sediment Yield (tyr^{-1})		
Sampling Station	Kusimi et al.(2014)x10^4	Current Study (2018)x10^4	%Change
Anwiankwanta	6.6094	6.0892	-7.9
Adiembra	11.5372	7.6054	-34.1
Brenase	15.0455	5.7834	-61.6
Assin Praso	22.0907	15.4767	-29.9
Twifu Praso	264.5002	282.1133	6.7

The results reveal some level of decline in most of the sampled stations. However, the specific suspended sediment yield (Fig. 5.16) of the drainage basins obtained are still higher in comparison to other river basins in Ghana, Africa and beyond (Vanmaercke *et al*., 2014; Kusimi *et al*., 2014; Akrasi and Ansa-Asare, 2008; Akrasi, 2005) and must not be countenanced. This means more effort is required in the operation of the task force for the restoration of the quality of the water resources in the basin.

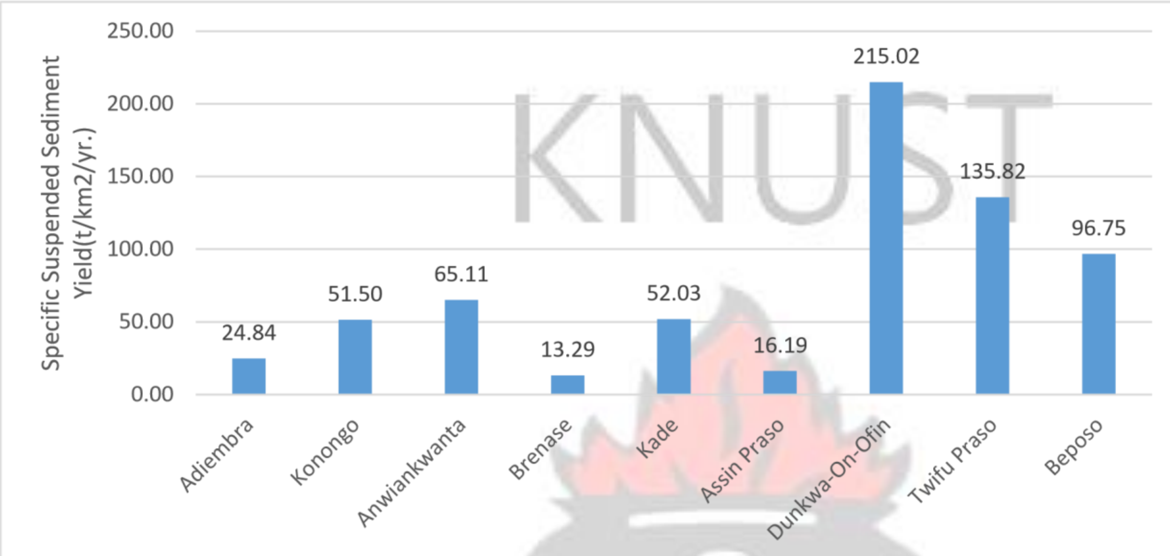


Fig. 5.16. Specific suspended sediment yield of sampled stations in PRB

5.4 Conclusions and Recommendations

Suspended sediment data was collected and analyzed from nine hydrological stations within the PRB. Results indicate reduction in the annual specific suspended sediment yield of the basin when compared with Kusimi *et al*. (2014).Yet, the levels (ranging between 13.29 $tkm^{-2}yr^{-1}$ and 215.02 $tkm^{-2}yr^{-1}$) are still very high in comparison to major rivers in the tropics for consumption and sustainability of aquatic life. There are spatial variations in the observed catchment's suspended sediment loads ($p<0.05$) resulting from the differences in the intensity of the anthropogenic activities within the respective sub-basins of the catchment. High sediment concentration for low flows and low sediment concentration for high flows were observed across PRB. This variability in sediment concentration points to the fact that the catchment's sediment flux is influenced greatly by the extent and intensity of land use activities within the immediate drainage basins and the catchment geomorphology.

The study also found that in catchment experiencing drastic changes in the land cover characteristics, sediment rating curves developed from sediment discharges and river discharges did not reflect the influence of the sediment supply controlling factors and therefore may under or overestimate. Hence, in sediment modelling, it would be appropriate and accurate to develop relations predicting sediment concentration instead of sediment discharge. However, it is important to investigate how the sediment controlling factors account for the observed variations. .

The study also reveals that the rivers in the galamsey prone areas (Dunkwa-on-Ofin, Kade, Konongo, Twifu Praso and Beposo) are highly polluted with sediment than the others, hence the formation and the operation of the anti-galamsey task force is a timely intervention and in the right direction. Their effort is gradually improving the state of the rivers in the basin. It can be recalled that some children who were swimming in the river at one of the sampling stations retorted “now through the effort of the President we can bath and swim in the river, which hitherto we could not, Thanks be to the President”. Seeing that the effort of the “Operation Vanguard” is making positive impact, it is important to sustain and improve the strategy to forestall the river quality in the basin. The formation of District ecological or environmental task force involving officials from the District Assembly, Water Resource Commission (WRC), Environmental Protection Agency (EPA), Minerals Commission, Security forces, Assemblymen and a Unit committee member instead of the national task force would be more efficient. The inclusion of the indigenes will facilitate their operation, since they are usually conversant with the nooks and crannies of the galamsey operators. The study also recommends that sediment rating curves cannot be reliable for predictions in catchments experiencing severe degradation since the predictions do not conform to reality.

CHAPTER SIX SPATIAL DISTRIBUTION OF SOIL EROSION AND SEDIMENT YIELD IN THE PRA RIVER BASIN

This part of the thesis is under review for publication in Geomorphology (Elsevier) (Ref. No: GEOMOR- 8763) **CHAPTER SIX**

SPATIAL DISTRIBUTION OF SOIL EROSION AND SEDIMENT YIELD IN THE PRA RIVER BASIN

6.1 Introduction

Soil erosion in river basins continue to be one of the critical environmental problems affecting agricultural productivity (Fadlalla *et al*., 2015), water quality and quantity (Amegashie *et al*., 2011;

Mensah, 2009) and reservoir /dam operations (Akuffo, 2003). It involves the detachment of soil particles, transport and deposition under the influence of rain droppings, runoffs and wind (Wischmeier and Smith, 1978). Sediment yield of a basin results from soil erosion and transport process taking place in a whole contributory area (Fernandez *et al*., 2003; Jain and Kothyari, 2000). Its severity is often enhanced by anthropogenic activities such as mining, urbanization and deforestation and climate change (Amsalu and Mengaw, 2014; Jain *et al*., 2010; Adornado *et al*., 2009). Vanmaercke *et al*. (2014) indicated that sediment yield observations of African catchments range between 0.002 and 157 t/ ha/ yr. Quansah *et al*. (1989) reported that 29.5 %, 43.3% and 23% of Ghana's land area is vulnerable to slight to moderate erosion, severe sheet and gully erosion and very severe sheet and gully erosion respectively. In Ghana, surface water bodies and reservoirs/dams continue to suffer the threat of soil erosion leading to siltation of rivers, deterioration in water quality and the reduction in reservoir capacities (Asante-Sasu, 2016; Kusimi, 2008; Ayivor and Gordon, 2012). As a result, the lifespan of reservoirs/dams are drastically reduced. Subsequently, water supply for both domestic and commercial uses, as well as for the generation of hydropower, for the growing energy demand is negatively affected (Boakye and Bentil, 2011). Thus, effective catchment management is needed to ensure the sustainability of water resources both for the current and future generation (Awotwi *et al*., 2017; Abroampah *et al*., 2015). This will require timely information on the rate and amount of soil loss and delineation of degraded areas (Jazouli *et al*., 2017; Yadav, 2010).

Conventional soil erosion and sediment yield measurement methods have had their challenges such as cost, time and technology (Silva *et al*., 2010) leading to inadequate or sometimes unavailability of reliable data, especially in developing countries for planning and project implementation purposes (Akrasi, 2005). As such empirical and physical models have been developed for soil loss estimations and predictions (e.g. Aksoy and Kavvas, 2005; Amore *et al*., 2004; Morgan *et al*., 1998). The Revised Universal Soil Loss Equation (RUSLE) (Renard *et al*., 1997) which is the updated form of Universal Soil Loss Equation (USLE) (Wischmeier and

Smith, 1978) is one of the widely utilized empirical models for the estimation of soil loss (Jazouli *et al*., 2017; Napoli *et al*., 2016; Tosic, 2011). RUSLE was firstly developed in the USA to forecast long-term average erosion under different management systems (Fadlalla *et al*., 2015; Renard *et al*., 1997). Unlike other models, RUSLE is comparatively simple, easy to determine and does not require complex data to operate with. Thus, it is very appropriate for data deficient countries like

Ghana. The integration of the RUSLE with Geographic Information Systems (GIS) and Remote Sensing (RS) makes it suitable for the assessment of the heterogeneous nature of the basin's topographic and drainage features (Jain and Das, 2010; Jain and Kothyari, 2000). The spatial display and analytic functions of GIS allows the RUSLE model to be applied to individual cells to spatially exhibit the pattern of soil erosion in a catchment (Dabral *et al*., 2008; Pandey *et al*., 2007; Jain and Kothyari, 2000). Hence its application in soil loss estimation and prediction has been catalogued in literatures (e.g. Jain *et al*., 2010; Kusimi *et al*., 2015, Jain and Kothyari, 2000, Yan *et al*., 2018). Zerihun *et al*. (2018) evaluated soil loss severity in the Dembecha District, Northern Ethiopia, using RUSLE integrated with GIS and RS. Their model evaluated the mean yearly soil loss in the district to be 49t/ha/yr. Tosic (2011) utilized the RUSLE to appraise the normal yearly soil loss and gave regionalization in the territory of republic of SRPSKA-BiH according to the level of erosion risk. Ayalew (2014) adopted RUSLE to Ethiopian conditions to estimate soil loss and identified severity areas in Gerdi for conservation measures. His study demonstrated that RUSLE integrated with GIS provides a good estimate of soil loss over areas. Ashiagbor *et al*. (2016) likewise modelled the spatial distribution of soil erosion in the Densu river basin of Ghana using RUSLE and GIS tools, and used the model to explore the connection between the catchment's soil erosion and the contributory factors. El Jazouli *et al*. (2017) evaluated soil erosion susceptibility in the Middle Atlas Mountain-Morocco using the USLE and the spectral index approach and realized an agreement between the two. Kayet *et al*. (2018) used the RUSLE and SCS-CN to estimate soil loss in the Kiruburu and Meghahatuburuu mining sites. Their results indicated a solid connection between the soils with runoff. Again, Fernandez *et al*. (2003) combined GIS with RUSLE model to evaluate the spatial distribution of soil erosion and sediment delivery of a catchment and concluded that the coordinated approach enables relatively simple and cost-efficient way of estimating soil erosion and sediment delivery.

In spite of the fact that the RUSLE and its integration with Geospatial technologies have gotten acknowledgment among hydrologist and erosion researchers, its application in Ghana is exceptionally insignificant. Considering the unavailability of soil loss and sediment yield data, and the need to monitor soil erosion, there is the need to adopt appropriate models to demonstrate the spatial distribution of soil erosion and sediment yield, especially in basins experiencing drastic land use and cover changes. One of such important basins is the Pra River Basin (PRB) in Ghana. It is the second largest basin in Ghana with an average discharge of 4174Mm^3/year (Water

Resources Commission, 2012). The climatic environment makes the basin susceptible to rainfall erosion (Akrasi and Ansa-Asare, 2008; Oduro-Afriyie, 1996). Previous sediment yield studies and estimates by Akrasi (2005) and Akrasi and Ansa-Asare (2008) indicated that the sediment yield of the basin was low by world's standard. However, the rise in the activities and operations of illegal miners (galamseyer's) in the basin and alluvial mining within the river bed (Awotwi *et al*., 2018; Kusimi *et al*., 2014), and the increasing urbanization since then can significantly alter the erosion regime of the basin. It is therefore likely that the estimates might not be reflecting the current situation, knowledge of which is important for basin management to ensure sustainability of the ecosystem.

In view of this, the study applies the RUSLE model to display the spatial distribution of soil erosion and the sediment yield of PRB. The study integrated the RUSLE and Sediment Distributed and Delivery (SEDD) model with GIS and RS to identify the sediment generating areas for prioritized attention. This is important for effective catchment management to reduce the soil loss rate and the amount of sediment yield in the Pra river system, thereby ensuring the sustainability of the ecosystem, longevity of reservoirs/dams and an improved agricultural productivity.

6.2 Materials and Methods

6.2.1 Methods and Dataset

The Revised Universal Soil Loss Equation (RUSLE) is an empirically based model used to estimate long-term average annual soil loss resulting from rainfall and runoff (Wischmeier and Smith, 1978; Renard *et al*., 1997) given as

$$A = R\ x\ k\ x\ LS\ x\ C\ x\ P \qquad (6.1)$$

Where

A is the annual soil loss/gross amount of soil erosion (t/ha/yr.); R is the rainfall erosivity factor (MJ mm ha/h/yr.); K is the soil erodibility factor (t ha $MJ^{-1}mm^{-1}$); LS is the slope length and steepness factor (dimensionless); C is the cover management factor (dimensionless) and P is the support practice factor.

