UNIVERSITY OF CAPE COAST

MORPHOLOGY OF THE KAKUM RIVER: A STUDY ON A SMALL FORESTED RIVER IN THE CENTRAL REGION, GHANA

BY
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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature……………… Date …………………..........

Name: ……………………………………………………………………

Supervisors' Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature ………………… Date ………………

Name: ……………………………………………………………………

Co-Supervisor's Signature ……………………. Date …………………

Name: ……………………………………………………………………

ABSTRACT

The Kakum River, a small-forested but major river in Cape Coast is the main source of water for about five major towns and all communities within its watershed. However, in recent times, it is faced with a lot of challenges including its Brimsu dam producing below designed capacity, relying on water from the Pra river basin, flooding in some parts of the basin and a lot of macrophytes especially in its middle section. This study set out to outline the linkages and influences of headwater and downstream processes and its effects on the Kakum river based on the Holistic approach proposed by Gregory (2006) to understand the consequences of both natural and human activities on such systems. Theories employed include the Geomorphic systems theory and chaos theory. The main data used included Toposheets, DEM, Digital Orthophotos and some field samples (soil, river sediment and water). Analysis employed in the study includes morphometric analysis, morphologic analysis, Laboratory analysis, land-use/land-cover analysis and river bankline analysis. From this study, it was found that Land-use/Land-cover, mainly built-up and rangeland have had profound influence on the river's form, water and sediment. It greatly reduced the surface area of the water land-use from 0.52% to 0.32% from 1991 to 2016. The river has responded to these effects through the processes of erosion and accretion. It has therefore been recommended for a major board to be set in order to overlook the various riparian activities that go on within the basin since this basin-wide holistic approach has indicated that past management lacked the integrated approach.

KEYWORDS

Holistic Approach

Morphometry

Hydro-geomorphic

Chaos theory

Geomorphic system.

Bank Stability

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DEDICATION

To my Dearest Husband Hon. Dennis Percyval Quaicoe and My Precious Dad, the Late Odeefuo Boa-Amponsem III.

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LIST OF ABBREVIATIONS AND ACRONYMS

AAS	Atomic Absorption Spectrometer
ANOVA	Analysis of Variance
ASCETC	American Society of Civil Engineers Task Committee
DEM	Digital Elevation Model
DGRP	Department of Geography and Regional Planning
DSAS	Digital Shoreline Analysis System
DTPA	Diethylenetriamine Pentaacetic Acid
EEA 1998	European Environment Agency
EPR	Endpoint Rate
FAO	Food and Agriculture Organization
GENSTAT	General Statistics
GIS	Geographic Information System
GPS	Global Positioning System
GRADISTAT	Grain Size Distribution and Statistics
IPPC	Intergovernmental Panel on Climate Change
ISSS	International Society of Soil Science
ISRIC	International Soil Reference and Information Center
TM	Thematic Mapper
EMT+	Enhanced Thematic Mapper Plus
LANDSAT	Land Satellite
OLI/TIRS	Operational Land Imager / Thermal Infrared Sensor
LSD	Lysergic Acid Diethylamide
LULC	Land-use Land-cover
MAP	Mangrove Action Project
Ma	Mega Annum/ Millions of years ago

NPS	Nonpoint Source
NRC	National Research Council
NSM	Net Shoreline Movement
OLGGWP	Office of Leading Group for Guanting Water Protection
RS	Remote Sensing
SRTM	Shuttle Radar Topographic Mission
U.N	United Nations
UAV	Unmanned Aerial Vehicle
UNEP	United Nations Environment Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS	World Geodetic System
WHO	World Health Organization

CHAPTER ONE

INTRODUCTION

Study Background

River systems are the most common and preferred units for water-related issues as far as humans are concerned (Klocking & Haberlandt, 2002). Rivers are recognized as complex mosaics of habitat types and environmental gradients with characteristics such as high connectivity and spatial complexity (Fausch, Torgersen, Baxter, & Li, 2002; Ward, Tockner, Arscott, & Claret, 2002).

This connectivity is demonstrated in the river channel linking the lowland territories with the montane headwaters and providing the possibility of the transfer of water, sediment, organic materials, nutrients, particulate matter as well as organisms not only in the downstream direction but in the lateral direction also (Gregory, Swanson., McKee, & Cummins, 1991). That is, whiles some of the loads carried by the river are transported downstream, some are as well deposited near the valley sides as well as on the floodplains when the river is in spate.

The river's spatial complexity, on the other hand, is revealed in the spatially- hierarchical organization of the river network and its landforms across different scales. This organization, according to Grant, Swanson, and Wolman, (1990) reflects the functional relationship between the river channel and the processes that create it. Thus, the processes operating at one scale can affect the geomorphic dynamics and structure at the other spatial scales.

Spatial scales within the fluvial landscape are defined and are dependent on physical mechanisms that drive landform change (termed stability) i.e. the persistence of geomorphic features at a location within the drainage basin (Gregory et al., 1991). In a fluvial landscape, about five spatial scales can be identified namely the network scale, the section or segment scale, the reach scale and the channel unit, sub-unit and particle composition scales. These scales are influenced by diverse external variables, for instance, the network scale is influenced by the regional geology, the section or segment scale by tectonics, climate and sea level changes, the reach scale by basin-wide aggradation or degradation or local base level whilst the channel unit, sub-unit and particle composition scales are dependent on the hydraulics, bed composition, organic debris and shear stress. Thus, aside geology, spatially nested controlling factors including climate and topography are now incorporated on the network scale in studying geomorphic processes affecting the intermediate and small scales (Snelder & Biggs, 2002).

Based on such complexities and connectivity of the river, a comprehensive system analyses have been proposed to be very relevant at all scales in order to understand the consequences of various natural and human activities on the water cycle and the environment (Klocking & Haberlandt, 2002). To accomplish this, there have arisen two main perspectives in line with investigating the river namely the landscape perspective and the ecosystems perspective. However, some elements of each other have been studied in an attempt to understand the structure and function from either perspective.

It is in line with this, that Gregory (2006) proposed the holistic or the comprehensive approach to studying the river. The holistic approach involves an investigation into the hydrological process changes (i.e. changes in the sediment and discharge characteristics); a conceptual model (an empirical equation for discussing natural and man-made induced changes); a drainage basin context (focusing on all channel changes within a single basin); Regional audits (causes and consequences of channel changes in a region); and a long-term perspective (Gregory, 1987).

Again, in this holistic approach according to Gregory and Davis (1992), the magnitude of river channel change could be described in addition to predicting approaches which can best help in the management of basins as emphasis is placed on the spatial pattern of channel adjustment. The relationship between channel cross-section, channel plan-form and channel extent is therefore exhibited.

Understanding river channel dynamics and morphology via this approach must be of primary concern globally, regionally and locally as such studies are able to: identify the conditions that may have existed (Hilton, 1963); examine the present conditions; and also identify conditions that could have been expected had there been no changes (Maddock, 1999).

It follows that factors relating to the river that are mostly considered include the ecological status, water quality, hydrology, geomorphology and the physical habitat (Poff & Ward, 1989; Rosenburg & Reesh, 1993; Maddock, 1999). Based on these factors some methods have been deduced to study, assess and measure the river channel dynamics and morphology. For instance, the ecological status of the river could be deduced by analyzing the presence of biofilms, land use and in-stream vegetation (Rosenburg & Reesh, 1993); heavy metals and nutrient concentration in the river substrate give a measure of the water quality (Surface Water Regulation, 1994); flow magnitude, duration and timing of extreme conditions as well as rate of change in flow conditions also examine or measure the hydrological response of the river (Richter, Baumgartner, Powell, & Braun, 1996); whiles grain size and sedimentary analysis help to understand the Atterberg grade scale and the relevance of Stoke’s law in sediment analysis.

A proper study on river channel dynamics and morphology warrants a consideration of the aforementioned factors and several studies internationally have considered these. For instance a review done by Clarke (2002) on Vegetation growth in rivers (macrophytes) and how they influence sediment and nutrient dynamics; also, Johnston, Bridgham, and Schubauer-Berigan (2001) studied Nutrient Dynamics in Relation to Geomorphology of Riverine Wetlands in northeastern Minnesota and northwestern Wisconsin (USA) ; whiles Tabacchi, Lambs, Guilloy, Planty-Tabacchi, Muller, & Decamps, (2000) reviewed the main impacts of riparian vegetation on hydrological processes briefly.

Water-related studies in Ghana, however, have not followed this trend critically as being done internationally. For instance, Kusimi (2008) worked on stream processes and dynamics in the morphology of the Densu river channel in Ghana. This was done by analyzing existing survey maps and air photographs thus through air photo interpretation and digitizing of old topographic maps which were overlaid on each other to identify changes in the river’s course; Again Kusimi (2009) worked on the analysis of sedimentation rates in the Densu river channel; Donkor, Bonzongo, Nartey & Adotey (2006) studied mercury in the different environmental compartments of the Pra River

Basin, Ghana; and Ayivor, & Gordon (2012) also researched the Impact of Land Use on River Systems in Ghana.

Since river channel morphology studied in this manner does not enable a full assessment of the river in its entirety, there is the need for the holistic approach which generates a move towards a more environmentally sensitive river management and its sustainability. This study on the Kakum River is geared towards such direction. The Kakum and its associated Brimsu dam have serious challenges in respect of changes in its physical structure, perhaps of ancient origin (Hilton, 1963) as well as water quality and quantity issues. Therefore, such a study is of great use to the understanding of its present form.

Statement of the Problem

The increasing awareness of the intensities of fluvial channel changes has led to a collective interest in understanding these altered systems. The very first step in understanding these systems is recognizing the extreme changes that they have undergone as well as the consequences of such changes. As such processes controlling channel adjustments should be understood to a scale extending to the upstream reaches (Gregory, 2006).

Visually inspecting the Kakum river from some part of its upper section in Assin Kruwa to its lower section at Abakam, one can notice very distinct characteristics of the upper, middle and lower sections of the river. The most spectacular scene is that in the middle section where some “wigs” of vegetation (in-stream vegetation growth or macrophytes) appear to create some pattern on the river which is totally different from both the upstream and downstream segments. Interviews with resident communities report the novelty and fast pace of this phenomenon leading to water scarcity for these communities as these wigs are so thick and extensive that they are not able to get water easily. This can be seen in the Plate 1.

Plate 1: Wig intrusion in the middle section of the Kakum river

Source: Field survey (2017)

Again, the Brimsu dam on the Kakum River has the central objective of supplying water to serve about five (5) towns including Cape Coast, Elmina, Komenda, Saltpond, and Moree. With its current state producing below capacity (from 29,200m^3/day to 13,600 m^3/day) it is now supplying water to just about three of these towns. Apart from this fact, the dam is also relying on water pumped from the Pra river several kilometers away. While riparian human communities and some workers have blamed this issue on some dynamics going on within the entire basin, others have blamed this low production on siltation and sedimentation of the dam while management have also blamed the reliance on water pumped from the Pra river on high iron levels which increase their cost of treatment and therefore production.

Aside from elucidating the hydro-geomorphic and biological processes, a better understanding of the functional linkages of sediment, nutrients, and water connecting the headwater systems and the lower sections is needed to address such relevant ecosystem (Wallace, Eggert, Meyer, & Webster, 1999; Sidle, Tsuboyama, Noguchi, Hosoda, Fujieda, & Shimizu, 2000). This, therefore, necessitates the evaluation of the linkages and influences of headwater processes and downstream linkages to understand cumulative factors and effects of changes in river channels (Rice, Greenwood, Joyce, 2001; Wipfli & Gregovich, 2002).

In order to comprehensively appreciate these dynamics, the physical, chemical as well as the biological characteristics of the various segments will be examined because river channels are made up of structural features (size, shape, bank structure, substrate size). The study was guided by the following questions;

- What are the hydro-geomorphic characteristics of the Kakum river basin?
- How distinct are the channel reach substrates within the Kakum river basin?
- What is the nature of land-use / land- cover and vegetation influences on the Kakum river system?
- How has the planform of the lower reaches been affected?
- What management approaches can be adapted to reverse the effect of headwater and downstream processes on the Kakum river?