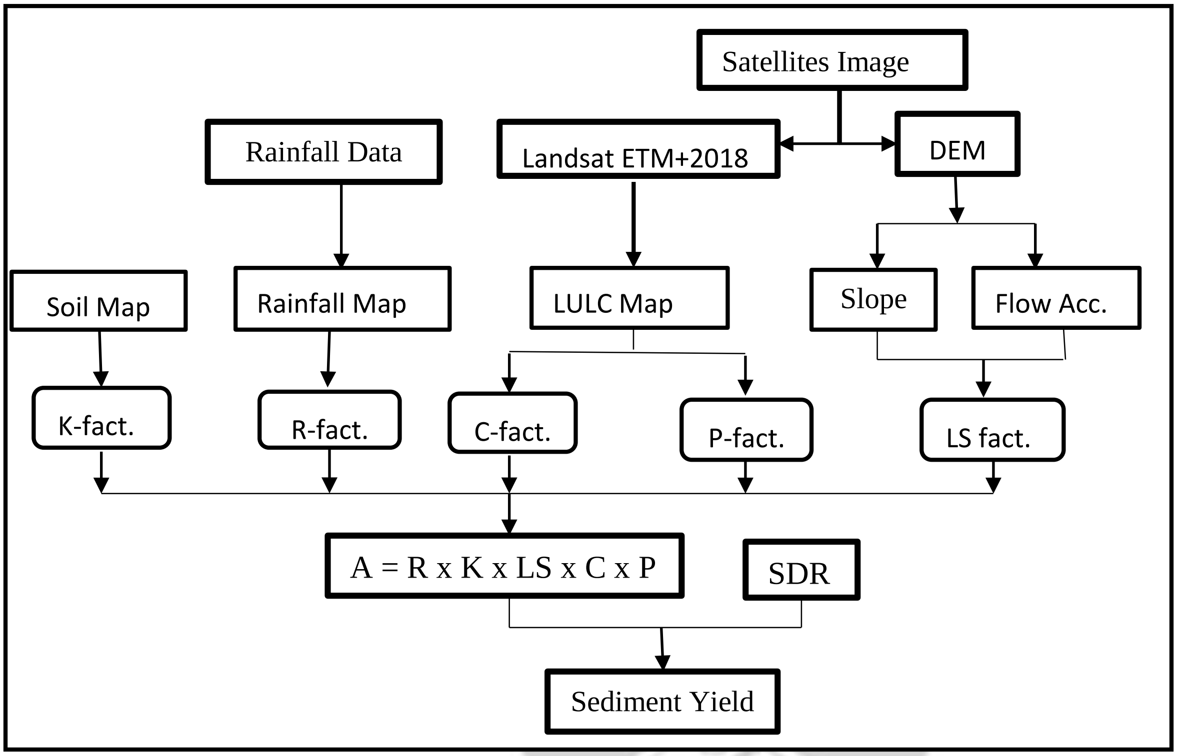


Fig.6.1. Flow chart of methodology

The rainfall erosivity factor (R) characterizes the impact of rain to cause erosion (Hudson, 1995). The rain drop size, distribution, frequency, intensity and velocity determine the amount of soil erosion detached and transported. Therefore, greater rainstorm intensity and duration result in higher erosion potential (Jain and Kothyari, 2000). Thus high R value indicates high potential of soil detachment and transport. The annual R factor is an element of the aggregate tempest vitality (E) and the most extreme 30-minute force (I_{30}) (Morgan, 2005). It is determined through the summation of every rainstorm, the result of the aggregate vitality and the greatest 30minute force, I_{30}. Be that as it may, these figures are not really accessible at standard meteorological stations (Ashiagbor *et al*., 2016; Mbugua, 2009) yet since long-term normal R-values are regularly related with all the more promptly accessible precipitation information, the yearly precipitation and the modified Fournier Index (Arnoldus, 1980) was utilized in building up the mean yearly precipitation map and the average yearly erosivity map in ArcGIS separately. The Modified Fournier Index (MFI) is more important for the investigation of precipitation forcefulness since it considers the estimation of precipitation in various long periods of the year and the variety amid a particular year or period.

The R-factor was then computed from Arnoldus (1980) equation developed for West Africa expressed as

$$R = 5.444MFI - 416 \quad (6.2)$$

MFI is the modified Fournier index expressed as

$$MFI = \sum_{i=1}^{12} \frac{{P_i}^2}{P} \quad (6.3)$$

P_i is the monthly average amount of precipitation for month i (mm) and P is the average annual quantity of precipitation (mm). In this study, daily rainfall records from twenty-two (22) meteorological stations within and around the basin, from 1986 to 2018 were used to calculate the mean annual rainfall. Then the rainfall map and the rainfall erosivity (R) map was produced by interpolation using the Kriging tool in ArcGIS. And since the constant mean of the data across the basin is unknown, ordinary kriging method using the spherical semivariogram model was adopted for the interpolation process.

- ✓ **Soil Erodibility factor, K**

The soil erodibility factor represents the soil's vulnerability to disintegration by precipitation and overflow (Renard *et al*., 1997). Morgan (2005) defines it as "the mean annual loss per unit of rainfall erosivity for a standard condition of bare soil, recently tilled up and down slope with no conservation practice". It is influenced by the soil's inherent properties such as texture, structure, organic matter, permeability etc. High K-value implies the soil is highly susceptible to detachment whilst low K-value indicates the soil's resistance to detachment or erosion during storm event (Adornado *et al*., 2009). In this investigation, the K-factors (Table 6.1) was obtained from Ashiagbor *et al*. (2016). Ashiagbor *et al*. (2016) estimated the soil erodibility factor for soils in Ghana using the erodibility monograph by Wischmeier and Smith (1978).

Table 6.1: K-factor of soils in the PRB

Soil Type	K-factor
Acrisols	0.253
Lixisols	0.234
Leptosols	0.275
Fuvisols	0.295

Luvisols	0.234
Alisols	0.250

The K-factors were allotted to the various soil classifications in the basin and used to generate Kfactor map in ArcGIS.

- ✓ **Cover Management factor, C**

The cover management factor C explains the proportion of soil loss from land under determined conditions to that from persistent fallow and tilled land (Wischmeier and Smith, 1978). The value of C indicates the soil's exposure to rain drops. High C-value indicate low vegetative cover, hence higher rate of erosion during rainfall, whiles low C-value indicates good vegetative cover, resulting in low erosion rate. In this study, the C-factor map was developed from Landsat ETM+2018 covering the PRB. The Landsat imagery was classified with the supervised classification technique using the spectral angle mapping technique. Six LULC classes were identified and classified, namely closed/dense forest, open/degraded forest, Farm/grassland, settlement, mining and water bodies. The details of the classification and the accuracy assessment have been described in section 4.2.2. The C-factor estimates corresponding to the different LULC classes suggested by Kusimi *et al*. (2015) and Wischmeier and Smith (1978) (Table 6.2) were allotted to their individual classes to produce the C-factor map.

Table 6.2: C-factors of land use and land cover classes in the basin

Land use and land cover class	C factor
Closed forest	0.001
Open forest	0.003
Farm/grassland	0.5429
Settlement	0.35
Mining	1
Water	0.000

Slope Length and Steepness factor (LS)

The LS factor depicts the impact of topography on soil erosion. It is the combination of slope length (L) and slope steepness (S) in relation to a unit cell (grid). The slope length (L) is characterized as the separation from the source of runoff to the point where settlement begins or runoff enters a well-defined channel which is part of the drainage system, whilst the steepness factor (s) demonstrates the impact of incline steepness on disintegration. For the determination of LS factor, hypothetical relationship in light of unit stream control hypothesis has been adopted from Jain *et al*. (2010) as this connection is most appropriate for integration with GIS. The relation is given as

$$LS = \left[\frac{As}{22.13}\right]^n \left[\frac{sin\beta}{0.0896}\right]^m \quad (6.4)$$

As is the specific area (A/b), characterized as the upslope contributing zone for overland lattice (A) per unit width typical to stream heading (b), β is the incline angle in degrees, n= 0.4 and m= 1.3. However, in this study, LS factor was determined from the DEM of the basin integrated into the GIS environment. The GIS technology enables relatively easy calculation of the L and S factors through the estimation of upslope contributing areas and the inclined slope individually. The overland flow length and the slope map were used as input in the derivation of LS factor map using equation 6.5 stated by Mitasova *et al*. (1996) and Ashiagbor *et al*. (2016)

$$LS = \text{Pow}([Flowaccumulation]*\frac{Cell\ resolution}{22.1,0.4})*\text{Pow}(\sin\left(\frac{slope\ of\ DEM}{0.09,1.4}\right) 1.4) \quad (6.5)$$

✓ **Conservation Support Practice,** P

The support practice factor (P) describes the effect of practices like contouring, strip-cropping, terraces and contour furrows on the rate of runoff and erosion. The P-factor ranges between 1 and 0.01 for bare soils with no erosion measures and fully protected land surface respectively (Arekhi, 2008).

In this study, field observation as well as the classification results showed that the basin is well protected by forest, grassland and crops. Accordingly, as demonstrated by Kusimi *et al*. (2015) P-factor of 1 was allocated to settlement and mining territories, and zero (0) to water. With regard to forest and farm/grassland reference was made to Sun *et al*. (2013) and Yan *et al*. (2018). Thus, P values of 0.31 and 0.05 were assigned to farm/grassland and forest respectively to generate P-factor map in ArcGIS.

Hence, raster maps of R, K, LS, C and P were coordinated in ArcGIS environment utilizing the RUSLE model to produce the annual soil loss map.

✓ **Sediment Yield**

If A_i is the measure of soil erosion created inside the i[th] cell of the basin, then according to Jain and Kothyari (2000) the sediment yield of the cell, SY is

$$SY = A_i * SDR_i \quad (6.6)$$

Where SDR is the sediment delivery ratio

✓ **Sediment Delivery Ratio (SDR)**

SDR explains the proportion of the gross soil loss from the i[th] cell that really reaches a stream system (Fernandez *et al*., 2003). It is assessed as a component of movement time (Ferro and Minacapilli, 1995) given as

$$SDR_i = \exp(-\beta\, t_i) \quad (6.7)$$

Where t_i is travel time (hr.) for cell i and β is basin specific parameter.

The movement time for every cell, t_i along a stream path as stated by Jain and Kothyari (2000) is

$$t_i = \sum_{i=1}^{m} \frac{l_i}{V_i} \quad (6.8)$$

l_i is the length of fragment I (flow length) in the stream way and is equivalent to the length of the side or askew relying upon the stream heading in the cell, and Vi is the stream speed for the cell (m/s). The flow length was derived from the DEM of the basin whilst the flow velocity is a function of the land surface slope and the land cover characteristics (Mbugua, 2009).

$$V_i = a_i\sqrt{s_i} \quad (6.9)$$

Where s_i – slope of the i[th] cell and a_i – coefficient dependent on land use.

Introducing equation 6.8 & 6.9 into equation 6.7 gives equation 6.10

$$SDR_i = \exp\left(-\beta \sum_{i=1}^{m} \frac{l_i}{a_i\sqrt{s_i}}\right) \quad (6.10)$$

The land use coefficients (Table 6.3) of the individual land cover classes adopted from Kusimi *et al*. (2015) was used.

Table 6.3: Land cover types and their coefficients, a_i

Land cover type	Coefficient, a_i
Closed forest	0.7600
Open forest	0.6401
Built up/bare lands	6.3398

Farm/grassland	0.4572
Water	0.1250

The basin specific parameter β is related to the morphology of the basin. For β, Kusimi *et al*. (2015) found that the sediment yield of the basin was insensitive to β-value, hence β-value of 1 was chosen.

6.3 Results and Discussion

The MFI of the basin ranged between 130 and 163 signifying that the basin is susceptible to severe rainfall erosion (Balogun *et al*., 2012; Akrasi and Ansa-Asare, 2008; Oduro-Afriyie, 1996). The rainfall erosivity factor, R (Fig.6.2b) obtained ranges from 349 – 455MJ.mm/ha/hr.

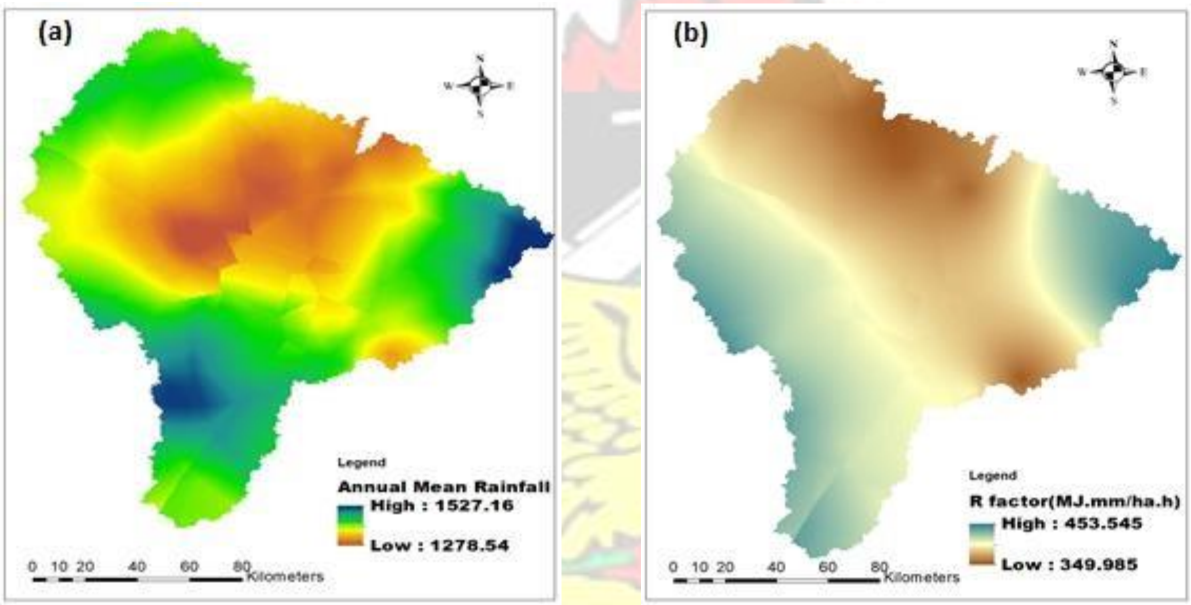
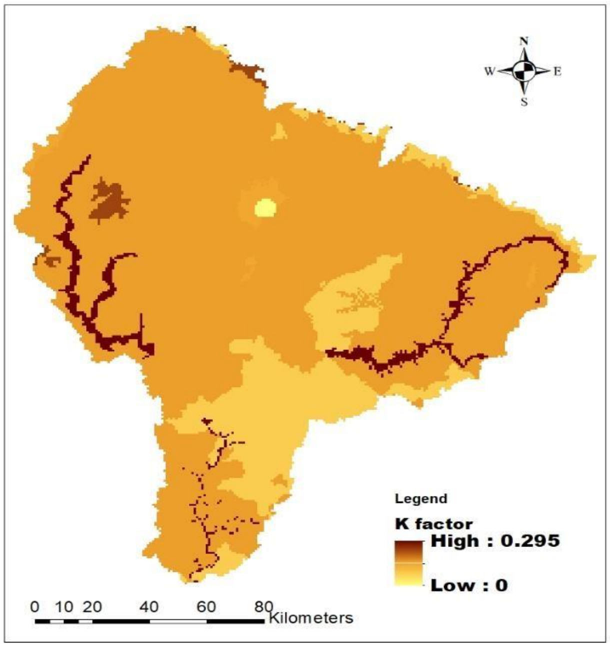


Fig.6.2. (a) Annual mean rainfall map and (b) Rainfall erosivity (R) map

The basin is underlain with wood ochrosols: Acrisols, Lixisols, Alisols, fluvisols, leptosols and luvisols. Their corresponding erodibility factor (K) showing the basin's susceptibility to erosion under the influence of rain droppings were assigned to produce the K-factor map (Fig.6.3), with values ranging from 0 – 0.295. This implies all the soils in the basin relatively have low erodibilities.



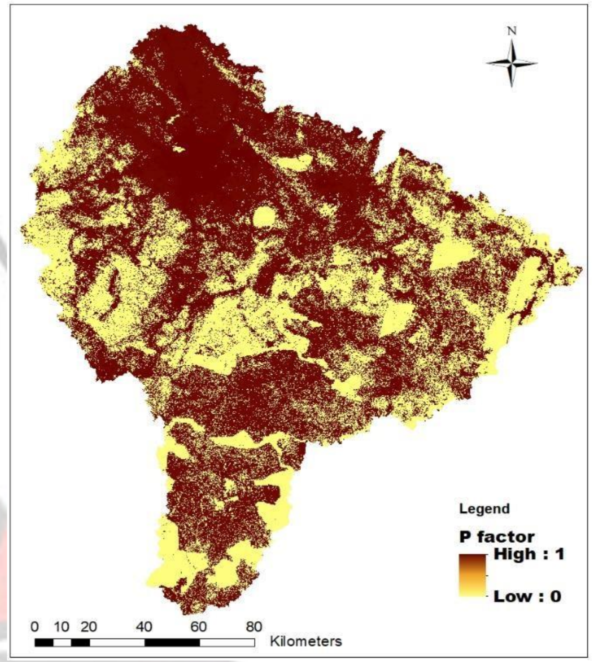
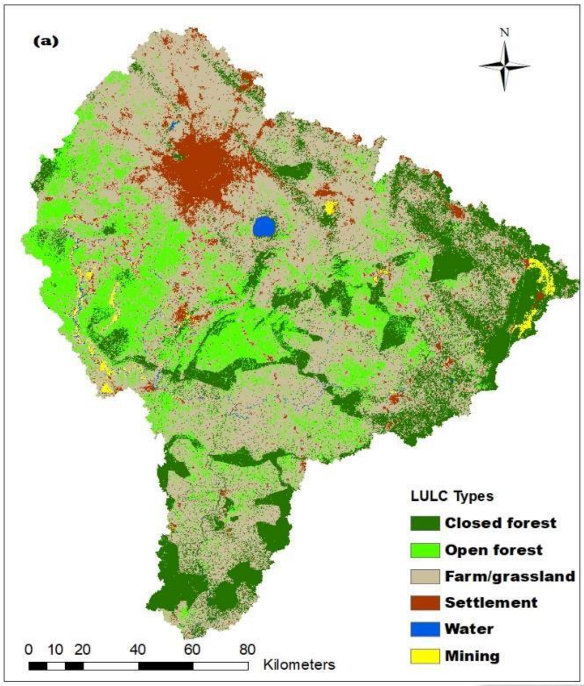


Fig.6.3. Soil erodibility factor (K) map **Fig. 6.4. P factor map of PRB**

The conservation support practice factor (P) obtained for the basin ranged between 0-1 (Fig. 6.4) with the mean of 0.17. P factor describes management practices that either enhanced or minimize soil erosion in the basin.

The cover management factor (C) map produced (Fig. 6.5b) shows the C factors of the basin ranges from 0 - 1 with a mean of 0.32. The 2018 land use/cover (LULC) map of PRB (Fig.6.5a) showed that 21.63%, 18.39%, 51.81%, 6.46%, 1.12% and 0.59% of the basin is covered with Closed forest, Open forest, Farm/grassland, Settlement, Mining and water respectively. Hence, spatial distribution of the C factor is heterogeneous. Low C values are associated with Forest covers while high values are associated with Mining, Farmlands and Settlement.



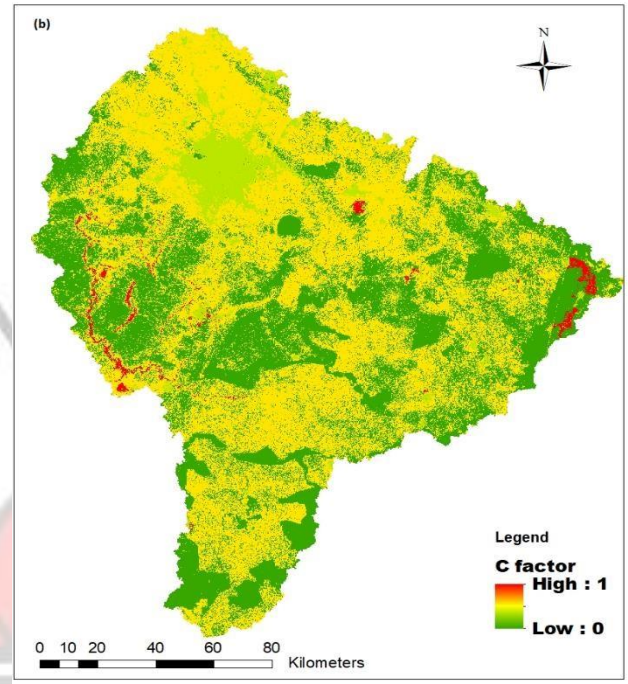


Fig.6.5. (a) LULC map (2018) and (b) Cover management factor (C) map

The LS factor values (Fig. 6.6) were within the range of 0 – 1955.36, with an average of 0.62. The low values correspond mostly to the plain areas, thus transport of eroded sediment is limited while high values correspond to the mountainous and hilly areas such as the Ashanti MampongKwahu scarps, around Lake Bosomtwi and Atewa Mountain.

- ✓ **Soil Erosion**

The RUSLE factors, R, K, LS, C and P were combined to depict the spatial distribution of the soil erosion in the basin (Fig. 6.7). The estimated gross soil erosion of the basin was 1.28 x 10^6 tons/yr. The soil loss ranges from 0 – 8,032 tons/ha/yr. with an average value of 38.3 tons/ha/yr. and a standard deviation of 116.87. Comparing the mean soil erosion value to the FAO (1967) classification scheme, the basin is classified as moderate risk zone. The soil erosion susceptibility zones in the basin is categorized into four types namely; low, moderate, severe and very severe erosion (Table 6.4). The range obtained shows that about 78.7% of the basin experiences Low to moderate erosion whilst about 21.30% experiences severe to very severe erosion risk. Such areas are basically Farmlands along steep slopes and exposed land areas due to illegal mining (galamsey) whilst the low risk zones are dominated with forest and crop cover as found by Kusimi *et al.* (2015).

Table 6.4: Categories of erosion risk, area and the amount of soil loss

Erosion Risk Categories	Severity Class	Area (%)	Soil Loss (tons/yr.)x10^3
0 – 10	Low	71.8	1.938
10 – 50	Moderate	6.9	73.142
50 – 120	Severe	11	298.099
>120	Very severe	10.30	907.731
-	Total		1,280.912.

The model results (Table 6.6) also shows that soil erosion rate varied with land use types in a decreasing order from Mining>Settlement >Farmland/grassland>Open forest>Closed forest. Mining, Farm/grassland and Settlement areas are susceptible to severe soil erosion rate than the forest zones. This means such areas must be given prioritized attention. For instance, there is the need to adopt support management practices such as terracing and contouring on farmlands to control the rate of soil loss. Also the buffer zone policy must be enforced. Illegal mining (galamsey) and alluvial mining must as a matter of urgency be stopped.

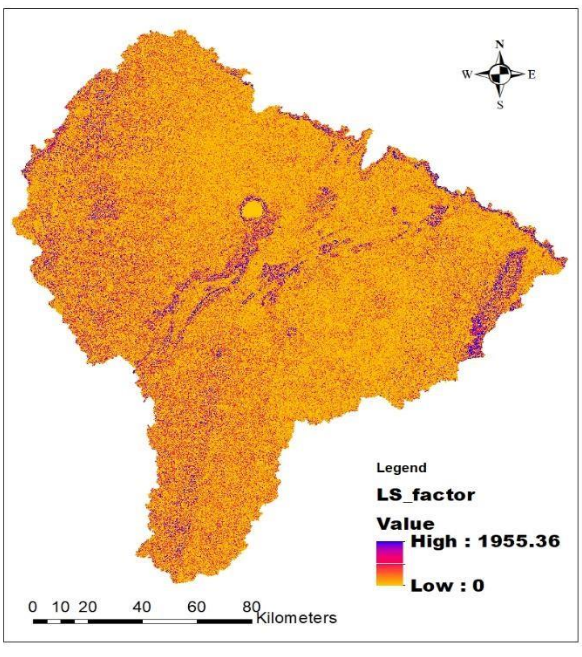


Fig. 6.6. LS factor map of the PRB

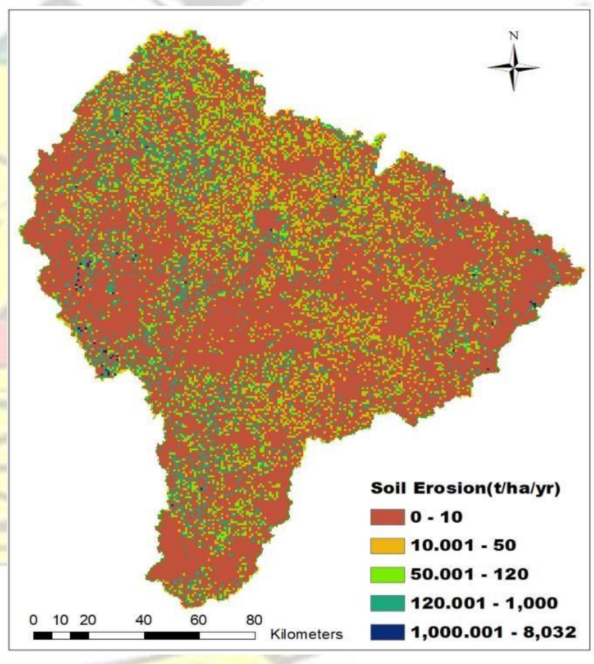


Fig. 6.7. Spatial distribution of soil loss of PRB

The soil erosion rate was categorized with respect to the sub-basins of the Pra River viz: Upper Ofin, Oda, Anum, Lower Ofin, Upper Pra, Twifu Praso, Birim, Assin Praso and Lower Pra by overlaying the shapefile and the soil loss map. This helped to prioritize the sub-basins for conservation measures with respect to their risk levels. The results (Table 6.5) show that the Lower Ofin sub-basin experiences the most soil loss of averagely 59.88 tons/ha/yr. ranging from 0 – 8032tons/ha/yr.