Objectives of study

The main objective of the study is to understand the linkages and influences of headwater and downstream processes as well as their effects on the Kakum river. Specifically, the study will:

- Analyze the hydro-geomorphic attributes of the Kakum river basin;

- Explore the variation of the channel reaches within the Kakum river basin;
- Investigate landuse and vegetation influences on water quality and quantity within the Kakum river basin;
- Assess dynamics in the planform of the lower reaches of the Kakum river;
- Propose management approaches to reverse the morphological challenges of the Kakum river.

Justification of Study

There is the need to know the morphological characteristics of the Kakum river which is the main source of water for the Cape Coast Metropolis. Some studies have forecast water quality and quantity threats facing the Kakum river thus the major reason for undertaking this study (Adombire, Adjewodah, & Abrahams, 2013; Kumah, 2006)

Again, in approaching issues related to fluvial systems, the history, locations, sequence, and agents of the change must be known. With little of such information known, in terms of the Kakum river basin, there is the need for such study to be done.

In Newson (1997), there is widespread international agreement about the appropriateness of the river basin unit for land, water and development policies. This is because regulators, such as floodplains and wetlands, are extensively destroyed during the process of development and the system is unlikely to recover in the way that rivers recover from a pollution episode. Aside from this, society incurs the costs of replacing their function, for example by water purification, structural flood protection, or increasingly by schemes for restoring them. With such an awakening to the need for environmental protection, this study will provide a guide on issues relating to the resilience and sensitivity of this very important river basin in the Central Region.

Ecosystems including rivers have been described as having ‘integrity, stability and beauty’ most especially when untainted by human impacts (Leopold, 1949). As a result of the more direct development processes and widely predicted rates of change, there is the need for such studies which will re-examine the basin and its ecosystem to facilitate its restoration to, if not it’s original state, then at least closer to its original form.

Limitation of Study

The focus of this study is on assessing the morphological characteristics of the Kakum river. Even though an attempt is made to study the entire river from its headwaters to its mouth, the difficulty in tracing the actual source of the river did not permit this study to begin from there. It was a mirage and practically not possible as it appears that the headwaters evolve from varied springs. Thus, some portion of its upper course specifically in Asuansi- Nyamedom is used as the origin/starting point for this study since it possesses characteristics of an upper course as suggested by Davis (1934).

An attempt was also made to study the ecological nature of the river. However, not everything on its ecology is done in this work. Aspects covered include examining the kinds of biofilms found at the upper course as well as the nature and characteristics of both in-stream and riparian vegetation.

Furthermore, even though an attempt is made to explain processes that existed based on the morphologic and pebble analysis, the specific timing and dates for such occurrences are not definite. It is only the satellite images used that go as far back as 1991.

Organization of the Study

This thesis is organized into ten chapters. The First Chapter gives background information on small forest river morphology as well as the underpinning issues that characterize it. It also discusses the problem statement, research questions of the study and also outlines the objectives of this research. Lastly, the chapter gives an account of the significance of the study, the study's delimitations and limitations as well as the scope of the study not forgetting the organization of the thesis.

Chapter Two covered a description of the study basin and Chapter Three reviewed relevant literature pertaining to the work. Existing literature on morphometric parameters especially the most important, but ignored ones such as hypsometry, overland run-off, and rho coefficient were reviewed with respect to their effects on the river Kakum basin issues. Theoretical review and existing models were also be appraised or studied to put this work in perspective. Chapter Four touched on the research philosophies and methodologies employed to accomplish the set objectives for this study. Chapter Five to Nine presented the various results on the set objectives as well as the discussions respectively. Chapter Ten summarized the major findings as well as the Conclusions and the Recommendations for the study.

CHAPTER TWO

DESCRIPTION OF STUDY BASIN

Introduction

This chapter describes the basin of study which is the Kakum river. It defines the location of the basin absolutely and relatively whiles giving a picture of its topography as well. Other characteristics of the basin that were covered were geology, vegetation, soils, climatic conditions and size.

Location and Topography

The Kakum river takes it source from the Kakum and Assin Attandanso Forest reserves and lies within longitudes 1°25' and 1°20' W and latitudes 5°20' and 5°30'N. Kakum Forest Reserve and Assin Attandanso Resource Reserve each covers about 210 km^2 and 150 km^2 respectively. The Kakum National Park is generally flat with only a few undulating hills ranging between 150-250m above sea level. Most of the hills occur in the south-western portion rising up to 250m. The Assin Attandanso Resource Reserve is generally flat with hills ranging from 120-150 m above sea level. The Kakum river two major tributaries including the, Nemini, and Nchemna flowing out in the South East direction toward the sea at Iture, Elmina. Below is a map of the Kakum Drainage Basin.

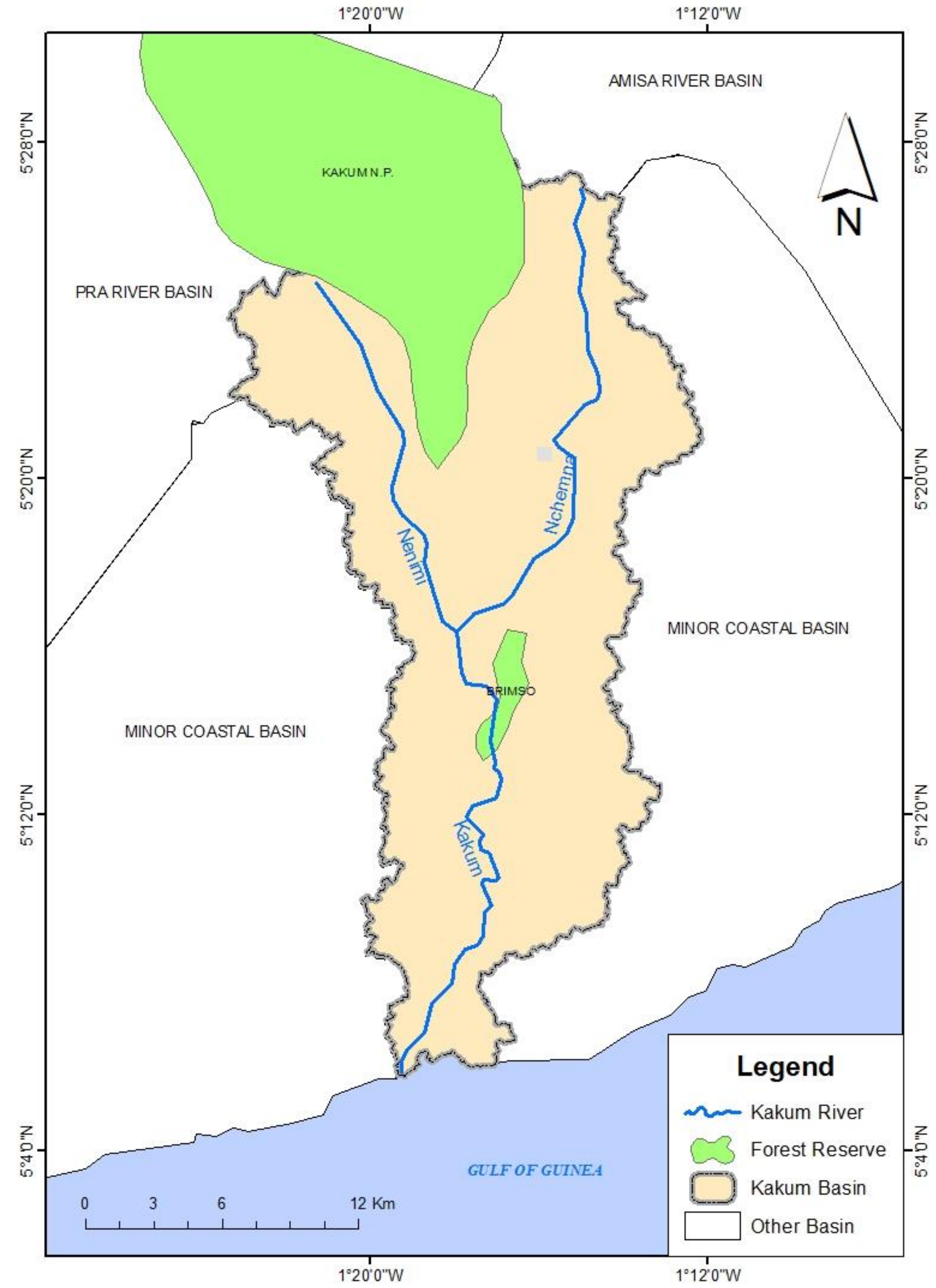


Figure 1: Map of study area.

Source: GIS Software, (Department of Geography and Regional Planning, [DGRP], 2017)

Vegetation and Climate

The basin typically has a moist evergreen forest and experiences two peak rainy seasons between May-July and September-December. Annual rainfall averages between 1500-1750mm. Following the wet season is a long dry season from January –April during which time the river break into pools as most of the tributary streams dry up (Forestry Commision, 1996). The Brimsu dam is fed by water from the Kakum river.

Geology

In the Kakum basin, the geology is mainly the granitoid undifferentiated and the Sekondian formation which covers the mouth of the Kakum river. The granitoid undifferentiated intruded the Birrimian formation during the latter stages of the Eburnean orogeny or cycle which was a series of tectonic, metamorphic and plutonic events about 2200-2000 million years ago (Wright, Hastings, Jones, & Williams, 1985). The Eburnean deformed the then structured Birrimian domain. Four main types of granitoids are recognized namely the Winneba, Cape Coast, Dixcove and Bongo granitoids (Junner, 1935; Kesse, 1985). The latter three have been recently termed Basin, Belt and K-rich‖ granitoids. (Leube, Hirdes, Mauer, & Kesse, 1990). The (Basin type) granitoids occur only within the Birimian sedimentary basins. This group also includes gneisses and are typically biotite-bearing. The one present in the study area is the Cape coast type which is most at times well foliated, often magmatic and potash-rich. Based on the degree of foliation, early workers assumed that the Basin type granitoids intruded during regional deformation whiles the Dixcove type were emplaced after deformation (Kesse, 1985). However, later work by Hirdes, Davis, and Eisenlohr (1992) demonstrated, in contrast to long held views that Dixcove granitoids formed at about 2,175 Ma and are about 60 and 90 Ma older than the Cape Coast granitoids. Taylor, Moorbath, Leube, & Hirdes (1988) suggest that the Cape Coast and Dixcove granitoids are coeval.

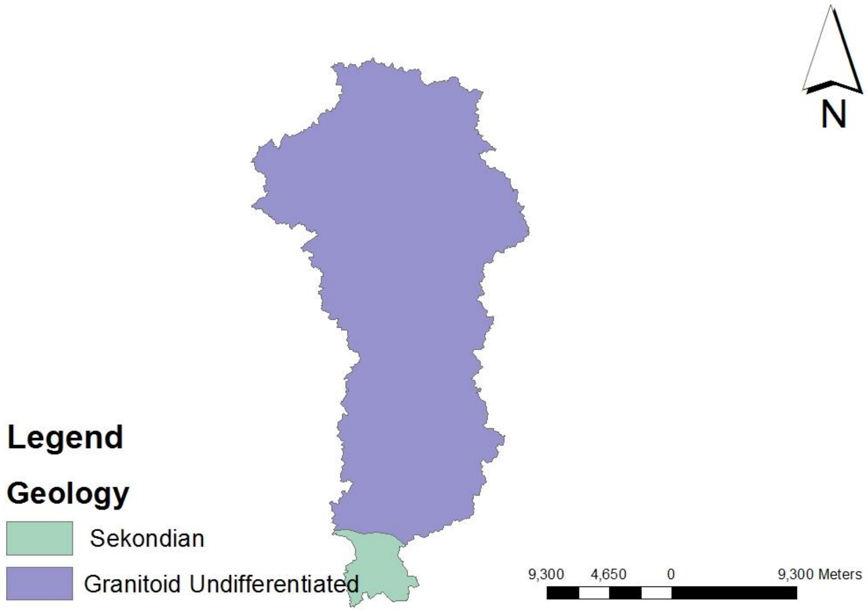


Figure 2: Geology map of study area.

Source: DGRP GIS Unit, 2017

The Sekondian formation is among the six formations making up the coastal sedimentary basin of Ghana. It mainly consists of sandstone, shales, conglomerate, pebble beds and mudstones. Crow (1952) has recognized six main different formations. These include the Sekondi sandstone, the Efia Nkwanta beds, Takoradi shales, Takoradi sandstone, Elmina sandstone and the Ajura shales. The one found in the study area is the Elmina sandstone-uniform, hard, massive and medium-grained sandstone with a characteristic chocolate purple color due to the pink feldspathic and dark limonitic cement. It is poorly bedded, well jointed and strongly cross-bedded. Figure 2 presents the geology map of the Kakum basin.

Soils

The two main soil types found in the Kakum basin belong to the Acrisols, and the Lixisols soil reference groups. The Acrisols group are the most widespread of the two while the lixisols group is found in just a small portion within the Kakum.

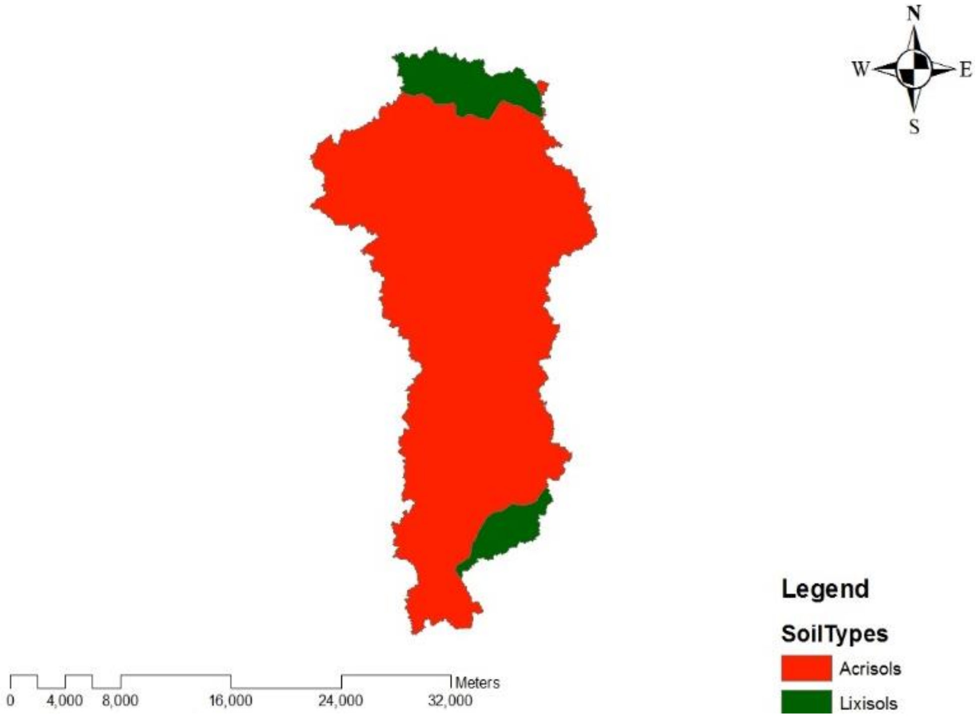


Figure 3: Soil map of study area.

Source: (Brammer,1962; International Society of Soil Science, [ISSS]/ International Soil Reference and Information Center, [ISRIC] / Food and Agriculture Organization, [FAO], 1998)

Soils belonging to the acrisols group are mostly found on weathered acidic rocks notably strongly weathered clays undergoing further degradation and so are not so productive and acidity tolerant crops as pineapple and oil palm mostly thrive well on them. Environments supporting these soils are mostly old lands with undulating topography with light forest and wet tropical or monsoonal climate type. In the lixisols group, soils are formed from unconsolidated and strongly weathered parent materials, thus, the soils themselves are strongly weathered with clay washed from the surface to some depth. Tropical to subtropical climate supports their formation on old erosional or depositional surfaces. These soils are believed to have started their development under wetter climate than now.

CHAPTER THREE

REVIEW OF RELEVANT LITERATURE

Introduction

As far back as about two centuries ago, Playfair (1822) gave a description of a river system as;

> *"Every river appears to consist of a main trunk, fed from a variety of branches, each running in a valley proportioned to its size, and all of them together forming a system of valleys, communicating with one another, and having such a nice adjustment of their declivities that none of them join the principal valley either on too high or too low a level."*

This ***"nice adjustment"*** which is viewed as a natural property of rivers even in modern quantitative approaches to studying river systems hardly exist in nature now. As a matter of fact, river channels over the past 5000 years have experienced human communities affecting their channels directly and indirectly (Downs & Gregory, 2004). This background sets the stage for this chapter on the review of relevant literature on the subject. In this chapter, literature is reviewed on the natural state of the Fluvial Landscape and the Geomorphological Dynamics as well as some theories, concepts, and methods employed in fluvial studies.

The Natural River Landscape

River landscapes are currently known as "Riverscapes" because of their complex mosaics of environmental gradients characterized by spatial connectivity and high complexity (Fausch et al., 2002; Ward, Malard, & Tockner, 2002). They have been defined by Tockner, Ward, Edwards, &

Kollmann (2002), as units pliable to study over an assorted range of spatial scales ranging from the largest (river basin/ landscape scale), valley segment, channel reach, and individual units which are the smallest for instance riffles and pools.

Talbot (1996) as well as Stanford and Ward (1993) describe these riverscapes as examples of non-deterministic open systems. These systems continually are in a state of flux with their upper constrained reaches being characterized by an abrupt descent into a single thread channel. The single thread channel is also boarded by a narrow band of riparian vegetation with thin alluvial deposits covering the bedrock whiles hydrological exchange is predominantly unidirectional. In the lower reaches, however, are expansive channels with related floodplains on which are deposited thick alluvium with terraces evidence of former higher levels at which the river was flowing. On the basis of process characteristics, Stanford and Ward (1993) roughly partition the watershed into two systems: the headwater system and the network systems

The distinction between the headwater and the network systems have commonly been based on processes from hillslopes to streams and on stream order (Hack & Goodlett, 1960; Strahler, 1957). For instance, relatively large substrate and woody debris in headwater channels lead to the modification in the hydraulics of the channel whiles providing sediment storage sites thereby leading to the accumulation of organic matter (Zimmerman & Church, 2001; Webster, Benfield, Ehrman, Schaeffer, Tank, Hutchens, & D’Angelo, 1999). Also, transported sediments from headwater tributaries creates various channel environments while modifying the patterns of channel morphology, riparian structure, and hyporheic exchange i.e. exchange of water between saturated sediment surrounding the open channel and the channel itself (Gregory et al., 1991; Wondzell & Swanson, 1999; Nakamura, Swanson, & Wondzell, 2000).

Based on the “order” concept, Strahler (1957) describes the headwater system as first- to second-order channels with the former being finger-tipped like channels with no tributaries discharging into them. The latter are those fed by the first order channels.

Even though defining headwaters based on processes from hillslopes to streams provides an outline of the downstream limits of headwater systems, the “order” concept by Strahler (1957) is highly dependent on the scale of a map and so not be very appropriate. Thus, Benda and Dunne (1987) based on the transition from mass movement–dominated to fluvial process–dominated reaches defined headwater streams of Oregon.

The Headwater System

In a headwater system, Hack and Goodlett (1960) identifies four topographic units with distinctive biological and hydrological processes including;

- hillslopes,
- zero-order basins,
- ephemeral or temporal channels emerging from zero-order basins (transitional” channels)
- First- and second-order stream channels depending on linkages from hillslopes to channels.

Hillslopes have typically no channelized flow. The zero-order basin, however, is an unchannelized hollow with colluvial materials (debris transported by gravity from adjacent hillslopes) typically filling such hollows (Tsukamoto. Ohta, & Noguchi, 1982).

From the zero-order basins emerge the headmost channels with definable banks with a temporary or ephemeral flow (Tsukamoto et al., 1982). The temporary channels have more or less continuous flow (at least 4 to 5 months in an average annually) whiles the ephemeral channels flow only for several days during wet periods (Dieterich & Anderson, 2000). They serve as temporary storage of organic matter and so are simply called transitional channels (Halwas & Church, 2002).

First-order streams are the uppermost, unbranched channels with either perennial flow or sustained intermittent flow (more than 4 to 5 months during an average year). Second-order (one branch) or even higher order (multiple branches) streams may also be considered headwater streams, depending on the degree of coupling between hillslopes and channels (e.g., transport distance of debris flow). Both first- and second-order channels may have intermittent reaches (dry parts), depending on groundwater level and volume of alluvium (sediment deposited by flowing water).

Headwater systems make up a spatial extent of the total catchment and so are important sources of sediment, water, nutrients, and organic matter for downstream systems (Sidle et al., 2000; Meyer & Wallace, 2001). Channel reach types may include cascades, steps, and pools. These stun mainly from sediment supply, larger substrate, exposed bedrock, and woody debris (Montgomery & Buffington, 1998; Halwas & Church, 2002).

The Network System

The numerous headwater tributaries that flow into downstream reaches affect hydrologic, geomorphic, and biological processes and attributes in downstream reaches of channel networks in the following ways:

- Synchronized or desynchronized inflows of water, sediments, nutrients, and organic matter from headwater tributaries create a variety of channel conditions and biological assemblages in downstream reaches.
- Temporal variations of disturbance regimes and riparian succession in headwater tributaries alter physical and biological conditions of channels, as well as the input of materials (sediment, invertebrates, and detritus), which in turn modifies food webs and their productivity in downstream reaches.
- Connectivity of headwater systems to downstream reaches affects both the cumulative and dispersed nature of material transport processes within watershed systems.
- Tributary junctions are unique in their physical and biological processes and are important as network nodes.
- Spatial and temporal variations of processes in headwater systems are critical factors affecting the dynamics of stream ecosystems, as well as the heterogeneity of riparian and riverine landscapes in channel networks.

Geomorphology of Fluvial Systems

Geomorphological characteristics such as channel width and depth, bank type and steepness, floodplain morphology, slope, bed and bank material, and valley wall confinement are the most obvious variations within and between fluvial systems (Perkin & Bonner, 2010; Robertson & Augspurger, 1999). Aquatic and riparian habitats are directly related to specific landforms and geomorphic processes (Johnston et al., 2001; Moret, Langford, & Margineantu, 2006)

Within the riverscape, there are three main surface water bodies which though differ in permanence are connected (Ward, Tockner, Arscott & Claret, 2002). These are the Lotic, Semi lotic and lentic. The waters flowing in the main channel and the tributaries having both upstream and downstream connections to the main channel are the lotic waterbodies while the semi lotic are the abandoned braided channels and the dead tributaries which only connect to the main channel at the downstream ends. The lentic waters are the natural and man-made lakes within the river basin (lakes of fluviatile and non-fluviatile origin).

In alluvial channels, the patterns may be straight, meandering, braiding or anastomosing while geomorphic features found on the floodplain (such as levees and crevasse splays) are the result of the interactions between climate, catchment geology, topographic relief and the river dynamics (Allen, 1965). The riparian vegetation on the floodplains exhibits the response of the channel to climate, soil moisture, disturbance and nutrients (Naimand & Decamps, 1997). These floodplains exhibiting such maximum heterogeneity in their natural state have been the most relentlessly altered (Ward & Stanford, 1995).

Again, the geomorphic structure of the channel landforms is defined by the geology, hydrology and the organic and inorganic matter supplied from adjacent hillslope vegetation. The rate of vegetation succession in the channels is defined by new geomorphic surfaces created in times of floods when there are deposition and battering of sediments (Gregory et al., 1991).

Thus, in the review of relevant literature explaining the geomorphological dynamics of a river, recognition is given to the strong relationship existing among geomorphic/hydrologic processes, channel hydraulics/structure, riparian vegetation, valley floor, aquatic biota, physical habitat and nutritional resources. In figure 4, is a diagrammatic representation of relationships among geomorphic processes, terrestrial plant succession, and aquatic ecosystems in riparian zones. Directions of arrows indicate predominant influences of geomorphic and biological components (rectangles) and physical and ecological processes
(circles).