Table 6.5: Sub-basins of the Pra River and their corresponding soil loss

Sub-basin	Area(ha)	Soil loss (tons/ha/yr.)			Conservation priority
		Range	Mean	Gross	
Upper Ofin	306,185	0 – 1,647	55.60	247,581.9	Second
Oda	93,515	0 – 736	43.22	60,072.5	Third
Anum	69,031	0 – 850	37.94	37,830.7	Fourth
Birim (Kade)	212,185	0 – 3,218	29.90	92,636	Eight
Assin Praso	308,645	0 – 1,507	22.11	100,077.7	Ninth
Lower Ofin	383,913	0 – 8,032	59.88	294,951.3	First
Upper Pra	366,076	0 – 1,888	31.39	169,449.5	Seventh
Twifu Praso	337,521	0 - 927	35.54	176,575.1	Fifth
Lower Pra	210,061	0 – 1,303	33.57	101,737.2	Six

- ✓ **Sediment Delivery Ratio (SDR)**

The SDR value (Fig. 6.8) describes the fraction of the eroded sediment delivered to the point in question. Thus, it's an index of the sediment transport efficiency. The SDR values ranged from 0 – 1. Generally, the SDR values of the basin were low except around the mountainous areas and hillslopes such as Mampong and Kwahu scarps, where the river takes it source, and around Lake Bosomtwe. Besides, river channels exhibit relatively high SDR values. This implies erosion occurring in the mining, farm and settlement areas (Yan *et al*., 2018) are entrained into the river channels and transported downstream.

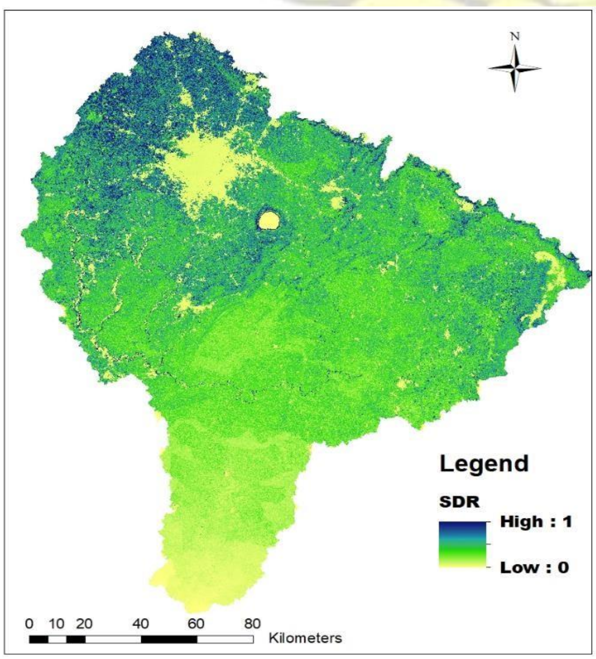
- ✓ **Sediment Yield**

The model estimated the sediment yield of the PRB (Fig. 6.9) ranging from 0 – 520.772 tons/ha/yr., with a mean of 2.70 tons/ha/yr. as opposed to Akrasi and Ansa-Asare (2008)' estimate of 0.508tons/ha/yr. Even though the mean obtained appears relatively lower than that for African catchment of 4.93tons/ha/yr. (Vanmaercke *et al*., 2014), the erosion rate and sediment delivery in the basin is increasingly being worsened. The increase in the sediment yield can be attributed to the increasing urbanization, and illegal mining and alluvial mining in the basin (Kusimi *et al*., 2014; Awotwi *et al*., 2017)

Table 6. 6: LULC types and their corresponding soil loss and sediment yield

LULC Class	Area (%)	Soil Loss (tons/ha/yr.)			Sediment Yield (tons/ha/yr.)		
		Range	Mean	Gross	Range	Mean	Total
Closed Forest	21.63	0 – 322	19.96	142,590.39	0 – 335	1.37	974.18
Open Forest	18.39	0 – 1981	23.87	147,851.12	0 – 137	1.66	1,078.52
Farm/Grassland	51.81	0 - 5089	43.49	756,559.45	0 – 521	3.53	6,482.9
Settlement	6.46	0 – 1642	63.73	140,386.88	0 – 106	1.67	3,658.57
Water	0.59	0 – 2936	87.47	18,456.38	0 – 440	14.1	2,969.68
Mining	1.12	0 - 8032	192.98	75,067.91	0 – 309	6.77	2,632.65

It is observed that the mean sediment yield (Table 6.6) in water is higher than that of other cover types. This is because high run-offs generated during rainfall causes erosion from especially farmlands, settlement and mining areas, and entrains the sediment into the streams and rivers. This means the water bodies serves as the major recipients of the sediment generated in the catchment, making it vulnerable to siltation, pollution and destruction of aquatic life (Mensah, 2009). Besides, the activities of the alluvial gold mining as well as sand winning in the river bed increased the sediment production in the rivers and streams in the basin.



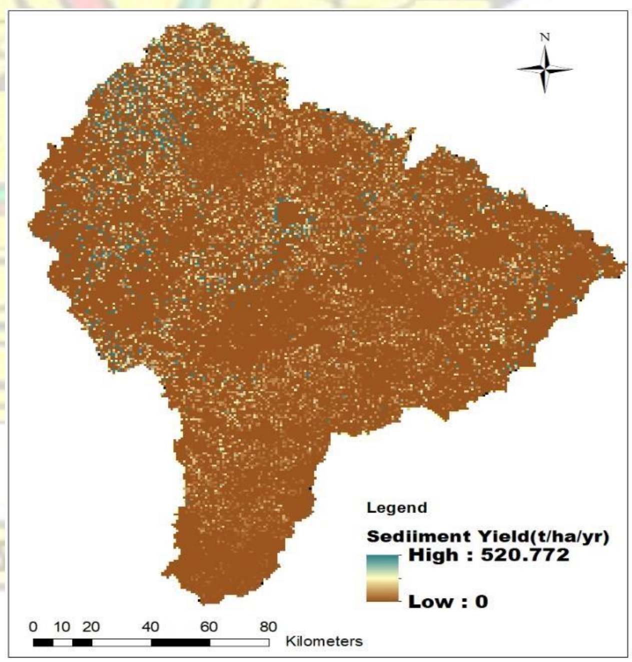


Fig.6.8. Sediment Delivery Ratio of PRB **Fig.6.9. Sediment Yield in PRB- 2018**

6.4 Conclusions and Recommendations

The RUSLE and the SEDD model integrated with GIS is adopted to estimate the annual soil loss in a grid basis and the sediment yield of the PRB. The model estimated annual soil loss of 1.28 x 10^6 t/yr. in the basin. The erosion map showed that about 21.3% of the basin comes under severe to very severe erosion category. High soil erosion occurs mostly in the farmlands, mining and settlement areas. An average of 2.70 t/ha/yr. of sediment yield was also predicted by the model.

Most of the sediments eroded from the catchment are entrained into the rivers and streams causing siltation and pollution. Areas characterized by severe to very severe soil loss should be given special and immediate conservation priority to reduce or control the rate of soil erosion whilst low to moderate prone areas should be protected from further erosion.

The study demonstrates that the RUSLE model integrated with GIS is an important tool in estimating soil loss of basins and their spatial distribution. Thus, it can be effectively adopted to indicate high or low risk soil erosion areas in basins where erosion and sediment data is virtually non-existent. However, it must be noted that the RUSLE model accounts only for surface erosion and sediments, and does not account for channel/gulley erosion. Hence the results obtained does not reflect the influence of bank and gully/channel erosion. There is also the need to painstakingly and consistently determine the soil erodibility factors for soils in the basin's, especially in the changing environment. This is important because the accuracy of the results from the RUSLE model depends largely on the accuracy of the factors used.

CHAPTER SEVEN STATISTICAL MODELLING OF SUSPENDED SEDIMENT CONCENTRATION OF RIVERS: THE EFFECT OF LAND COVER ON MODEL ACCURACY

This part of the thesis is submitted to the journal of Water Resource Management (Springer) (New submission)

CHAPTER SEVEN STATISTICAL MODELLING OF SUSPENDED SEDIMENT CONCENTRATION OF RIVERS: THE EFFECT OF LAND COVER ON MODEL ACCURACY

7.1 Introduction

Frequent measurement of suspended sediment concentration and accurate determination of suspended sediment yield in rivers is crucial to water resources management and development. This is because cumulative loss of water storage capacity within channels and reservoirs due to sedimentation affects adversely the long-term sustainability of the water resource and its associated projects (Awotwi *et al*., 2017; Sun *et al*., 2013; Mavima *et al*., 2011; Kusimi, 2008). Conventionally, the determination of suspended sediment yield requires continuous measurement of suspended sediment concentration and water discharges. However, due to the challenges regarding the acquisition of continuous sediment concentration data such as remoteness of site, number of sampling sites, economic constraints as well as technical difficulties, continuous sediment data rarely exist, especially in developing countries. Hence, water managers, hydrologist and scientist have employed various approaches such as the application of physically-based and empirical models to estimate the sediment yield of river basins, and for future predictions. However, these models usually require substantial amount of data for calibration and validation, which often times are not available in data-poor countries (Silva *et al*., 2010). This makes the application of these models in data-deficient zones difficult.

Therefore, statistical (regression) techniques (Table 7.1) have commonly been used to estimate and predict catchment sediment yield. Wuttichaikitcharoen and Babel (2014) investigated the factors affecting suspended sediments in Ping, Wang, Yom and Nan river basins in Thailand using Principal Component Analysis (PCA) and multiple regression techniques. They concluded that basin geomorphology, rainfall distribution and land use are the key factors influencing the variations in suspended sediment yield. Akrasi (2011) also used regression analysis to develop a model relating sediment yield to both mean annual runoff and the basin area of Southwestern Rivers in Ghana. Their model showed that runoff and catchment area accounted largely for the variation in suspended sediment yield. Akrasi and Ansa-Asare (2008) developed a regression model to estimate suspended sediment and nutrient yield in the Pra basin and for prediction.

Tamene *et al*. (2006) implemented different statistical analysis such as Pearson's correlation, PCA and multiple regression to analyze the relationship between sediment yield and catchment characteristics, and to identify major factors controlling sediment yield variability in Northern Ethiopia. They showed that variations in catchment sediment yield results from variations in catchment geomorphology and land cover status but did not quantify how the various land cover categories contributes to the observed variation. Verstraeten and Poesen (2001) used multiple regression to analyze variation in sediment yield from twenty-six (26) cultivated catchment in Belgium and concluded that catchment area alone accounted for 64% of the observed variance in the Area-Specific sediment yield. However their model failed to integrate the land cover factor. Again, in 2005, Akrasi used regression analysis to establish the relationship between specific suspended sediment yield and both mean annual runoff and the basin area for predictions in the Volta basin of Ghana without integrating the land cover component.

In summary, most of these statistical models basically relate the sediment concentrations to discharges and basin size, assuming water discharges as the dominant controlling factor in sediment yield rather than sediment supply (e.g. Kusimi *et al*.,2014; Akrasi, 2011; Akrasi and Ansa-Asare, 2008). Even though land cover characteristics determines greatly the rate and amount of sediment supply (Lu *et al*., 2017; Ayivor & Gordon, 2012; Nunes *et al.*, 2011), the statistical models employed in the existing literature usually do not reflect its influence. Even the models that consider the land cover component consider the catchment land cover characteristics to be homogenous (Wuttichaikitcharoen and Babel, 2014; Dunne, 1979) and therefore treat it as categorical. Sediment yield studies greatly attribute variations in catchment sediment fluxes to land use and cover. Dedkov (2004) found that rivers in uncultivated basins are characterized by low suspended sediment yield as compared to the cultivated basins. With regard to the relationship between specific suspended sediment yield and drainage area, he noted that a positive relationship existed between them for uncultivated basins or basins with limited cultivation. But for intensively cultivated basins, a negative relationship exists. Dunne (1979) also noted that land cover change is the dominant cause of sedimentation and that the influence of other factors becomes pronounced as the density of land cover decreases. Thus to model sediment yield of a basin without incorporating the proportions of land cover types will likely result in under or over estimation especially in catchment's experiencing significant land use and cover changes (Asselman, 2000). Good sediment yield model should be able to predict the effect of the combination of various controlling factors in the basin in order to conform to reality.

The purpose of this study is to assess the contribution of incorporating land cover types in regression/statistical models built to explain the variation in sediment yield of a basin and to forecast same. It tests the effect of the different land use classes on the sedimentation of the river and their relative importance in explaining the observed variations in the catchment's suspended sediment concentration. The outcome will be used to accurately estimate the suspended sediment yield of a basin experiencing drastic changes in the land use patterns. The study therefore enhances the understanding of the effect of land use/cover variations on catchment sediment fluxes. This will aid consistent monitoring of sediment yield which is crucial for effective water resources management and development.