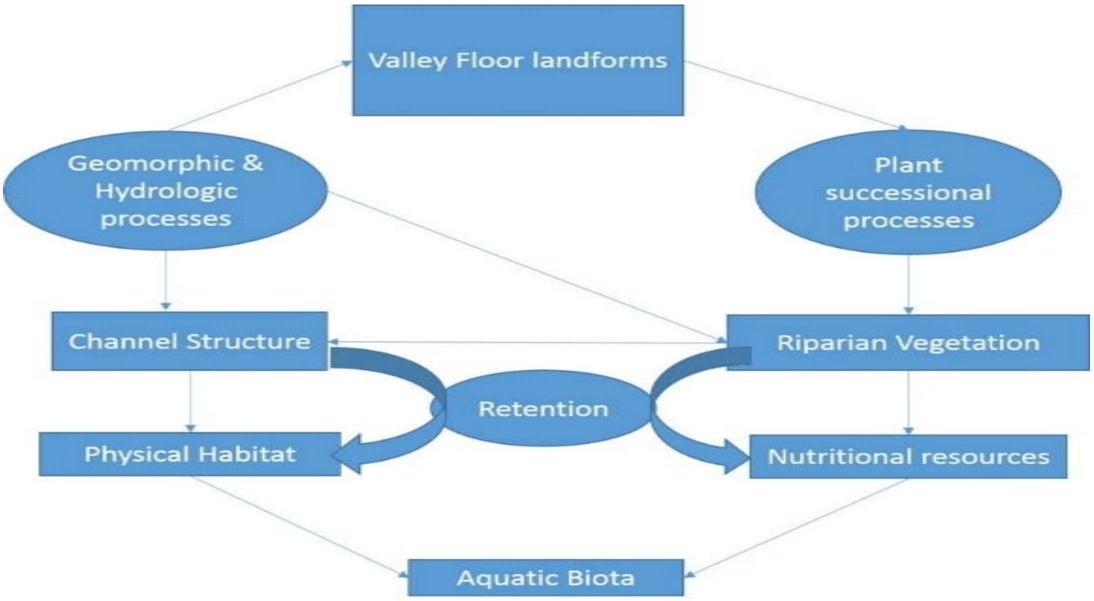


Figure 4: Relationships among geomorphic processes, terrestrial plant succession, and aquatic ecosystems in riparian zones.

Source: Adapted from Gregory et al., 1991

Valley floors according to Gregory et al. (1991) are mosaics of geomorphic surfaces, including active channels, floodplains, terraces, and alluvial fans. Their landforms are organized in a temporal hierarchical manner as the forces required to modify geomorphic surfaces at different spatial scales is directly linked to the recurrence intervals for floods or other geological events of such magnitude (Frissell, Liss, Warren, & Hurley, 1986; Swanson 1980; Swanson et al., 1988). Thus, on the one hand long-term geomorphic processes (volcanism, glaciation, and tectonic uplift) modify landscapes over tens of thousands to hundreds of thousands of years. On the other hand, more localized geomorphic processes (land-slides) extending over many square kilometers and occurring over hundreds to thousands of years may constrain valley development within stream reaches. Smaller channel features ultimately are altered by high-flow events that recur over several years to several decades, and small patches of sediment particles or hydraulic features may be reshaped several times within the year (Gregory et al., 1991).

Geomorphology of the Kakum River

Based on the preceding review, the geomorphology of the Kakum River has been examined based on the adapted figure by Gregory et al., 1991;

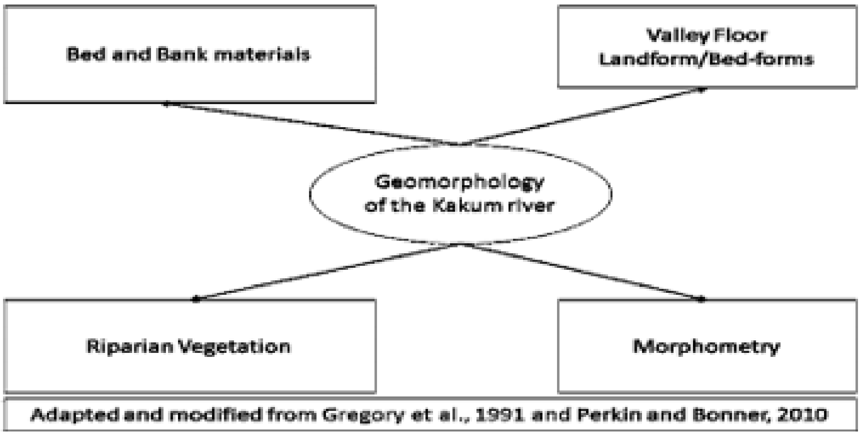


Figure 5: Geomorphology of the Kakum river basin.

Source: Adapted and Modified from Gregory et al. (1991) and Perkin & Bonner (2010).

Gregory et al. (1991) has been adapted based on the fact that not all it's original component are being studied in this work. Even though Perkin and Bonner (2010) exactly spell out the geomorphological characteristics that are most obvious within fluvial systems, the scope of this study does not permit the use of all the factors. Thus, the adaption and modification of both concepts for the purposes of this study.

Bed and Bank Materials: Particle Size Distribution

Important clues to sediment provenance, transport history, and depositional conditions are provided by the analysis of the grain sizes of sediments (Folk & Ward, 1957; Friedman, 1979; Bui, Mazullo & Wilding 1990). Among the various techniques employed in the determination of grain size include direct measurement, dry and wet sieving, sedimentation, as well as measurement by laser granulometer, X-ray sedigraph and Coulter counter which describe widely different aspects of the grain 'size', including the maximum calliper diameter, sieve diameter and equivalent spherical diameter. However, the variations in the grain shape, density and optical properties to a greater or lesser extent exert some influence on the result, thus making them difficult to compare (Pye, 1994).

According to Blott & Pye (2001), four main parameters are used to describe grain size distribution. These include: the mean parameter which measures the average size; the sorting parameter which measures the spread of the sizes around the average; the Skewness parameter which measures the symmetry or preferential spread to one side of the average; and the Kurtosis parameter which measures the degree of concentration of the grains relative to the average.

Prior to the advent of mordent computers, these parameters were measured and determined by means of the method of moments. In this method, frequency data was plotted as a cumulative frequency curve so that selected percentiles were read off graphically (Trask, 1932; Krumbein, 1938; Otto, 1939; Inman, 1952; McCammon, 1952; Folk & Ward, 1957; Blott & Pye, 2001).

However, with the advent of modern computers and computerized data analysis, calculations of the parameters can be automated by the method of moments and by the graphical method (Isphording, 1970; Slatt & Press, 1976; Utke, 1997). However, the cumbersomeness of these programs has led to the development of a new program written in Microsoft Visual Basic and integrated into Microsoft Excel spreadsheet known as GRADISTAT.

According to Blott and Pye (2001), in this program the method of moments is used to calculate statistics arithmetically (based on normal distribution with metric size values), geometrically (based on log-normal distribution in metric size values) and logarithmically (based on log-normal distribution in Phi values) following the basis or terminology of Krumbein and Pettijohn (1938). Values are extracted using a linear interpolation between adjacent known points on the curve and used to calculate Folk and Ward (1957) logarithmically and geometrically.

Sediment Sorting and Implications of Sorting Coefficients

Grain-size distributions are modified during transport as different size fractions are routed along different transport pathways under the influence of non-uniform bed topography and associated flow patterns (Powell, 1998). Sorting coefficients relate to textural attributes of sediments. A knowledge of sediment sorting patterns and processes is important because it is fundamental to our understanding of modern and ancient fluvial systems (Carling & Dawson, 1996), boundary roughness (Robert, 1990), heavy mineral enrichment and the generation of economic placers (Force, 1991), the fate of chemical and metal pollutants (Webb & Walling, 1992; Macklin, Hudson-Edwards, & Dawson, 1997) and for maintaining the ecological diversity of aquatic habitats (American Society of Civil Engineers Task Committee [ASCETC], 1992; Montgomery, Buffington, Peterson, Schuett-Hames, & Quinn., 1996).

Moss (1963) and Kuenen (1966) describe the process of selective deposition as a `like seeks like' effect whereby newly arriving sediment is preferentially deposited in pockets where it can resist the imposed fluid drag. The mobility of a particle is, in part, determined by the pocket geometry in which it rests. Coarse grains project relatively far out of pockets on a finer bed, experience a large drag force across their exposed surface area and are therefore more mobile than they would be on a bed of similar large grains. Conversely, small grains sit in deep pockets on a coarse bed, are partly hidden from the flow and are therefore less mobile than they would be on a bed of similar grains (Powell, 1998).

Three main coefficients exist in contemporary literature namely Trask Sorting coefficients (S_Q) (Trask, 1932); Phi deviation measure by Inman (1952); and Inclusive graphic standard deviation (Folk & Ward, 1957). According to Trask, a sorting coefficient of less than 2.5 indicates a well-sorted sand, a coefficient of 2.5-4.5 is normal and a value in excess of 4.5

reflects a poorly sorted sediment. Trask (1932) sorting coefficient is given by the equation;

$$\sqrt{Q1}/Q2$$

Trask uses the 25th and 75th percentile as a measure of sorting but Inman (1952), following Krumbien (1938) and Otto (1939) noted that size distribution and measures of sorting based on quartiles have less significance in the geometry of a normal curve, thus his advocacy for the use of the 16th and 84th percentiles (Friedman, 1962).

Inman's sorting characteristics is thus measured by the equation;

$$\sigma\Phi = ½(\phi 84 - \boldsymbol{\phi 16})$$

Folk and Ward, however, modified Inman's phi deviation by the inclusion of the 5th and 95th percentile, thus having an equation as;

$$\sigma\boldsymbol{\phi} = \boldsymbol{\phi 84} - \frac{\boldsymbol{\phi 16}}{\mathbf{4}} + \boldsymbol{\phi 95} - \boldsymbol{\phi 5/6.6}$$

The sorting classification of Folk and Ward (1957) is thus:

Table 1: Sorting Classification of Folk & Ward

Interval	Sorting Designation
< 0.35	Very well sorted
0.35-0.50	Well sorted
0.50-0.70	Moderately Well Sorted
0.70-1.00	Moderately sorted
1.00-2.00	Poorly sorted
2.00-4.00	Very poorly sorted
>4.00	Extremely poorly sorted

Source: Folk & Ward, 1957

Drainage Basin Morphometry

Morphometry is a means of understanding the geometric characteristics of the master channel and its tributary network. This approach to river basin studies was first initiated by Horton (1945) and Strahler (1957) and through this, many stream attributes are measured. It has been used to predict and describe geomorphic processes relating to flood peaks, sediment yield and erosion rates (Diakakis, 2011; Youseff, Pradhan & Hassan, 2011; Ajibade, Ifabiyi, Iroye & Oguntеru, 2010). Infiltration and runoff characteristics of a watershed are the governing factors in shaping its drainage pattern (Sharma, Sahai, & Karale, 1986; Dar, Chandra & Romshoo, 2013).

The concept of drainage composition by Horton (1945) showed that stream networks had a particular pattern with each stream segment relatively exerting some importance in the entire network of streams. However, due to the cumbersomeness of Horton’s approach to demonstrating this, Strahler (1952) refined Horton’s approach after which several other methods have arisen (Shreve, 1966; Hack, 1957; and Scheidegger, 1968). However, the main ones in use are that of Strahler (1952) and Shreve (1966).

In Strahler’s system of ordering, segments with no tributaries are designated as first order streams and when two of these first-order streams join, a second-order stream is formed and two second-order streams form a third-order in that succession. There is however, no change in order when a channel is joined by lower order channel. Shreve’s magnitude, on the other hand, considers streams as links within the network with the magnitude of each link representing the sum of the link numbers of all the tributaries that feed it; that is networks in which the downstream segments are of the same magnitude have equal numbers of links within the basin. Thus, in this method, the number of first-order streams are expressed from a given point and so makes this approach very useful for some geomorphic phenomena as rainfall and run-off relationships.

Every basin is believed to have a quantifiable set of geometric properties which can define the linear, areal and relief characteristics of the basin and so basin morphometry is mostly divided into those parameters describing these three characteristics; linear, areal and relief parameters. Nonetheless, two types of numbers have been used to do these characterizations, according to Strahler (1957, 1964 & 1968). These are linear scale measurements which allow size comparisons of topographic units and dimensionless numbers which are derived as ratios.

Some parameters commonly used to express the linear characteristics of a basin include stream numbers, of each order (No), total stream numbers in a basin (N), average stream length, total stream length, bifurcation ratio and length of overland flow. Some parameters commonly used to express relief characteristics of the basin include total basin relief, relief ratio, relative relief, relative basin area and ruggedness number while some parameters for describing the areal characteristics include drainage density, basin shape, stream frequency, constant of channel maintenance.

The Implication of Linear Parameters on Drainage Basin Characteristics

Bifurcation ratio

According to Strahler (1958), much of the linear morphometry is a function of bifurcation ratio which is defined as the ratio of a given order to the number in the next higher order according to Strahler's ordering method.

This value is not constant between each set of adjacent orders but since the variation from one order to the other is small, a mean value can be used according to Horton and with a given homogeneous geology (undergone minimum structural disturbances) throughout a basin. Rb values usually range from 3.0 to 5.0, values of more than 10 shows the influence of structures according to Chow, Maidment, & Larry (1988). Mean Rb values of about 4 – 5 are indicative of the absence of structural control and local slope relief (Sreekumar & Aslam, 2016; Singh & Awasthi, 2011). Much higher Rbm values greater than 5 are indicative of matured topography, accelerated erosion as well as early hydrograph peak during storm events (flash floods) (Sreekumar & Aslam, 2016; Ozdemir & Hassan, 2009; Meraj, Romshoo, Yousuf, Altaf, & Altaf, 2014).

Thus, in a study by Hajam, Hamid, & Bhat (2013) on the Vishav drainage basin in India, the highest Rb was found to be 4.26 and this was indicated to be corresponding to the highest overland flow and discharge attributable to hilly, less permeable rock formation associated with high slope configuration. It was also explained that the relatively high bifurcation ratio was an indication of early hydrograph peak with a potential for flash flooding during the storm events in the areas in which these stream orders dominate.

Patel, Dholakia, Naresh, & Srivastava (2012) found an Rb value as low as 1.57 and another as high as 6.19 in their study of mini-watersheds in the Lower Tapi Basin. These rare Rb values were described as the characteristics of structurally less disturbed watersheds without any distortion in drainage pattern (Nag, 1998).

Stream Length Ratio (Rl)

Horton (1945) describes this as the average length of streams of a given order to those of the next higher order and can be used to determine the length of streams in an unmeasured given order as well as their total length. In Horton's law of stream length, the mean length of stream segments of each of the successive orders of a basin tends to a roughly direct geometric series, with stream lengths increasing towards higher stream order. This relationship plots as a straight line according to Schumm (1956), Chorley (1957) and Morsawa (1962). Stream length is indicative of the stage of geomorphic development, differencesin slope and topography (Magesh, Chandrasekar, & Soundranayagam, 2011; Sreekumar and Aslam, 2016; Sreedevi, Subrahmanyam, & Ahmed 2005; Golekar, Baride, & Patil, 2013).

The Implication of Relief Parameters on Drainage Basin Characteristics

Basin relief

The importance of basin relief (Bh) as hydrologic parameters has long been recognized (Sherman 1932; Horton 1945; Strahler 1964). With increasing relief, steeper hillslopes, and higher stream gradients, time of concentration of runoff decreases, thereby increasing flood peaks (Patton 1988). In Ozdemir and Hassan (2009) and Sreedevi et al (2013), the highest Bh values found ranged between 1000-1200 and 150 respectively and such values were indicated as high Bh values and so related to the gravity of water flow, low infiltration, and high runoff conditions.

Relief ratio

This according to Schumm (1956), indicates the maximum basin relief divided by the longest horizontal distance of the basin measured parallel to the major stream and indicates the overall steepness and relief of the basin. Hajam, Hamid, & Bhat. (2013) state that aside from measuring the overall steepness of a drainage basin, it is also an indicator of the intensity of erosional processes operating on slope of the basin and in their study of the Vishav drainage basin, a relief ratio of 0.045 was indicated as moderate relief and steep to moderate slope. This is similar to the findings of Magesh, Chandrasekar, & Soundranayagam (2011) and Golekar et al. (2013).

Ruggedness number

This parameter according to Horton (1945) aside from being the product of relief and drainage density also indicates the structural complexity of the terrain. This parameter is indicative of susceptibility to erosion as well as peak discharge (Patton, 1988; Ozdemir & Hassan, 2009). In the work by Sreedevi et al (2013), Rn value varied between 0.1 and 0.59 and basins having high Rn values were related to be highly susceptible to erosion and therefore susceptible to an increase in peak discharge.

The Implication of Areal Parameters on Drainage Basin Characteristics

Basin Area (A)

The drainage area (A) is probably the single most important watershed characteristic for hydrologic design and reflects the volume of water that can be generated from rainfall.

Length of Overland Flow

Length of overland flow is the length of water over the ground before it gets concentrated into definite stream channels and is equal to half of the drainage density (Horton 1945). It relates inversely to the average channel slope (Patel et al., 2012; Romshoo, 2012)

Drainage Density (Dd)

The Drainage density (Dd) is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area, which is expressed in terms of km/km2, thus, Dd has units of the reciprocal of length (1/L). Drainage density (Dd) is indicative of storm response rate, infiltration capacity as well as the hydraulic conductivity. A high value of the drainage density would indicate a relatively high density of streams and thus a rapid storm response (Srivastava, Mukherjee, Gupta, 2008; Yildiz, 2004; Melton, 1957). Drainage density is generally inversely related to the hydraulic conductivity of the underlying soil (Sreedevi, Sreekanth, Khan & Ahmed, 2013; Montgomery & Dietrich, 1992; Romshoo et al., 2012). In a study by Pater et al. (2012), drainage densities were categorized in three, with averages over 4km/km2 being in the high drainage density category, followed by the watersheds within the moderate drainage density category with an average value of 2–4 km/ km2 and those under the low drainage density category (0–2 km/km^2). The latter group gives an indication of a poorly drained basin with a slow hydrologic response.

Stream Frequency (Fs)

The Stream Frequency (Fs) of a basin may be defined as the number of streams per unit area (Horton 1945). Generally, high stream frequency is related to an impermeable sub-surface effect of thrusting and faulting in the basin. Stream frequency is related to permeability, infiltration capacity and relief of watersheds (Montgomery & Dietrich 1989, 1992). A higher stream frequency points to larger surface runoff, steeper ground surface, rocky terrain, and very low infiltration capacity (Vittala, Govindaiah, & Gowda, 2004; Romshoo, Bhat, & Rashid, 2012).

Drainage Texture

The drainage texture depends upon several natural factors such as climate, vegetation type and density, rock and soil type, infiltration capacity, relief and stage of development. Low drainage density leads to coarse drainage texture while high drainage density leads to fine drainage texture that in turn depends on the infiltration capacity of the mantle rock or bedrock.

Shape Parameters

In general, the shape of the basin affects the stream flow hydrography and peak flows. Important parameters include form factor, circularity ratio, elongation ratio, compactness coefficient and shape factor.

According to Horton (1945), the Form factor which is defined as the ratio of the basin area (*A*) to the square value of the basin length (Lb) varies from 0 (in highly elongated shape) to unity, i.e. 1 (in perfect circular shape). Hence, the higher the value of form factor, the more circular the shape of the basin and vice versa (Babu, Zahoor, Nahm, Ramachandran & Rajan, 2014;

Chopra, Dhiman & Sharma, 2005). Also, in Gajbhiy (2014), the value of form factor would always be <0.7854 for a perfectly circular basin. The smaller the value of a form factor, the more elongated will be the basin. Basins with high form factor, have high peak flows of shorter duration, whereas those with low form factor have lower or flatter peak flows of longer duration and are easier to manage than those of circular basins, according to Gajbhiy.

According to Schumn (1956) elongation ratio is the ratio of the diameter of a circle (*D*) of the same area in the basin to the maximum basin length (Lb). Singh and Singh (1997), indicates relief and steep slope, thus susceptible to high erosion and sediment yield. And according to Manu and Anirudhan (2008), high values of elongation ratio indicate that the denudational process plays a major role in controlling the shape of the basin. A circular basin is more capable of discharge of run-off than an elongated basin. These values can be grouped into 4 categories namely: circular (> 0.9), oval (0.9 to 0.8), less elongated (<0.7).

The Circularity ratio (Rc) is expressed as the ratio of the area of the basin (*A*) to the area of a circle having the same perimeter as that of the basin (Strahler, 1964). Rc values approaching 1 indicates that the basin shapes are circular and structurally controlled but low value indicates the basin's elongation which is not structurally controlled (Babu, Sreekumar & Aslam, 2016). Gajbhiy (2014) suggested that circulatory ratio ($R_{c)}$ is influenced by the length and frequency of streams, geological structures, land use/land cover, climate, relief, and slope of the basin. In his study, Rc values of 0.15–0.44, were implied as indicating an area characterized by high relief and a drainage system structurally controlled. Circularity ratio values approaching 1 indicates that the basin shapes are like circular and as a result, it gets a scope for uniform infiltration and takes a long time to reach excess water at basin outlet (Sreedevi, Sreekanth, Khan & Ahmed, 2013).

In Patel et al. (2012), Compactness coefficient (Cc) can be represented as basin perimeter divided by the circumference of a circle to the same area of the basin and is also known as the Gravelius index (GI). Lower values of this parameter indicate more elongation of the basin and less erosion, while higher values indicate less elongation and high erosion.

The shape factor can be defined as the ratio of the square of the basin length to the area of the basin (Horton, 1945) and is in inverse proportion with form factor (Rf). Shape factor indicates a range of 1.88–2.72 indicating the elongated shape of a basin.

Constant of Channel Maintenance

Schumn (1956) used the inverse of drainage density as a property termed as ‘‘Constant of channel maintenance (C)’’. It depends on the rock type, permeability, climatic regime, vegetation cover, and relief as well as duration of erosion. It decreases with increasing erodibility (Schumn 1956). Higher values suggest more area is required to produce surface flow, which implies that part of water may get lost by evaporation, percolation, etc. lower value indicates fewer chances of percolation/infiltration and hence more surface runoff (Bhagwat, Shetty, & Hegde, 2011).

Sinuosity Index

Sinuosity is highly significant in studying the effect of terrain characteristics on the river course. It is a significant quantitative index for interpreting the significance of streams in the evolution of landscapes and beneficial for geomorphologists, hydrologists, and geologists. The calculated value of the Vishav basin is 1.02 that shows the stream has sinuous course.

River Channel Types and Bedforms

Studies relating morphology and channel processes in mountainous channels have been done to facilitate the understanding and prediction of their responses to both natural and human disturbances. Thus, way back in 1850 and 1891, Dana (1850) and Shaler (1819) respectively recognized the distinction between the mountainous sections and the lower counterparts of channels. Stream channel reaches, according to Frissel et al. (1986), a continuum of characteristics identifiable at spatial scales range from individual channel units to the entire drainage basin. Studying stream reaches defines a useful scale over which to relate stream morphology to channels processes, responses and habitat characteristics.

Even though a variety of classification of mountain channels exist, only a few are process based with the majority not being as such thereby compromising of their use for assessing channel condition, response potential and relations to ecological processes (Pausitian et al., 1992; Whiting & Bradley, 1993). Thus, in Montgomery and Buffington (1997), three channel reach substrates are recognized, namely: bedrock, and colluvium and alluvium substrates. This has been described to be an expansion on Schumm’s (1977) general delineation of erosion, transport and deposition reaches and also provides an examining framework for channel processes in mountain drainage basin (Montgomery & Buffington 1997).

In relation to the bedrock reaches, Buffington and Montgomery describe them as lacking a contiguous alluvial bed and also being a reflection of high transport capacities relative to sediment supply. Valley walls are also typically confined with steep slopes. Although some alluvial materials may be temporarily stored in scour holes, or behind flow obstructions, there is little, if any, valley fill. It is reasonable to adopt Gilbert's (1914) hypothesis that bedrock channels lack an alluvial bed due to high transport capacity associated with steep channel gradients and deep flow. Although bedrock channels in low-gradient portions of a watershed reflect a high transport capacity relative to sediment supply, those in steep portions of a watershed may also reflect recent catastrophic scouring.

Colluvial channels are small headwater streams at the tip of channel networks that flow over a colluvial valley fill and exhibit weak or ephemeral fluvial transport. Even though first-order channels comprise approximately half of the total length of a channel network (Montgomery, 1999). Dietrich et al. (1982) recognized that shallow flow in headwater channels have little opportunity for scouring and therefore sediment delivered from neighboring hillslopes generally accumulates to form colluvial valley fills. Shallow and ephemeral flow in colluvial channels appears insufficient to mobilize all of the Colluvial sediments introduced to the channel, resulting in significant storage of this material (Dietrich & Dunne, 1978; Dietrich, Dunne, Humphrey, & Reid, 1982; Benda, 1990). Large clast woody debris, bedrock steps, and in-channel vegetation further reduce the energy available for sediment transport in colluvial channels. Intermittent flow may rework some portion of the surface of the accumulated material, but it does not govern deposition, sorting or transport of the valley fill. Dietrich and Dunne (1978) recognized that the residence time of sediment in a headwater debris-flow prone channel was on the order of hundreds of years.