Table 7.1: Summary of sediment models, accuracy and significant variables

Author	Model	Accuracy	significant Variables
Akrasi (2011)	$SY = 0.014Q_{w}^{1.438}A^{0.757}$	$R^2 = 0.91$	Discharge, Area
Akrasi &Ansa-Asare (2008)	$SY = 135.62Q_{w}^{0.38}A^{0.17}$	$R^2 = 0.85$	Discharge, Area
Akrasi (2005)	$SY = 0.24Q_{w}^{0.84}A^{0.26}$	$R^2 = 0.92$	Discharge, Area
Wuttichaikitcharoen &Babel (2014)	$SY = 28.74Area^{1.1636}$	$R^2 = 0.83$	Area
	$ASSY = 0.0068DSR^{1.8506}$	$R^2 = .078$	Dry Seasonal Rainfall
Tamene et al.(2006)	$\log SSY = 0.007SBCR + 0.003EL +0.002RG - 0.007BUSH +2.3$	$R^2 = 0.96$	Terrain form, surface lithology, surface cover, gullies
	$\log SSY = 0.\ 0011HD +0.009EL + 0.019$	$R^2 = 0.87$	Height difference, Erodible lithology
Verstraten & Poesen(2001)	$\ln SSY = 3.72 - 0.72\ln A - 0.84\ln HI + 0.11\ln DL$	$R^2 = 0.76$	Area, Drainage length, Hypsometric Integral
	$SY(t/yr.) = 0.21D + 22.2HD - 988HI$	$R^2 = 0.92$	Horizontal distance, Elevation difference, Hypsometric Integral

7.2 Methodology

The study involves basin data collection and multiple (stepwise) regression analysis. The data used for the analysis were the mean slope of the catchment, catchment area, river discharges, suspended sediment concentrations and land use categories.

7.2.1 Basin Data Collection

The land use/cover types and compositions were obtained from the 2018 Landsat ETM+ images covering the Pra River Basin. The basin was divided into nine sub-basins with respect to their drainage basins. Supervised classification of the images was performed using the spectral Angle mapping technique in QGIS. Then using Anderson's classification scheme (1976), six land cover types were identified and classified, namely, Closed forest, Open forest, Farm/Grassland, Settlement, Mining and Water. The spatial extent of each land cover type was determined; these are expressed as percentages in Table 7.2. The mean slope, elevation and area of the sub-basins were derived from their respective DEM using the Spatial Analyst Extension in ArcGIS.

River discharge measurement and suspended sediment sampling were undertaken at the outlet of the nine drainage basins from October 2017 to September 2018 in order to cover both low and high flows. The discharges were measured with Acoustic Doppler Current Profiler (ADCP) while the suspended sediment was collected using the Integrated Sampler. The samples were collected in clean plastic bottles and analyzed at the sediment laboratory of Water Research Institute, Ghana to obtain the suspended sediment concentration.

Table 7.2: Some Characteristics of the sub-basins of the PRB

SUB-BASIN	Mean Elevation	Mean Slope	Area (Km^2)	Proportion of Land Use Class (%)				
				Closed Forest	Open Forest	Farmland	Settlement	Mining
Twifo Praso	150.32	9.86	3375.21	31.54	13.08	51.21	3.23	0.64
Assin Praso	162.54	7.65	3086.45	3.11	39.47	52.67	4.42	0.10
Lower Offin	195.00	10.27	3839.13	30.20	39.10	23.73	2.94	2.29
Upper Offin	272.41	6.87	3061.85	23.83	6.75	51.25	17.42	0.59
Anum	271.72	7.35	690.31	35.50	41.81	15.71	4.87	2.08
Birim	250.85	9.25	2121.85	35.37	19.81	39.66	2.78	1.76
Oda	263.31	6.37	935.15	18.58	7.76	23.96	48.92	0.54
Upper Pra	227.94	7.81	3660.78	38.35	20.78	34.84	4.43	0.27
Lower Pra	100.60	10.27	2100.67	44.23	15.25	37.85	1.99	0.25

7.2.2 Statistical Analysis

Statistical analyses were performed using SPSS software version 16.0. These include correlation analysis, factor analysis and multiple regression analysis.

7.2.2.1 Correlation Analysis

Preliminary analysis using Spearman's rho (non-parametric) and Pearson (parametric) correlations was conducted. The correlation coefficient, r is a statistical measure of the strength of linear relationship between paired data. This was used to determine the nature, extent and significance of the relationship between suspended sediment concentration (as response variable) and the controlling factors (predictors). The correlation matrix also explains whether the predictors exhibit levels of multi-collinearity (Landau and Everitt, 2003). Zero correlation values indicate no linear relationship, however it does not connote no relationship between the response and the predictor variables. The relationship may be exponential or logarithmic even though r may be low.

7.2.2.2 Factor Analysis

PCA was performed to identify cluster of variables that predominantly can be characterized with respect to a single variable. It enables the determination of latent variables underlying the variations in the dataset. Data suitability for the PCA was assessed using the Kaiser–Meyer–Olkin (KMO) measure of sampling adequacy and Bartlett's test of sphericity (Armah et al., 2017; Landau and Everitt, 2003; Bartlett, 1954). The Bartlett's test of sphericity checks for correlations in the data set that are appropriate for the PCA. The dominant factors were categorized using the Eigen values rule (Landau and Everitt, 2003).

7.2.2.3 Regression Analysis

Regression relationship between suspended sediment concentration, Sc (response variable) and discharge (Q), topography (S) and catchment area (A) (Predictors) as it exist in literature is

$$S_C = Q^a S^b A^c \qquad (7.1)$$

Including the land use categories results to the equation

$$S_C = U_i Q^a S^b A^c \qquad (7.2)$$

In the logarithmic form, equation 7.2 is transformed into

$$\ln(Sc) = \delta_0 + \delta_1 \ln(U_1) + \delta_2 \ln(U_2) + \delta_3 \ln(U_3) + \delta_4 \ln(U_4) + \delta_5 \ln(U_5) + a\ln(Q) + b\ln(S) + c\ln(A) + \ln\varepsilon \qquad (7.3)$$

where S_C is Suspended sediment concentration (the response variable), U_i, Q, A and S are predictor variables (dominant factors influencing sediment concentration of a basin), δ_i, a, b and c are regression coefficients determined by the least squares method (Landau and Everitt, 2003).

Q is river discharge, A is drainage Area, S is mean Slope. U_1, U_2, U_3, U_4 and U_5 are the proportions of Closed forest, Open forest, Farmland, Settlement and Mining in respective drainage basins. The inclusion of the land cover categories enable the quantification of the effect of their proportions on the sediment concentration at the sub-basin level. In order to minimize the effect of multi-collinearity the 'Best subset' (stepwise approach using an F probability of 0.05), was used to select the significant predictors. The criterion for selecting the best model was characterized by high coefficient of determination (R^2) and low Standard error. The accuracy and suitability was measured by the R^2, the P-value whilst the adequacy of the model was determined using a set of residual diagnostic test (Makridakis *et al*., 2008).

7.3 Results and Discussions

7.3.1 Correlation Coefficients

The Spearman's rho and Pearson's correlation matrix (Table 7.3) shows significant linear relationship ($P<0.05$) between suspended sediment concentration and slope, Area, closed forest (U1), Settlement (U4) and Mining (U5). On the other hand, Discharge, Open forest (U1), and Farmlands did not correlate significantly with suspended sediment concentration. Besides, it is observed that significant linear relationship ($p<0.05$) exists among some of the predictor variables indicating the possibility of the model suffering from the problem of multi-collinearity.

Pearson's product moment correlations (parametric)

	S_c	Q	S	A	U1	U2	U3	U4	U5
Sc	1	0.099	.703**	.399**	.235*	0.187	-0.119	-.295**	.378**
Q		1	.393**	.534**	0.131	-0.113	.237*	-0.204	-0.15
S			1	.706**	.509**	0.139	0.1	-.658**	.259*
A				1	.240*	-0.151	.431**	-.414**	-.381**
U1					1	-0.165	-.339**	-.384**	.291**
U2						1	-.359**	-.499**	.509**
							1	-.240*	-.612**
								1	-.226*

U3									
U4									
U5									1

Table 7.3: Pearson's product moment correlations (parametric) and Spearman's rho correlations (non-parametric)

Spearman's rho correlations (non-parametric)

Sc	1	0.204	.743**	.475**	.231*	0.016	-0.128	-.675**	.289**
Q		1	.382**	.521**			.238*	-.315**	-0.09
							-0.042	-.921**	0.159
S			1	.711**					
							.467**	-.633**	-.433**
A				1	0.022	-0.189	-.383**	-.467**	0.083
					.494**	0.209	-.350**	-0.217	0.167
U1					0.133	-0.083	1	-0.117	-.533**
U2					1	0.167			
						1			
U3									
U4								1	-0.05
U5									1

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Practically, land use data exhibit co-linearity. This is because an increase in the percentage of one land use type proportionally decreases one or more of the other types (Yan *et al*., 2013). Thus as the percentages in the spatial extent of the individual land use types changes due to anthropogenic influence, the proportionate effect on sediment concentration should be evident.

The effect of the multi-collinearity was minimized by using the stepwise regression approach.

7.3.2 Factor Analysis

The KMO score and the Bartlett's test of sphericity showed significance (p = 0.00) of relations indicating the factorability of inter-correlation matrix or suitability of the data set for factor analysis.

PCA results (Table 7.4) of the data set shows four components with Eigen values greater than 1.0 explains **77.4%** of the total variability in the data set. PC1, which accounted for 28.9% of the total variance correlated with catchment area and topography. PC2 accounting for 22.2% of the variance correlated positively with mining and negatively with farmland. PC3 accounted for

17.1% of the total variance and correlates with closed forest whereas PC4 accounted for only 9.2% of the total variance and was correlated with months. Based on the factor loadings after Varimax rotation (Table 7.4), Variance factor 1 reflects the influence of catchment characteristics, Variance factor 2 reflects the influence of anthropogenic activities (mining), Variance factor 3 reflect the influence of vegetative cover, whilst Variance factor 4 reflects seasonal variability. These findings are consistent with previous studies which indicated that the sediment yield of basins result from the multiplicative effect of runoff, vegetative cover and catchment properties (e.g. Wuttichaikitcharoen and Babel, 2014; Tamene *et al*., 2006; Chakrapani, 2005; Dunne, 1979).

Table 7.4: Total variance explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.187	28.969	28.969	3.187	28.969	28.969	3.183	28.937	28.937
2	2.469	22.448	51.417	2.469	22.448	51.417	2.441	22.187	51.124
3	1.852	16.839	68.257	1.852	16.839	68.257	1.882	17.111	68.235
4	1.011	9.191	77.448	1.011	9.191	77.448	1.013	9.213	77.448
5	0.886	8.055	85.503						
6	0.736	6.690	92.193						
7	0.519	4.720	96.913						
8	0.193	1.754	98.667						
9	0.123	1.123	99.790						
10	0.023	0.210	100.000						

Extraction Method: Principal Component Analysis.

Table 7.5: Varimax rotated component matrix

Months	Component

	1	2	3	4
	0.008	-0.013	0.003	0.985
Sub-Basins	-0.220	-0.067	0.889	0.011
Sc	0.683	0.282	-0.007	0.039
Q	0.503	-0.396	-0.039	-0.199
S	0.954	0.040	0.119	0.007
A	0.761	-0.529	0.003	-0.005
U1	0.477	0.143	0.796	-0.001
U2	0.211	0.719	-0.426	-0.002
U3	0.180	-0.749	-0.483	0.032
U4	-0.761	-0.171	0.165	-0.025
U5	0.207	0.889	0.036	-0.014

Extraction method: Principal Component Analysis.

Rotation Method: Varimax with Kaiser Normalization. Rotation converged in 6 iterations

7.3.3 Estimation Results: Suspended Sediment Concentration

Table 7.6 presents the parameter estimates of suspended sediment concentration. Model 1 is the initial model containing variables as stated in equation 7.1. This model presents the results of estimating suspended sediment concentration from discharges, slope and catchment Area without considering the land use characteristics of respective drainage basins. The model which is significant at 1% level explains about 60% of the variation in suspended sediment concentration. The results indicate that the parameter estimates for S, A and Q significantly account for the variance in suspended sediment concentration. Collinearity diagnostics showed acceptable tolerance (>0.4) and Variance Inflation Factor (VIF < 3), indicating no or minimum level of multi-collinearity.