In contrast, notwithstanding, alluvial channels exhibit a wide range of morphologies and roughness configurations that vary with slope and position within the channel network and may either be confined with little to no associated floodplain or unconfined with a well-established floodplain. Alluvial reach morphologies may, therefore, include cascades, step-pool, plane bed, pool-riffle, and dune-ripple.

However, the main channels popularly distinguished are the bedrock and alluvial channels. In Massong and Montgomery (2000), the fundamental distinction between bedrock and alluvial channels is considered at two different scales namely at the entire drainage basins scale and finer scales or various reaches. Bedrock channels at the basin scale are mountain channels with at most a thin alluvial cover, whereas alluvial channels are those that occupy broad alluvial valleys. At finer scales within mountain drainage basins, bedrock channels can be considered those reaches that lack an alluvial cover (Howard, 1980; Montgomery & Buffington, 1997).

Two main models expatiate the distribution of bedrock and alluvial channels. The first model is the general model on spatial controls which uses slope and discharge (or drainage area as a surrogate) to express criteria for an excess of either sediment supply or transport capacity, and thereby channel type (Howard, 1987; Howard & Kerby, 1983; Howard, 1994; Montgomery et al., 1996). In the second model, it is based on the propagation of sediment waves through mountain channel networks (Benda & Dunne, 1997) and focuses on predicting temporal variations in the distribution of bedrock and alluvial channels due to the downstream routing of sediment stochastically introduced into the channel network by hillslope processes.

Table 2 summarizes the characteristic features of each channel type as in Buffington and Montgomery (1997).

In Bisson (1982) and Grant, Swanson, and Wolman (1990), "cascade" connotes tumbling flow over individual grain steps. These generally occur on steep slopes, are narrowly confined by valley walls, and are characterized by longitudinally and laterally disorganized bed material typically consisting of cobbles and boulders. Due to the large particle sizes relative to flow depth, these large bed forming materials become effectively immobile during typical flows but typically become mobile only during infrequent (i.e. 50 – 100 years) hydrologic events over steep gradients (Grants et al., 1990; Kondolf, Cada, Sale, & Felando, 1991; Whittaker, 1987). During lesser floods, gravel stored in low energy site mobilized and travels as bedload over the larger bed–forming clasts (Griffiths, 1980; Schmidt & Ergenziger, 1992). Gravels and finer materials are locally stored on stoss and lee sides of flow obstruction (i.e. large grains and large woody debris) due to physical impounding and generation of velocity shadows (Montgomery & Buffingtong, 2018). Cascade channels are defined by ubiquitous tumbling and jet – wake flow series of individual large clast that together exceeds a channel width in length with small, irregularly placed pools spaced less than a channel width apart, (Montgomery & Buffingtong, 1998).

Step–pool channels on the other hand according to Chin (1989) and Grant et al. (1990) are associated with a steep gradient, small width to depth ratios, and pronounced confinement by valley walls. They are characterized by longitudinal steps formed by large clasts organized into discrete channel spanning accumulation that separate pools containing finer materials.

Table 2: Classification of Channel Reach Substrates

	Dune-ripple	Pool-riffle	Plane bed	Step-pool	Cascade	Bedrock	Colluvial
Typical bed material	Sand	Gravel	Gravel cobble	Cobble boulder	Boulder	Rock	Variable
Bedform pattern	Multi-layered	Laterally oscillatory	Featureless	Vertically oscillatory	Random	Irregular	Variable
Dominant roughness element	Sinuosity, bed forms (dunes, ripples, bars) grains, banks	Bed forms (bars, pools), grains, sinuosity, banks	Grains, banks	Bed forms (Steps, pools) grains, banks	Grains, banks	Boundaries (bed & banks)	Grains
Dominant sediment sources	Fluvial, bank failure	Fluvial, bank failure	Fluvial, bank failure, debris flow	Fluvial, hillslope, debris flow,	Fluvial, hillslope, debris flow,	Fluvial, hillslope, debris flow,	Hillslope, debris flow,
Sediment storage element	Overbank, bed forms	Overbank, bed forms	Overbank	Bed forms	Lee and stoss sides of flow obstructions	Pockets	Bed
Typical confinement	Unconfined	Unconfined	Variable	Confined	Confined	Confined	Confined
Typical pool spacing (Channel widths)	5 to 7	5 to 7	None	1 to 4	<1	Variable	Unknown

Source: Montgomery & Buffington (1997)

Although step-pool and cascade channel morphologies both reflect supply limited transport, they are distinguished by differences in the spatial density and organization of large clasts. Step-pool channels are defined by discrete channel- spanning steps less than a channel width in length that separates pools spaced every one to four channel width. Plane bed channels have been applied to both planar bed phases observed to form in sand – bed channels (Simons et al., 1965). They can also be formed in planar gravel and cobbles-bed channels lacking discrete bars due to the low width to depth ratios and large values of relative roughness (Ikeda, 1975, 1977; Florsheim, 1985). Occurring at moderate to high slopes, plane beds may be either unconfined or confined by valley walls and are typically composed of sand to small boulder grain sizes, though are dominantly gravel to cobble bedded. The absence of tumbling flow and small relative roughness distinguish plane-bed reaches from cascade and step-pool channels. Plane–bed channels with armored bed surfaces indicate a transport capacity greater than sediment supply (i.e. supply-limited conditions) whereas unarmored surfaces indicate a balance between transport capacity and sediment supply (Dietrich et al., 1989).

Pool-riffle channels have an undulating bed that defines a sequence of bars, pools and riffles (Leopold, Wolman, & Miller, 1964). Pools are topographic depressions within the channels and bars are corresponding to high points. Pools are rhythmically spaced about every five to seven width in self-formed, pool-riffle channel (Leopold et al., 1964; Keller & Mellhorn, 1978) but channels with a high loading of a large woody debris exhibit smaller pools spacing (Montgomery et al., 1996). Pool-riffle channels occur at moderate to low gradient and are generally unconfined and have a well-established floodplain. Pool-riffle channels have heterogeneous beds that exhibit a variety of sorting and packing, commonly with a coarse surface layer and finer sub-surface (Leopold et al., 1964; Milhous, 1973). Substrate size in pool-riffle streams varies from sand to cobble but typically is gravel sized. Pool-riffle channels, like plane-bed channels, exhibit a mixture of supply and transport-limited characteristics depending on the degree of bed –surface armoring and consequent mobility thresholds. Unarmored pool-riffle channels indicate a balance between transport capacity and sediment supply, while the armored surface represents supply- limited conditions (Dietrich et al., 1989).

Dune-ripple morphology is mostly associated with a low –gradient, sand-bed channel. The bedform configuration of dune-ripple channels depends on the flow depth, velocity, and bed-surface grain size and sediment transport rate (Gilbert, 1914; Middleton & Southard, 1984) but generally follows a well-known morphologic sequence with increasing flow depth and velocity; lower-regime plane bed-ripples, sand waves, dunes, upper-regime plane bed and antidunes (Gilbert, 1914, Simon et al., 1965; Harms, 1975). Dune-ripple channels also exhibit point bars or other bedforms forced by channel geometry. In contrast to the threshold sediments transport of plane-bed and pool-riffle streams, dunes-ripple channels exhibit “live bed” transport (e.g. Henderson, 1963), in which significant sediment transport occurs at most stages. Hence dune-ripple channels are effectively transport-limited. The frequency of bed mobility and the presence of ripple and/or dunes distinguish dune-ripple channels from pool-riffle channels.

Flow obstructions can force a reach morphology that differs from the free-formed morphology for a similar sediment supply and transport capacity.

This is a common phenomenon in forested mountain drainage basins, in which large woody debris may force local scour, flow divergence and sediment impoundment that respectively form pools, bars, and steps. Montgomery et al. (1996) found that log jams forced alluvial streambed in otherwise bedrock reaches of a mountain channel network in western Washington. Forced pool-riffle and step-pool channels are the most common obstruction-controlled morphologies in forested mountain drainage basin and these Forced morphologies can extend beyond the range of conditions characteristic ofanalogous free-formed morphologies (i.e. to steeper gradients and/ or lower sediment supply). Thus, recognition of forced morphologies as distinct channel type helps make interpretation of whether such obstructions govern bed morphology and is vital for understanding channel response.

The Distinction between Land use Land cover

In Lambin, Geist, & Lepers (2003), the attributes of the earth's land surface and immediate subsurface including its biota, soil, topography, human structures as well as surface and groundwater define the land cover of an area. In representing datasets for land use/cover research, land surface attributes have been denoted by discrete (for single land cover categories) or continuous for continuous biophysical variables (Loveland, Zhu, Ohlen, Brown, Reed & Yang, 1999; Los, Justice, & Tucker, 1995). The distinction, however, must be drawn between land cover conversions and land cover modifications. In the case of the former, it is the complete replacement or shift of one cover type by another as in change in a urban extent and deforestation whiles the latter implies more subtle changes that affect the character of the land cover without changing the classification in totality (Lambin et al., 2003).

Land use is contrarily defined by Lambin et al. (2003) based on the purposes for which humans exploit the land cover and is highly dependent on the biophysical environment, socioeconomic activities and cultural contexts which are highly variable in space over time. As a complicated term, natural scientists define it in terms of patterns of human activities such as agriculture, forestry and building construction that alter land surface processes including sbiogeochemistry, hydrology and biodiversity while social scientists and land managers, on the other hand, define land use more broadly to include the socio-economic purposes and contexts for and within which lands are managed such as subsistence versus commercial agriculture, rented versus owner occupier, or private versus public land (Ellis & Pontius, 2007; Ayivor & Gordon, 2012).

Views on Causes of Land Use Land Cover Changes

Before identifying the causes of land use-land cover changes (hereafter known as land use), an understanding of the various factors that interact to influence people’s land use decisions must be clarified. Land use decisions even though are driven by change processes especially of the market and political reforms, however, are constrained by the given natural, socio-economic and political conditions locally, regionally and even globally (Klocking & Habelandt, 2002; Lambin et al., 2003). The causes may, therefore, be grouped into Proximate (direct) or Underlying (Indirect or Root) causes (Ojima, Galvin & Turner, 1994; Leemans et al., 2003).

Ojima et al. (1994) describe the Proximate or direct causes as the physical actions on land cover originating from the immediate human actions initiated by the intended land use. These most generally operate at the local level i.e. individual farms, household or communities. This highlights the belief of Ayivor and Gordon (2012) as well as Udo (1978), that land use is place-specific being influenced by the nature of the rural economy. Thus, in Ghana like any other traditionally agrarian economies where over 60% of the population depends directly or indirectly on agricultural land for livelihoods, land use types are always influenced by local livelihood demands.

The underlying causes, on the other hand, are the ultimate bases that reinforce the more proximate causes and operate from a distance i.e. districts, regional, national or global thus mostly exogenous to local communities (Leemans et al., 2003). They are formed by a complex web of social, political, economic, demographic, technological, cultural and biophysical variables which represent the primary conditions in the human environment relations (Contreras-Hermosilla, 2002; Geist & Lambin, 2002).

Land-use scenarios are thus based on spatial suitability (agricultural production, ecological response & economic as well as social conditions) and neighborhood relations. Klocking and Habelandt propose tendencies of development on the macroscale to include reducing agricultural areas, Increasing urbanization and renaturation of wetlands and river valleys. Landuse changes, no matter the tendencies for such change influence water availability through the increase in evapotranspiration coupled with a decrease in groundwater recharge as well as a reduction in discharge (Klocking et al., 2002). Their study revealed that the conversion of arable land into mixed fixed forest led to a significant reduction of basin discharge caused by increase evapotranspiration. The study of Ayivor and Gordon (2012) on three major basins in the Okyeman traditional area (Densu basin, Birim basin and Ayensu basin) also revealed land use changes have resulted in catchment erosion and subsequent river sedimentation, water shortage, pollution, and other physico-chemical impacts. Other cascading effects of such disturbances by Ansah-Asare (1995) on water resources also include nutrient enrichment of surface water from urban sources and agricultural chemicals, sediment loading caused by deforestation and eutrophication.

Similar to Klöcking, & Haberlandt (2002), Boakye, Odai, Adjei, and Annor, (2008) also believe that the rate of transformations within a country's landscape is the direct result of population growth and pervasive poverty. However, others like Lambin, et al. (2001) rather believe that the peoples' responses to economic opportunities, as mediated by institutional factors, orchestrate land-use changes. Thus, the global forces through national markets and policies create opportunities and constraints for new land uses (Ayivor & Gordon, 2012). De Hart and Soule (2000), as well as McCusker and Carr (2006), used the I=PAT explanatory framework to highlight the three primary influences namely Population, level of **A**ffluence and level of technology.

Global Trends in land use changes

The most rapid land cover changes include forest cover changes, deforestation, which according to the United Nations (U.N.) Food and Agriculture Organization (FAO) is the conversion of forests to another land cover or when the tree canopy falls below a minimum percentage threshold of about 10%. The Global Forest resources Assesment 2000 estimated that a loss of about 4.2% of natural forests existed in the 1990's but in Africa, the loss was about 2.1% and this mainly was as a result of cropland expansion by smallholders (Lambin et al., 2003). Again forest cover changes in Africa have been found to be very rapid in countries such as Madagascar, Cote d'Ivoire and some small scattered hot spots in the Congo basin.

Another factor resulting in land-use change have been changes in agricultural areas as increases in agricultural output have mainly been achieved through bringing more land into production (Lambin et al., 2003). With this, therefore, the greatest concentration of farmlands globally is found in Eastern Europe where about 70% of the land area in the United Kingdom is classified as agricultural land i.e. croplands, grasslands/ rough grazing (Ramankutty, Foley & Olejniczak, 2002). However, after the 1960's, there has been a declining correlation between food production and cropland expansion but rather an increase in the food production alongside phosphorus and nitrogen application as well as irrigation (Tilman, 1999). Western Africa was the only area which witnessed cropland expansion with a decrease in fertilizer use.

Other natural land covers have turned into pasture which is mostly defined as land used permanently for herbaceous forage crops either cultivated or growing wild (FAO, 2001). After Asia (33%), most pastures sometimes called natural savannas or steppes are located in Africa (28%). But many areas of pasture are classified as natural vegetation in Africa according to FAO (2001).

The other significant land use changes is in urbanization with urban population growing more rapidly than the rural populace with an associated increase in built up and paved-over areas . Urbanization though is experienced in the urban areas has an effect on the rural areas through the ecological footprint of cities which includes the consumption of prime agricultural lands in peri-urban areas for residential, infrastructure and amenities which blurs the distinction between cities and countryside (Lambin et al., 2003). Other land cover changes which remain unmeasured include forest cover changes caused by selective logging, fires and insect damage, drainage and other forms of wetlands alterations, soil degradation in croplands as well as the changes in the productive capacity of pastoral lands without leaving out dryland degradation commonly known as desertification (Lambin et al, 2003).

Local Trends

Within Densu basin as revealed in a study by Yorke and Margai (2007), the dominant land use types are agriculture, urban development, grazing, residential, transportation, infrastructure and fishing with specific activities under these, including the conversion of lands into croplands leading to deforestation, conversion of tree crop farms into food crop farms, livestock grazing, shifting cultivation, slash-and-burn farming practice and urban sprawl (De Moraes et al., 1998; FAO, 1999; Ayivor & Gordon, 2012). But three major land use patterns were found to be conspicuous namely agricultural intensification, conversion to residential land use to meet the growing needs of human settlements with fast-growing areas as Gbawe, Kasoa, Ablekuma etc making areas within the Densu to be one of the most populated and lastly, conversion from cocoa farms to food crop farms to meet urban food demands.

The Birim Basin is another major basin in Ghana included in the study by Ayivor and Gordon to outline land use activities impacting the river to be mainly farming, mining, indiscriminate waste disposal, water extraction, deforestation for fuel wood and other domestic uses and excessive use of chemical fertilizers (Ansah-Asare & Asante, 2000). The result of this was found to be the slightly acidic nature of water from the Birim as well as increasing nutrient levels during the rainy season.

The Ayensu basin, on the other hand, is confronted with unsanitary conditions such as open defecation along river banks, improper location and poor maintenance of dumpsites along river banks. There is also the heaping of industrial waste notably saw-dust from nearby sawmills along river banks, farming close to river banks and inappropriate use of agro-chemicals by farmers within the basin (Appau-Attafuah, 2000).

The Relationship Between Land Use/Cover- Soil Nutrients and Trace Metals

Soils have been described as possessing some properties which tend to be dynamic across human time scales due to natural, human, and other factors. These properties include soil composition in terms of nutrients and trace metals (Wills & Herrick, 2008; Laing et al., 2009; Park et al., 2011). Spatial variability/heterogeneity of soil nutrients have been found in several studies to be affected by significantly Land-use types and moderately by vegetation as well as human interference (Lal, Kimble, Levine, & Whitman , 1995; Intergovernmental Panel on Climate Change, [IPPC], 2000; Chen, Wang & Wang, 2005). Land use is an integrator of several environmental attributes which influence soil nutrients export and other related soil processes, such as erosion, oxidation, mineralization, and leaching, (Lepsch, Menk, & Oliveira, 1994; Young, Marston & Davis, 1996; Fu, Ma, Zhou & Chen, 1999; Hontoria, Saa & Rodríguez-Murillo, 1999). These consequently modify the processes of transport and redistribution of nutrients.

Soils found in forest and farmlands tend to have a high content of total nitrogen and organic matter distributed in forests and farmland areas. However, there are variations in the content levels as found by Elrashidi, Wysocki, and Schoeneberger (2016) that Forest>Pasture>Cropland. However, at the surface, these nutrients are susceptible to changes especially in areas which are dominated by soil erosion and intensive cropping tend to lose a lot of surface soil nutrients such as nitrogen and organic matter content (Skidmore et al., 1986; Desjardins et al., 1994; Schipper & Sparling, 2000; Levi et al., 2010; Chen et al.,2011). Again, through mechanisms such as combustion during a fire, soil organic matter is vulnerable to loss and even more rapid decomposition from postfire changes (Juo and Manu 1996). At low temperature, Nitrogen has been found to be volatilized resulting in losses of about 50% to 90% of the Nitrogen content stored in aboveground vegetation, depending on the intensity of the burn (Holscher et al.,1997; Kauffman et al., 1998).

Some studies have also discovered a strong relationship between organic matter and several other nutrients including nitrogen, phosphorus, and potassium (Liu et al., 2009). These relationships also varied with land-use and in a study by Chen et al. (2011), even though the correlation between organic matter and nitrogen was highly significant, it varied with the different land-use types. Thus, the variation in the relationship between organic matter and nitrogen was such that, among the five land-use types, grass land>cultivated land >forestland>orchard land>unused land. This is similar to McGrath, Duryea, and Cropper, (2001) that soil organic carbon/ matter and Nitrogen decline following forest to pasture conversion. However, Wander and

Bollero (1999) concluded that the carbon and nitrogen contents of undisturbed soil were significantly greater than no-till (NT) and conventional till (CT) soils. In Chen, Wang, Fu, and Qiu (2001), soils from woodland, shrubland, and grassland contained significantly greater organic matter compared to those from fallow land and cropland. Analogous studies have been done (Grigal & Ohmann, 1992; Davidson & Ackerman, 1993; Jaiyeoba ,1995; Hontoria et al., 1999; Fu et al., 2000).

Soil Phosphorus concentrations from both secondary forest and shifting cultivation fields, although diagnostically low, have been found to be significantly higher than those found in both pasture and primary forest (McGrath et al., 2001). Relating organic matter and phosphorus, the relationship was only significant for two land use types namely unused land and cultivated land whilst all the other relationships were insignificant. This was in line with the study by Zou et al. (2006) that soil phosphorus was influenced by some factors such as parent material, fertilizer, and human activities. High potassium content levels, however, have been found to be deeply influenced by the parent material.

Some hazardous micronutrients or trace metals such as cadmium (Cd), copper (Cu), Zinc (Zn), due to some new land use practices have also been introduced into soils. Several studies of these nutrients and trace metals/micronutrients have brought to bear the different accumulation levels and effects in soils under different land use (Bloemena, Markert, & Lieth, 1995; Zheng et al., 2005 a, b, c, d; Chen, Zheng, Chen, 2005b, c; Gaw et al., 2006).

These are highly spatially variable especially in the topsoil because apart from the properties of the parent materials, humans, through some land-use practices and other anthropogenic activities input these micronutrients. These new practices include excessive applications of agrochemicals, industrial by-products, municipal wastes, animal manure, and the aerial fallout from industrial activities as well as automobile exhaustion. Phosphate fertilizers are an important source of heavy metals entering agricultural soils, especially cadmium (Cd), copper (Cu), and zinc (Zn) (Nicholson et al., 2003). They are easily transferred from the topsoil by runoff and leaching to surface and groundwater supplies which can affect animal and human health (Pinay et al., 1992; Ma, Wang & Anders., 2001; Wang, Chu & Xu, 2003). Copper studies by Elrashidi et al. (2016) indicated that land use had a significant effect on the Cu concentration in topsoil, whereas the effect on Zn concentration appeared to be insignificant. In a similar study, Luo et al. (2007) also found significant relations between copper and land-use. The reason for such relations/findings were related to reports in the international literature that orchid soils especially vineyards had a wide range of relatively high copper (Merry, Tiller & Alston , 1983; Deluisa et al., 1996; Holland & Solomona, 1999; Besnard, Chenu & Robert, 2001). This was proposed to have risen from the long-term use of copper-based fungicides and pesticides, thus the Guanting reservoir. Zinc concentrations have been related to parent rocks with a high level of pyrite and phosphate as well as long-range atmospheric transport of metals from areas with increasing industrial activity (Office of Leading Group for Guanting Water Protection, [OLGGWP], 1977; European Environment Agency, [EEA], 1998; De Vries et al., 2002).

The relationship between Land use Land cover and Biogeochemistry of River Sediments

Land use types have been studied widely as an important factor influencing both the source of sediment and it's geochemical and nutrient content of channel bed sediments (Bormann, Likens, Siccama, Pierce, & Eaton, 1974; Hassan, Church, Lisle, Brardinoni, Benda, & Grant, 2005; Horowitz & Stephens, 2008). Sediments form a natural buffer and filter system in the material cycles of waters, aside from being the main source of nutrient for aquatic organisms thereby impacting on the ecological quality (Stronkhorst et al., 2004). The suspended and precipitated (non-floating) substances and organic substances stored on the bottom of rivers form a reservoir for many pollutants and trace substances of low solubility and low degree of degradability (Biney et al., 1994; Barbour, Gerritsen, Snyder & Stribling, 1998, 1999). They may be divided to include trace metals (Cu, Pb, Zn), nutrients (P, N) and other organic compounds.

Variation in the amount and composition of river sediments has been studied to be the consequence of various natural and anthropogenic control factors (Jennerjahn, et al., 2008). Knowledge of the properties and composition of sediments allows the evaluation of the condition and disturbance resulting from the accumulation of anthropogenic and natural substances that could pose risks to the ecosystem health (Taghinia et al., 2010).

Nitrate in river sediments has been found in several studies to be relatively lower with densely vegetated areas rather than agriculture dominated regions (Turner & Rabalais, 1991; Soman, 1999; Filoso et al., 2003; Jennerjahn et al., 2004; Ahearn et al., 2005; Voss et al., 2006). This has been related to the application of artificial fertilizers and organic manure which type, in most cases, are dependent on the type of soil and plant. In Raychaudhuri (1980), due to the fact that acidic laterite soils lack P, application of P fertilizers would be increased (Arheimer & Liden, 2000). As a result, unconsumed portions by plants are likely to be out washed by surface water runoff especially since the prevailing soils (Laterite) may hinder percolation, thereby increasing phosphorus concentration in river sediments.

Raw sewage, the interaction between water and dead plant and animal remains at the bottom of rivers as well as firm rock deposits have been added as other sources of nitrates and phosphates in rivers (Aggarwal, Singh, & Gupta, 2000; Adeyemo, 2003). However, phosphorus is exceptionally high during rainy seasons and considered the most significant and primary initiating factor, among the nutrients responsible for eutrophication in water bodies. Eutrophication may originate from nutrient enrichment, productivity, decay as well as sedimentation and may increase algae and aquatic plant growth (Adeyemo, 2003; Bernhardt et al., 2003; Murdoch, Cheo, & O'Laughlin, 2001; Boesch, Brinsfield & Magnien 2001; McDowell, Drewry, Muirhead, & Paton 2003). Nitrates are rather higher during the dry season (Wolfhard & Reinhard, 1998; Johnson, Cheng, & Burke, 2000).