Table 7.6: Model Results

Model	**1**	**2**	**3**	**4**

Response Variable	ln(Sc)	ln(Sc)	ln(Sc)	ln(Sc)
N	108	108	108	108
Predictor Variables				
Constant	-5.376[a]	-5.786	-14.848[a]	-14.601[a]
ln(Q)	-0.082[b]	-0.144[a]	-0.131[a]	-0.126[a]
ln(S)	4.757[a]	7.427[a]	9.724[a]	9.539[a]
ln(A)	0.019[b]	0.238		
ln(U1)		-0.520[b]	-0.209[b]	-0.235[a]
ln(U2)		-0.597		
ln(U3)		-1.115[b]	-0.423[b]	-0.345[b]
ln(U4)		0.337	0.847[a]	0.826[a]
ln(U5)		0.139	-0.064	
Model Utility				
R^2	0.602	0.776	0.768	0.767
Adj.R^2	0.591	0.757	0.755	0.755
SEE	0.346	0.497	0.5	0.499
Highest VIF	2.444	48.927	5.819	5.272
Minimum Tolerance	0.409	0.020	0.172	0.190
Significant level	1%	1%	1%	1%

NB: [a] Significant at 1%; [b] Significant at 5%.

The integration of the proportions of land use types (equation 7.3) produced model 2 (Table 7.6). The model explains 77.6% of the variation in suspended sediment concentration. The increase in the explained variance due to the inclusion of the land use types at 1% level shows that the land use characteristics of a drainage basin cannot be ignored in estimating or predicting sediment concentration of surface waters. In this model, the parameter estimates for Q, S, U1 and U4 were detected to be statistically significant. It also indicates that sediment concentration is positively but insignificantly affected by catchment area. This suggest that land cover type is a better predictor of sediment concentration than the catchment area. Collinearity diagnostics of model 2 shows the existence of excessive multi-collinearity in the data set (Tolerance <0.1, VIF = 48.927). It therefore implies some predictors might mask the influence of others which can possibly render some predictors insignificant in the model. Besides, it can affect the model by producing erratic signs in the regression coefficient (Luis *et al.*, 2008). Hence the application of the stepwise approach to select the best regression model led to the removal of some variables (U2 and A) and thus minimized the extent of multi-collinearity. This produced model 3 with minimum multi-collinearity effect (VIF = 5.819). Generally, model 3 is statistically significant ($p<0.01$) and explains 76.8% of the variation in suspended sediment concentration. The significant predictors were discharges, topography, closed forest, farmlands and settlement. Model 4 was developed using only the significant variables in model 3. It explains 76.7% of the variance in sediment concentration at 1% significant level. The Model indicates slope (S), river discharge (Q), closed forest (U_1), settlement (U_4) and farmland (U3) largely explains the variation in the catchment's sediment yield. Collinearity diagnostics indicates minimum multicollinearity effect (Tolerance >0.1, VIF <10). Model selection criterion shown in Table 7.6 reveals that model 4 has good adj.R^2, minimum standard error and suffers minimum effect of multi-collinearity.

The positive regression coefficients of S and U4 signifies that the increase in topography as well as the increase in anthropogenic activities will correspond to proportionate increase in suspended sediment yield of the catchment. On the other hand, the negative regression coefficients of U1 denotes increasing afforestation will reduce the production and transport of sediment (Tang *et al*., 2005). Usually the relationship between sediment concentration and discharges is positive. However, the relation obtained in this research is negative. This can be explained as a result of the increasing intensity in alluvial gold mining and sand winning activities within some portions of the Pra River especially during low flows. This resulted to the observation of high sediment concentration level at low flows. Similar findings were observed by Kusimi (2008) in the Densu River.

The model results (Table 7.6) reveals that catchment area does not play significant role in the variation of suspended sediment concentration when land cover types are included. However, it is significance in the absence of land cover types as Akrasi and Ansa-Asare (2008), Akrasi (2011), Verstraeten and Poesen (2011) and Chakrapani (2005) found. This means that the inclusion of land cover types kick out the significance of the area and explains the variation in suspended sediment better.

The purpose of multiple regression analysis is to assess the relationship between several predictors and a response variable. The results obtained for model 4 can be used to estimate the suspended sediment concentration using the identified controlling variables, in that the model explains 76.7% of the catchment sediment yield at a significance level of 0.01. The mean of the residuals equals zero. The residuals are normally distributed [$\chi2$ (2) = 0.605, p-value = .772] and the residual plot does not violate the homogeneity of variance assumption, indicating the adequacy of the model. However, the Durbin-Watsons statistics obtained (1.4 < 2) indicate some level of serial correlation in the data set. It was also realized that each of the sub-basins studied exhibited unique latent characteristics making them to have different intercepts and slopes (see Fig. 7.1).

Thus, there is natural heterogeneities in the sub-basin's response to runoff (discharge) over time and this can only be represented by an appropriate probability distribution. For this reason, to fit a regression model with fixed intercept and slope will lead to several under and or over estimations.

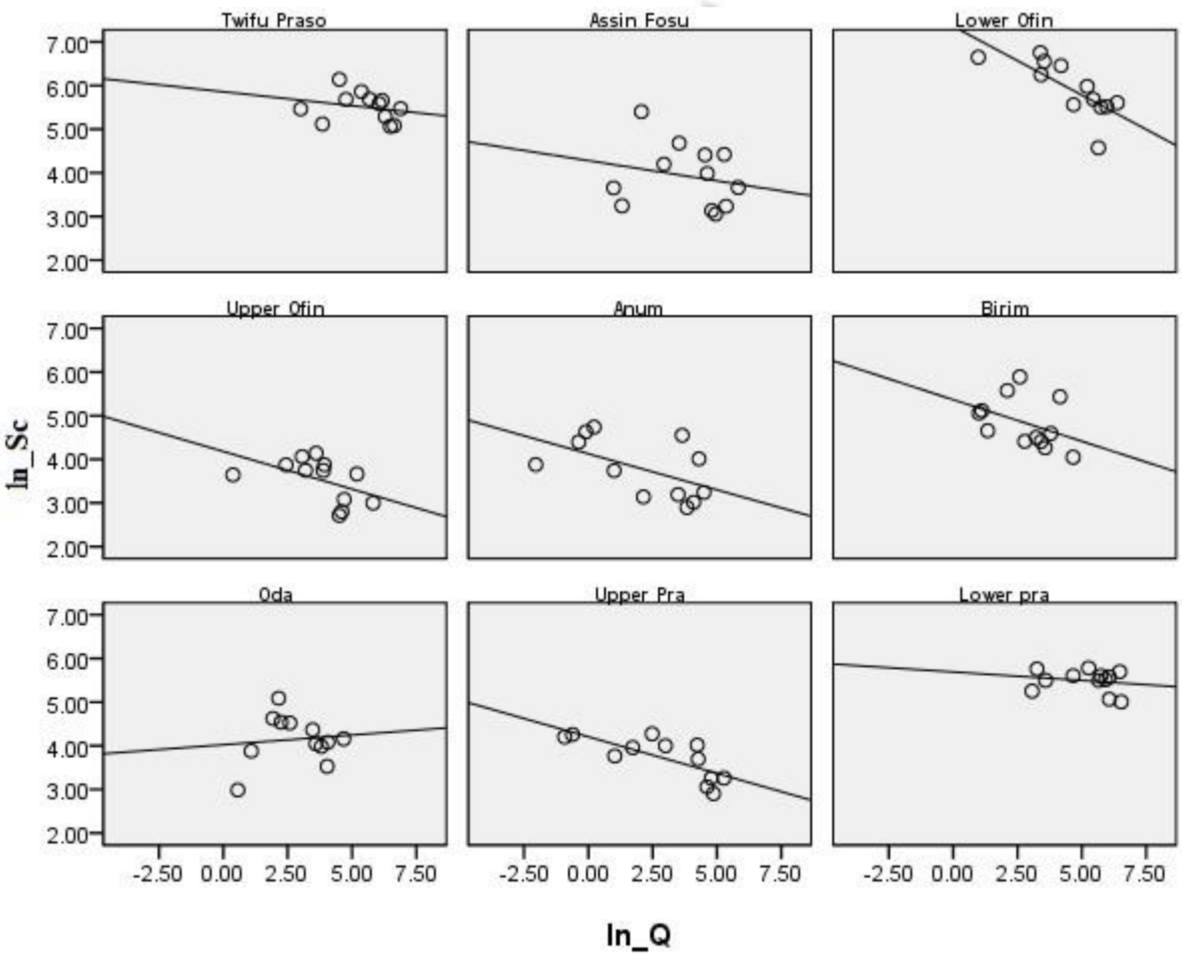


Fig.7.1. Response of sub-basin's sediment concentration to discharges

Hence the model can be upgraded through the development of a robust model that allows heterogeneity in both slope and intercept, and also accounts for the serial correlation in the data. The mixed effects or the random coefficient modelling method may be suitable for such analysis (Winter, 2013; Landau *et al*., 2003). Mixed models account for the sources of variation in a single model. Unfortunately, the size of the data for this work is inadequate (due to time and unavailability of secondary data) to estimate the parameters.

7.4 Conclusions and Recommendations

Reliable suspended sediment models are key for strategic basin management, especially in datadeficient countries. However, the parameters in the model must be reflective of the factors controlling sediment fluxes in the basin. It's only through this that the model estimate and prediction can conform to reality. This study questioned the relevance of land cover types in explaining the variation in catchment suspended sediment yield. To test our hypothesis that the land cover variable is important, we used a dataset collected from the Pra River Basin in Ghana. The study found that land use characteristics play a significant role in explaining the variations in the catchment sediment yield. Model accuracy increased significantly when land cover types was included as a predictor variable. The model shows that topography, discharge (runoff) and land cover characteristics are the major factors influencing sediment supply into surface waters. It also showed that catchment area in the presence of land use types is not a significant contributor to the variations in suspended sediment concentration.

It must be noted that the accuracy of the resulting model can further be improved to cater for the uncertainties arising from the heterogeneities in the latent characteristics of the sub-basins. There is therefore the need to develop a robust model that allows such variations in a single model. The appropriate tool to use perhaps is the mixed effect or the random coefficient modelling. Since this is data-driven, the availability of limited data posed retrain to it application in this study. It is suggested that a robust model be developed with long-term data under variable land use condition that accounts for the random selection of the basins, and also the serial correlation. This approach will help to determine the effect of land cover conversions on the variability of suspended sediment concentration, providing quantitative information that basin managers can adopt for effective and efficient land and water resources management.

CHAPTER EIGHT GENERAL DISCUSSIONS AND SYNTHESIS

8.1 Introduction

One of the key issues threatening water security both in quantity and quality is the increasing rate of siltation and pollution resulting from increasing rate of sediment generation and transport from contributing drainage basins. Therefore, for efficient water resources development and management, it is important for such physical mechanisms responsible for the variations in suspended load of rivers to be monitored so that sustainable interventions can be implemented.

This requires accurate and consistent data on catchment's sediment fluxes as well as the identification of sediment generating areas. However, due to the difficulties associated with field measurement, continuous sediment data hardly exist. As such empirical and physically based models such as SWAT, WEPP, MUSLE, ANSWERS etc. have been developed for soil loss estimations and predictions. However, these models usually require huge amount of data for warming, calibration and validation, which often times are difficult to obtain in data-poor countries. This makes the application of these models in data-deficient zones difficult. Therefore, water researchers and hydrologists have commonly resorted to statistical (regression) techniques and rating curves to estimate and predict catchment sediment fluxes for planning and implementation of conservation measures. However, most of these statistical models basically relate the sediment concentrations to discharges and basin size, assuming water discharges as the dominant controlling factor in sediment yield rather than sediment supply.

Thus, even though land use characteristics and activities have generally been accepted by both land use researchers and hydrologist as an influencing factor controlling sediment supply, the existing statistical models do not reflect its significance. The developed models do not show the empirical evidence of the effect of land use types on the variation in the catchment suspended sediment. And even the models that consider land use component, includes it as a categorical variable assuming the catchment land cover characteristics to be homogenous. This makes the models to either under or overestimate suspended sediment yield since most catchment cover characteristics are heterogeneous in nature. Good sediment model therefore should be able to predict the effect of the combination of various controlling factors in the basin in order to conform to reality.

It is in line with this that this research is conducted to ascertain the extent with which land cover types influence the variation in suspended sediment concentration of surface water bodies especially in catchment's experiencing severe land cover changes and anthropogenic influence.

8.2 Trend and pattern of land use and land cover change

Four Landsat images of multi-temporal years 1986, 1998, 2008 and 2018 were produced for each of the nine sub-basins in PRB. The images were classified and accuracy assessment and change detection analysis was performed. In all six land cover classes were identified and classified namely; Closed forest, Open forest, Farm/grassland, Settlement, Mining and Water. It was realized

that the extent, distribution and pattern of LULC classes differ significantly ($p<0.05$) across the sub-basins. On the average, Closed forest is dominant in Lower Pra followed by Birim sub-basin. With regard to Open forest, Assin Praso has the highest cover followed by Lower Pra. Farm/grassland is dominant in the Twifu Praso, Upper Ofin, Upper Pra, Birim,
Lower Ofin and Assin Praso sub-basins whilst Settlement is mostly prevalent in the Oda, Upper Ofin and Anum Sub-basins. The classification results indicated that illegal mining (referred to as galamsey) and alluvial gold mining became obvious since 2008 and that Lower Ofin, Anum, Birim, Twifu Praso sub-basins were greatly affected. This according to previous researchers have led to the severe pollution and siltation of the Pra River.

It was also identified that LULC changes have taken place in all the sub-basins between the period 1986 and 2018. Generally, conversion occurred from Closed and Open forest to farmlands, settlement and mining. PRB lost 10.4% and 11% of its land mass occupied by closed forest and open forest respectively towards settlement, farm/grassland, mining and water which gained 7.8%, 12.4%, 0.95% and 0.2% of the basin's land mass respectively. However, each subbasin experienced different rate and direction of land use conversions ($p<0.05$). The variation in LULC composition and their changing rate implies each sub-basin would exhibit different vulnerability responses.
The observed transitions were realized to be as a result of the following drivers: 1). Population increase; 2) Movement in response to socio-economic opportunities and policies and 3) Availability of mineral resources. The classification results showed settlement increased consistently across all the sub-basins especially those in and around the District and Regional capitals.Population growth rate of 2.2% in the catchment would correspond to expansion in residential and commercial land uses. Besides, as a result of the availability of social amenities and infrastructural development, movement towards the districts/municipals/metropolitans was enhanced, leading to increase in settlement areas. Also, the demand for housing for the growing population and higher economic gains (i.e. land for construction of industries and infrastructures) over agriculture returns led to conversion of farmlands to settlement especially in the Oda, Upper Ofin and Anum sub-basins.

Then also, between 1986 and 1998, the classification indicated increase in farmlands across the sub-basins. This was as a result of the government's structural adjustment/economic recovery programme phase II (1987-1991). The implementation of the policy led to importation of fertilizers and other agricultural input which were supplied to farmers. This migrated a lot of farmers back into agriculture and since the basin is an agriculturally productive zone it suffered the effect. Similarly, Anum, Lower Ofin, Twifu Praso and Birim sub-basins which saw conversion of forest and farm lands to mining activities (illegal) was due to high economic gains in mining over agriculture.

8.3 Variability of suspended sediment yield

Suspended sediment sampling and discharge measurement were undertaken at the outlet of the nine sub-basins to assess the sediment fluxes in the basin and to explore the spatial variability across space. Sediment concentration analysis was performed in the sediment laboratory at Water Research Institute of Council for Scientific and Industrial Research, using the evaporation method. The results of the analysis revealed the following;

- Weak correlation and insignificant relationship between sediment concentration and water discharges indicating that changes in the discharge regime of rivers alone do not correspond to proportionate variation in sediment concentration. Besides, low magnitude of the discharge rating exponents ranging from 0.69 to 1.13 also reflects that the rivers remain turbid over a wide range of flows.
- The occurrence of high sediment concentration at low flows can be attributed to the land cover characteristics and the intensity of anthropogenic activities within the immediate contributing basin.
- Sediment yields of the basin is very high (ranging between 13.29 and 215.02 $tkm^{-2}yr^{-1}$) and differs significantly ($p < 0.05$) with respect to the contributing drainage basins. These levels of sediment load threatens the sustainability of the basin’s water resource and the performance of the hydraulic structures of the Ghana water Company, and also increases treatment cost leading to high water tariff’s.
- The variations in the suspended sediment yield can be attributed to the differences in the land cover types as well as the intensity of anthropogenic activities across the sub-basins.
- Rivers in the galamsey prone sub-basins (Lower Ofin, Birim, Anum, Twifu Praso and Lower Pra) are more polluted with sediment than the others, hence the formation and the operation of the anti-galamsey task force (Operation Van Guard) is a timely intervention and in the right direction. Even though this research lacks enough data prior to their

operation to enable detail assessment of their impact, the trend of sediment concentration levels observed especially in the galamsey ravaged areas showed some decline after some months of their operation. Besides, comparing the results of this research to Kusimi's sediment analysis for some selected hydrological stations in the basin in 2012, there is appreciable decline in most of the stations indicating positive results.

- Even though Sediment rating curves gives indication of the rate of sedimentation it lacks the influence of factors controlling sediment supply. Hence, in catchment experiencing severe degradation, sediment rating curve estimates and predictions cannot be reliable for strategic interventions and management.

8.4 Spatial distribution of soil erosion and sediment yield

The RUSLE and SEDD model integrated with GIS was adopted to estimate and spatially display the distribution of soil loss and sediment yield in the basin. This model was adopted because it is relatively simple and easy to parameterize since it does not require complex data to operate with. The model result showed that about 21.3% of the basin comes under severe and very severe erosion risk category. It indicated that soil erosion rate varies with land use types in a decreasing order from Mining > Settlement > Farmland/grassland > Open forest > Closed forest. Mining prone and the settlement dominated sub-basins (Lower Ofin, Anum, Birim, Twifu Praso, Upper Ofin and Oda) were identified to be highly erosion susceptible sub-basins. It also showed that water bodies serve as the major recipients of the sediment generated in the catchment, making the water resource vulnerable to siltation, pollution and destruction of aquatic life.

8.4.1 Limitation of the RUSLE model

The model predicts only surface erosion and sediment and does not account for bank, gully or channel erosion. Therefore for a large basin like PRB with significant channels and gullies, and also experiencing severe degradation activities in the river and along the banks, it will be incorrect to use the observed sediment load data which comprises of both surface, bank and channel erosion for validation. Hence the model could not be validated.

8.5 Modelling of suspended sediment concentration of rivers: the effect of land cover on model accuracy

Multiple regression technique was adopted to develop a model for the estimation and prediction of sediment concentration. Initial model was built between sediment concentration (as response variable) and discharge (Q), slope (S) and catchment area (A) (as predictors). Then a new model was built where the land cover types was included in the predictor variables to determine the contribution of land cover characteristics on the variation in suspended sediment concentration. The inclusion of the land cover types in the model led to an increase in the models accuracy from 60.2% to 77.6%. The increase in the explained variance due to the inclusion of the land cover types at 1% significant level shows that the land use characteristics of a drainage basin cannot be ignored in estimating or predicting sediment concentration of surface waters. The final model (model 4) explains 76.7% of the variance in sediment concentration at 1% significant level and indicates that topography, discharge (runoff) and land cover characteristics significantly explain the variation in the catchment's suspended sediment yield. The model results also revealed that when the land cover types are incorporated into the model, catchment area plays insignificant role in the variation of suspended sediment concentration. Collinearity diagnostics indicates minimum multi-collinearity effect (Tolerance >0.1, VIF <10). Model selection criterion reveals that model 4 has good adj.R^2, minimum standard error and suffers minimum effect of multicollinearity.

However, the model is still pre-mature for accurate prediction as there are uncertainties arising from the heterogeneities in the latent characteristics of the sub-basins, making them to have different intercepts and slopes. Therefore, to fit a regression model with fixed intercept and slope will lead to several under and or over estimations. Hence, there is the need to develop a robust probability distribution model that allows heterogeneity in both slope and intercept, and also accounts for the serial correlation in the data. The mixed effects or the random coefficient modelling method may be suitable for such analysis. Unfortunately, the available data acquired is insufficient to produce all the parameter estimates.

8.6 Limitations of the study

The study though is successful but has several limitations such as

- Lack of available reliable secondary data
- Insufficient resources to monitor the hydrological stations continuously
- Inability of the RUSLE model to account for bank, gully and channel erosion

CHAPTER NINE CONCLUSIONS AND RECOMMENDATIONS

9.1 Conclusions

Based on the formulated objectives, the following conclusions can be drawn;

- In all the sub-basins, land use conversion occurred generally from closed and open forest to farmlands, settlement and mining. However, each sub-basin experienced different rate and direction of land use conversions. Population growth and movement in response to socio-economic opportunities and policies as well as availability of mineral resources were identified as drivers behind land use change in the basin.
- High annual suspended sediment yield ranging between 13.29 and 215.02 $tkm^{-2}yr^{-1}$ was observed. Suspended sediment yield varied significantly ($p < 0.05$) with respect to the contributing drainage basins. The observed variations resulted from the differences in the composition and extent of LULC types and the human activities within the immediate contributing drainage basins. Rivers in the galamsey prone sub-basins (Lower Ofin, Birim, Anum, Twifu Praso and Lower Pra) are highly polluted with sediment than the others, hence the formation and the operation of the anti-galamsey task force is a timely

intervention and in the right direction. Results also revealed that increase in water discharge alone is not a controlling factor for river sedimentation.

- Erosion map showed that about 21.3% of the basin comes under severe and very severe erosion risk category. Mining prone and the settlement dominated sub-basins: Lower Ofin, Anum, Birim, Twifu Praso, Upper Ofin and Oda were identified to be highly erosion susceptible sub-basins. Soil erosion rate varied with land use types in a decreasing order from Mining > Settlement > Farmland/grassland > Open forest > Closed forest
- Model accuracy increased from 60.2% to 76.7% when land cover types were included as predictor variables at 1% significant level, indicating that land cover characteristics play a significant role in explaining the variations in catchment suspended sediment yield. This means that significant changes in land use and land cover characteristics will correspond to proportionate variation in suspended sediment yield. Also, the inclusion of land use types in the model increased the models accuracy than the catchment area. This means land use characteristics are better predictors of suspended sediment than the catchment area.

9.2 Recommendations

9.2.1 Recommendations for Policy

Based on the findings of this research, the following suggestions are presented for action:

- Immediate conservation measures, policies and enforcement needs to be applied to reduce or control the rate of soil erosion in the affected sub-basins.
- Since there are variations in the changing rate of LULC classes across the sub-basins different intervention and management strategies need to be applied. In Upper ofin, Oda and Anum sub-basins, there is the need for efficient land use planning and utilization. Adherence to the building code and buffer zone policy will help reduce the extensification of residential and commercial land uses. In the lower Ofin, Birim, and Twifu Praso sub-basins, the illegal mining (galamsey) activities must be stopped as the government has embarked on, whilst small scale mining must be effectively regulated. Buffer zones of all water resources must be delineated and defined, and that no anthropogenic activity must be allowed to take place in the buffer zones, along the river banks nor in the river bed. Moreover, farmers in the basin must be educated consistently on how to have good yield

and agricultural productivity so as to encourage agricultural intensification instead of extensification.

- The formation of District ecological or environmental task force involving officials from the District Assembly, Water Resource Commission (WRC), Environmental Protection Agency (EPA), Minerals Commission, Security forces, Assemblymen and a Unit committee member instead of the national task force would be more efficient in curbing environmental menace and degradation.

9.2.2 Recommendations for Further Research

Based on the findings of this study, the following areas are recommended for further research:

- There is the need to improve the model by developing robust model with long-term data under variable land use condition that accounts for variations in catchment characteristics in a single model, and also the serial correlation. This integration will help to estimate and predict suspended sediment concentration of rivers that conforms to reality, providing quantitative information that basin managers can adopt for effective and efficient land and water resources management.
- For a large basin like PRB with significant gullies, channels and bank erosion, there is the need for a model that will account for both surface and gully/channel erosion but still easy to parameterize so that data-deficient countries could adopt for basin management.
- It is also important to further evaluate the impact of the activities of anti-galamsey task force “Operation Van Guard” on the basins water resource.

8.3 Contributions to Knowledge

In general, the contributions of this study to the scientific society include the following:

- This research has empirically prove that land cover types are significant factors that control the variations in catchment suspended sediment yield and must be included in all sediment prediction models.
- In the absence of land cover types in sediment models, catchment area is significant, but once land cover types are included, area becomes insignificant whilst the models accuracy increases. This indicates that land cover type is a better predictor of suspended sediment yield than the area.

- The study also brings to fore that in catchment experiencing severe degradation or land cover changes, sediment rating curves cannot be reliable for predictions.
- This research also provides quantitative information on the catchment sediment yield and areas requiring immediate intervention for the Pra basin secretariat.

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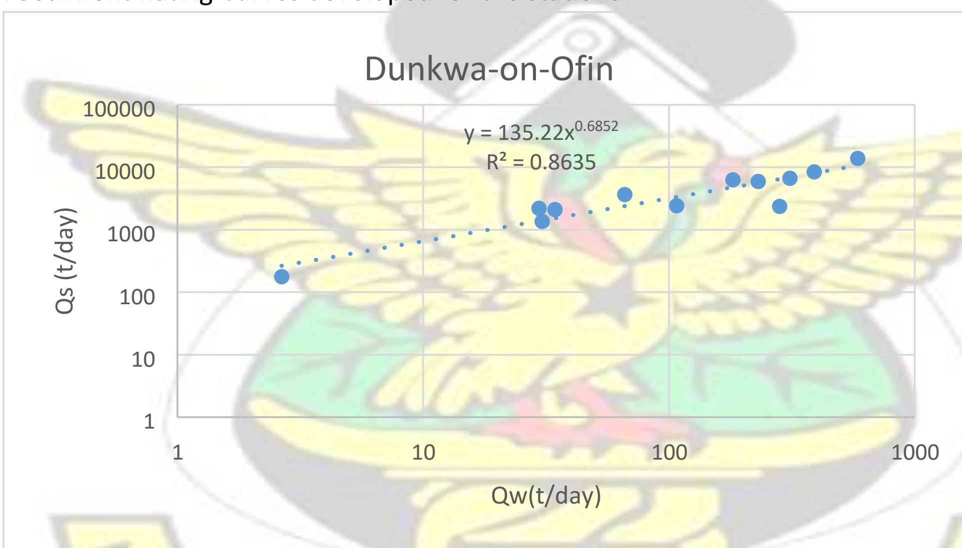
APPENDICES Appendix A

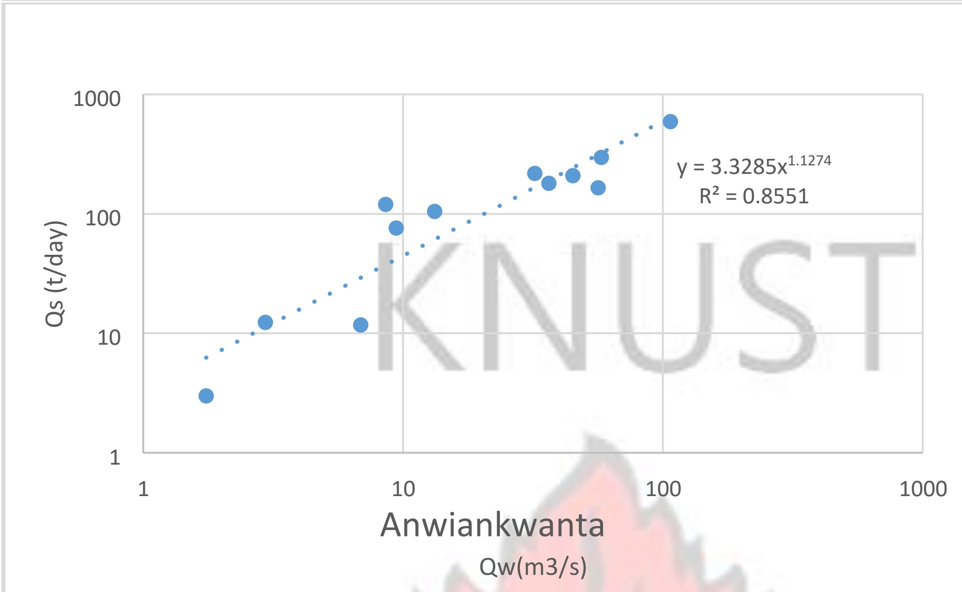
Table 4.4: Summary of the classification accuracy of LULC derived from 2018 Landsat ETM+ imagery

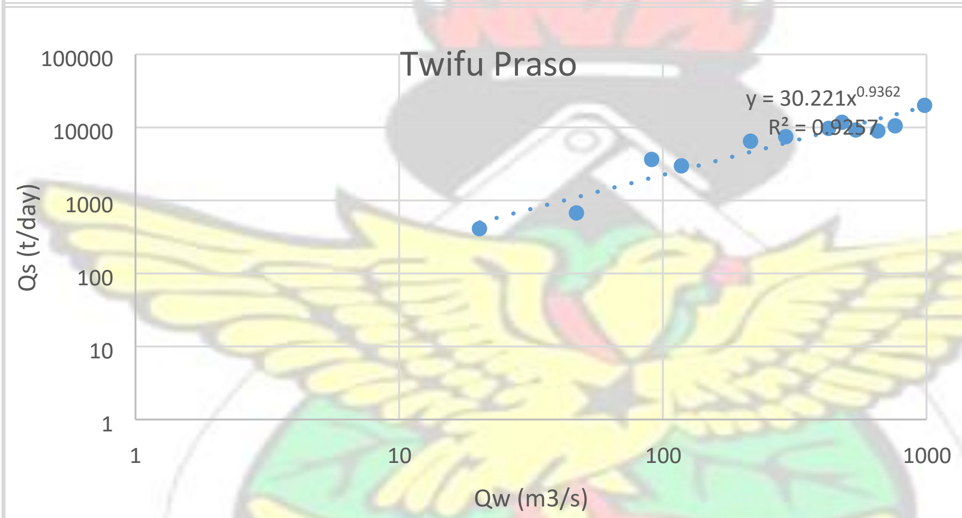
Sub-Basin	Accuracy measures	Closed forest	Open forest	Farm/ grassland	Settlement	Mining	Water
Lower Pra	User	93.1	87.3	90.4	100	92.9	94.6
	Producer	95.8	92.4	81.4	72	88.6	90.9
	Overall accuracy	93.35%					
	Overall Kappa	0.89					
Oda	User	98.7	76.2	70.3	95.9	85.2	78.6
	Producer	91.9	73.2	86.4	92.6	80	83.7
	Overall accuracy	85.15%					
	Overall Kappa	0.87					
Anum	User	97.3	65.4	61.2	100	90.2	85
	Producer	96.8	89.9	81.3	80.1	86.8	75.8
	Overall accuracy	84.18%					
	Overall Kappa	0.88					
Upper Pra	User	89.2	96.4	89.2	79.4	91.9	90.4
	Producer	99.4	78.1	76.7	93.1	88.7	91.3
	Overall accuracy	89.42%					
	Overall Kappa	0.94					
Assin Praso	User	89.7	74.9	91.5	90	74	85.22
	Producer	97.9	86.1	91.9	86.7	90.1	81.4
	Overall accuracy	88.55%					
	Overall Kappa	0.91					
Twifu Praso	User	91.7	76.4	89.1	93.6	79.2	89.7
	Producer	85.9	80.7	93.2	94.9	90	70.5
	Overall accuracy	87.62%					
	Overall Kappa	0.78					
Birim	User	79.9	77.3	77.4	98.5	61.3	88.6

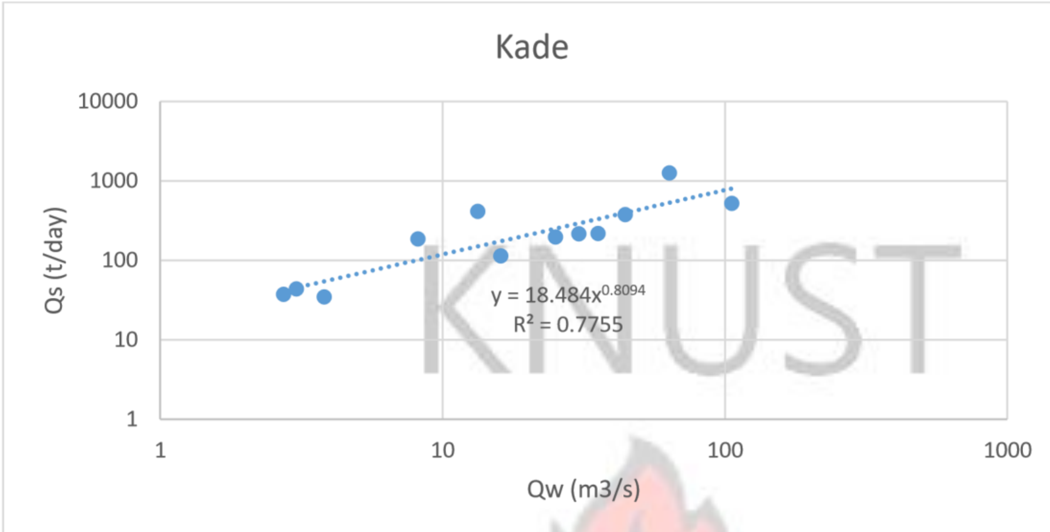
	Producer	85.6	85.7	68.5	92.1	83.3	72.0
	Overall accuracy	79.93%					
	Overall Kappa	0.76					
Lower Ofin	User	84.2	95.6	79.7	91.3	75.8	91.6
	Producer	89.8	76.5	90.1	89.5	71	78.8
	Overall accuracy	89.61%					
	Overall Kappa	0.81					
Upper Ofin	User	79.4	78.1	76.5	93.1	95.9	91.6
	Producer	91.2	93.4	89.2	78.8	91.9	90.4
	Overall accuracy	85.77%					
	Overall Kappa	0.95					

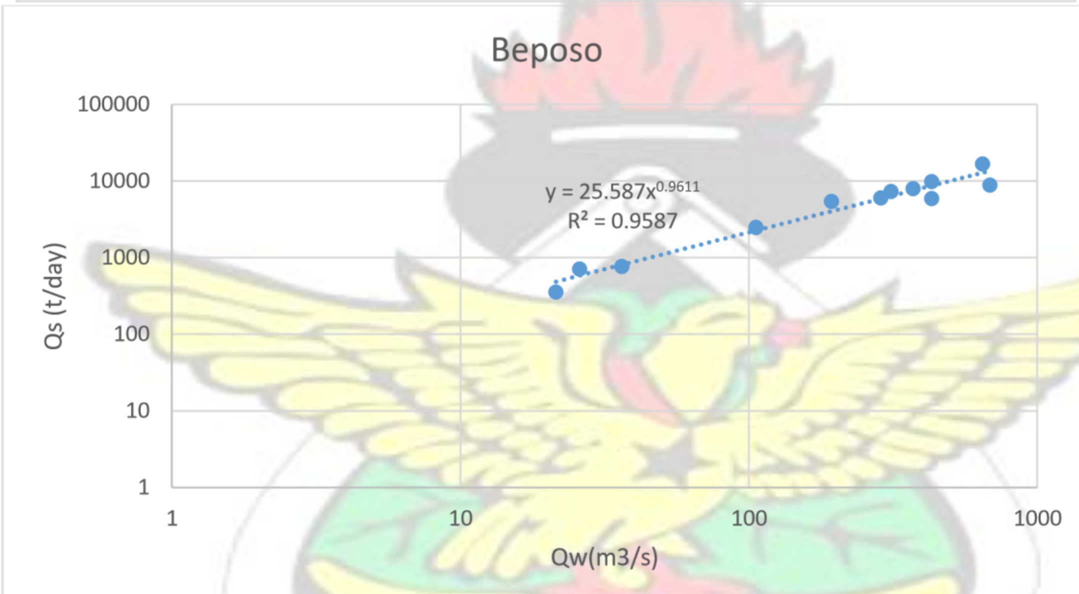
Appendix B: Sediment Rating Curves developed for the stations

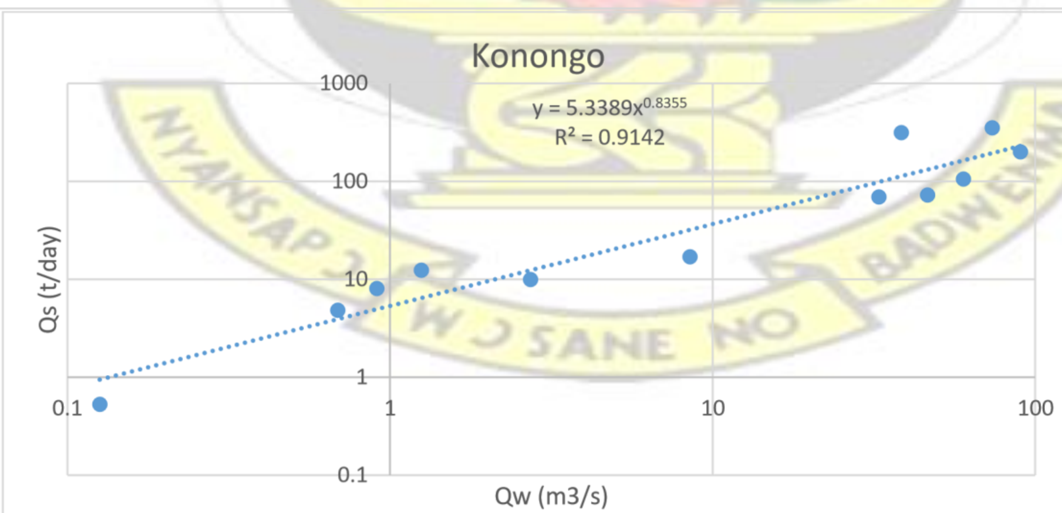



1000
100
10
1
Qs (t/day)
y = 3.3285x^1.1274
R² = 0.8551
1
10
100
1000
Anwiankwanta
Qw(m3/s)


Twifu Praso
100000
10000
1000
100
10
1
Qs (t/day)
y = 30.221x^0.9362
R² = 0.9257
1
10
100
1000
Qw (m3/s)


Kade
10000
1000
100
10
1
Qs (t/day)
1
10
100
1000
Qw (m3/s)
y = 18.484x^0.8094
R² = 0.7755


Beposo
100000
10000
1000
100
10
1
Qs (t/day)
1
10
100
1000
Qw(m3/s)
y = 25.587x^0.9611
R² = 0.9587


Konongo
1000
100
10
1
0.1
Qs (t/day)
0.1
1
10
100
Qw (m3/s)
y = 5.3389x^0.8355
R² = 0.9142

Appendix C: Discharge measurement and suspended sediment sampling

a. Discharge measurement with Acoustic Doppler Current Profiler (ADCP)

b. Flow measurement with Propeller and current meter

c. Suspended sediment Sampling with the Integrated sampler

Appendix D: Suspended Sediment Concentration Analysis

a. Decantation process

b. Measurement of samples

c. Sediment determination using the evaporation method