Zinc (Zn) and copper (Cu) levels in river sediments have been directly related to mining activities (Lecce & Pavlowsky, 1997; Edward- Hudson, Schell, & Macklin, 1999; Florea, Stoica, Baiulescu, & Capotă, 2005). Zn, Fe and K in fluvial sediments have, however been related to deforestation

(Christie & Fletcher, 1999; Scott, Agnew, Soja, & Storper, 2001; Tremblay et al., 2009).

The Relationship between Land use Land cover and River Water Quality

Rivers and streams act as integrators of land-water interactions but are particularly vulnerable to land use change and ubiquitous exploitation (Withers et atl., 2009; Vörösmarty et al., 2010). Therefore, several studies have established correlations between land use and water quality and have concluded that once the role of different land use combinations are known in an area, water quality can potentially be improved (Amiri & Nakane, 2006; Woli , Nagumo, & Hatano , 2002; Jarvie, Withers, & Neal , 2002; Chen et al., 2002; Jones et al., 2001; Sliva & Williams, 2001; Norton & Fisher, 2000; Basnyat et al., 1999).

However, several other studies have established the importance of season in such correlations. Thus, during rainy periods, upper watersheds are likely to deliver relatively insignificant amounts of nutrients and sediment when compared to the lowlands which may rather act as sediment or nutrient sinks (Ahearn et al., 2005; Holloway & Dahlgren, 2001). Impoundments along a river's course have also been identified to affect the relationship between water quality and land use. They have been known to act as substantial chemical sinks for most constituents thereby reducing the flux moving from upper watersheds to affect downstream water quality (Ahearn et al, 2005; Kelly, 2001). With the reservoirs acting as sinks for many constituents and lowland LULC contributing to increased sediment and nutrient loading, the lowlands have become the primary beginning for Non-Point Source (NPS) pollution. In this context, the biogeochemical cycles of several elements, including nitrogen (N), carbon (C), phosphorus (P) and, oxygen (O) which influence water quality are affected (Galloway et al., 2003; Likens, 2004). Strong positive relationships have been observed between agriculture, urbanization and water nutrient concentrations. Forest clearing for farms and pastures leads to an increase of overland flow of several solutes such as phosphates, nitrate, calcium, magnesium (Mendiguchıa et al., 2007; Germer et al., 2009, Michaud & Wieger, 2011).

Water quality has been affected by the high concentration of nutrients making them contaminants instead of necessities for life (Sprague & Lorenzen, 2009). High nutrient concentrations, especially of nitrogen (N) and phosphorus (P), have led to increased eutrophication, taste and odor problems, and increase of algal blooms (Falkowski et al., 2000; Dodds, 2006; Howarth, 2008; Gravelle, Ice, Link, & Cook, 2009; Lombardo, O'Farrell, & dos Santos Afonso, 2010; Zhou, Wu, & Peng, 2012). These are by-products of human activities such as agricultural practices, mining, and emission of urban and domestic effluents such as detergents and sewage (Marins, Paula Filho, & Rocha, 2007; Ortiz-Zayas et al., 2006; Pellerin et al., 2004; Silva et al., 2007).

Nitrate (NO_3) is a natural constituent of plants and is found in vegetables at varying levels depending on the amount of fertilizer applied and on other growing conditions. Water naturally, contains less than 1 mg nitrate-nitrogen per liter and is not a major source of exposure. Higher levels indicate that the water has been contaminated (Speijers & Meulenbelt, 2003). Common sources of NO_3 contamination include fertilizer, animal waste, septic tanks, municipal sewage treatment systems, feedlots and decaying plant debris. Most nitrogenous materials in natural waters tend to be converted to nitrates and therefore, all sources of combined nitrogen (particularly organic nitrogen and ammonia) should be considered as potential nitrate sources (Dubrovsky & Hamilton, 2010).

Phosphorus or Phosphates enter the waterways through both non-point sources and point sources. Non-point source (NPS) pollution refers to water pollution from diffuse sources. The non-point sources of phosphates include natural decomposition of rocks and minerals, storm-water runoff, agricultural runoff, erosion and sedimentation, atmospheric deposition, and direct input by animals/wildlife; whereas: point sources may include: wastewater treatment plants and permitted industrial discharges. In general, the non-point source pollution typically is significantly higher than the point sources of pollution. High concentration of phosphate in water bodies is an indication of pollution and largely responsible for eutrophication (MacCutheon, Martin & Barnwell, 1983).

Calcium occurs in water naturally. One of the main reasons for the abundance of calcium in water is its natural occurrence in the earth's crust. Rivers generally contain 1-2 part per million (ppm) calcium, but in lime areas, rivers may contain calcium concentrations as high as 100 ppm. Calcium is essential to human health but is also an important determinant of water hardness. Calcium also gives water a better taste (Moodley, 2002).

Rivers contain approximately 4 ppm of magnesium is also responsible for water hardness. A large number of minerals contains magnesium, for example, dolomite (calcium magnesium carbonate; CaMg (CO_3) and magnesite (magnesium carbonate; $MgCO_3$) (O’Farrell et al., 2002). Magnesium is washed from rocks and subsequently ends up in water. It also ends up in the environment from fertilizer application and from cattle feed (World Health Organization, [WHO] 2006; Eisenberg, 1992).

Bankline Movements

The river channel network is not confined to a symmetrical track. The river channel shifts or changes with respect to time and space. This movement or shifting is the process by which stream channels move and shape floodplains through time and therefore one of the important fluvial physico-climatic processes by which a river can readjust to variations in hydrology, sediment load and active tectonics (Leopold &Wolman, 1957; Baishya & Sahariah, 2015). The ability of streams to achieve these are products of the general structure and character of watersheds which may include the characteristics of sediments being carried, flow regime, valley or watershed geology, riparian vegetation as well as woody debris in the channel (Montgomery, 1999). Due to the fact that these vary systematically even as one approaches the downstream of a particular river, migrating channels are usually put into a landscape context (Vannote et al., 1980).

Channel migration may occur through processes of channel expansion, gradual bend migration, and/or abrupt channel switching called avulsions (Knighton, 1998). A channel may accomplish these by manipulating its floodplains through vertical and lateral erosion. This is much common in channel bends as streamflow detach materials from the outside bank and deposits sediment along the other (Leopold & Wolman, 1960; Nanson & Croke, 1992). Thus, lateral outside erosion and accretion of material on the inside of channel bends often occur simultaneously (Nanson & Hickin, 1986).

Erosion may be as a result of either the undercutting of the upper bank materials during the high floods to produce an overhanging cantilevered block that eventually fails or by over-steepening of bank materials closer to the bank during the falling stages due to migration (Goswami, 2002). Channel widening can also occur episodically in response to floods (Konrad, 2012) or as a long-term change due to increases in surface water runoff resulting from the upland development or climate change. It can also occur because of riparian vegetation removal (Brooks & Brierley, 2002; Brooks, Brierley, & Millar, 2003; Eaton, 2006).

Channel migration is generally dependent on-stream power and tends to migrate the greatest distances during major flood events whiles larger channels tend to migrate at greater rates (Konrad, 2012; Nanson & Hickin, 1986; Richard et al., 2005). For instance, in the plains of the Lower Subansiri basin which is characterized by heavy flow and enormous volume of sediment load during flood season, continuous changes in its channel morphology, bank line migration and lateral changes in its channels have been observed, leading to considerable loss of good fertile land every year (Sarkar, Garg, & Sharma , 2012). Similar studies and observations were made by Desai, Naik and Shah (2012); Goswami et al. (1999); and Schumm & Litchy (1963).

Even though unconfined, alluvial valleys with broad bottoms composed of sediment are those most associated with channel migration because they allow channels to migrate across their floodplains (Montgomery & Buffington, 1997; Church, 2002), where confined streams can also be subject to channel incision and migration if there is a change in geomorphic controls (Booth et al., 2004); these are all dependent on the factors controlling the channel's resilience as well as the migration process. Thus, channel migration can occur throughout a channel network and be influenced by a range of geomorphic processes.

However, not all channels experiencing floods necessarily migrate due to the differences in bank resistance which is affected by sediment size and cohesion (Nanson & Croke, 1992). Cohesion is either from chemical bonds associated with clay particles or mechanical bonds from plant roots or riparian vegetation (Thorne, 1990; Langendoen et al., 2009). This is may be real cohesion due to the presence of silt and clay fractions, or apparent cohesion due to either capillary suction in the unsaturated zone or the binding effect of vegetation roots and rhizomes (Thorne, 1991). Usually, serious erosion of cohesive banks takes place through the loosening or detachment of aggregates by sub-aerial or sub-aqueous processes, and later by entrainment of the disturbed materials by the flow. These are the two main constituents of erosion (Wolman, 1959).

Due to the nature of most alluvial soils, (swelling and shrinking markedly with varying cycles of wetting and drying), they tend to possess weaker cohesion as they assume a ped and crumb structure with desiccation cracks between them (Thorne, 1991). However, in the case of heterogeneous soils, where cohesive materials underlie non-cohesive materials or vice versa, it is a bit different as the non-cohesive layers are eroded more quickly than cohesive ones. This leads to berms and terraces or cohesive material underlies non-cohesive material and under-cutting respectively.

River Continuum Concept

Within a watershed and across its stream networks, geology, climate, and topography vary and control the distribution of geomorphic processes (Montgomery & Buffington, 1997; Montgomery, 1999). Human actions such as forest clearing, development, and channelization have been known for impacting pronouncedly on channel and floodplain processes. These fundamental controls, as well as the human actions, influence factors like sediment supply, stream discharge, land-surface slope, and vegetation, which are important variables determining the form and processes of channels (Lane, 1954).

The valley slope, which is the cumulative result from landscape evolution including gradual and catastrophic processes of erosion and sedimentation that have occurred over geologic timescales, controls the overall capacity for a stream to erode its floodplain (Nanson & Croke, 1992).

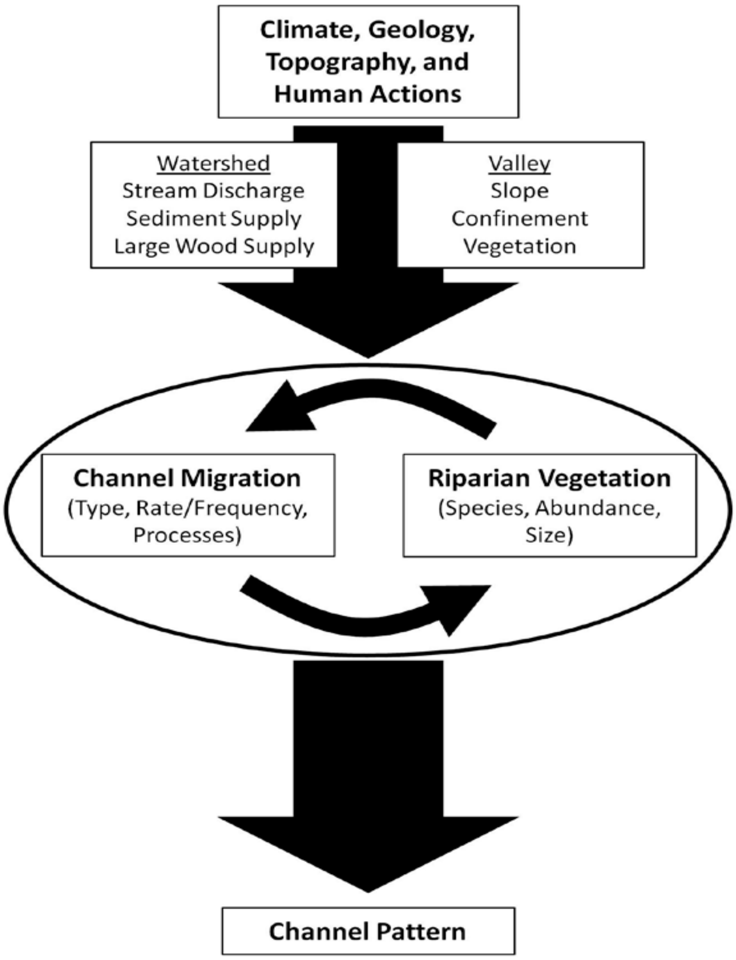


Figure 6: Landscape controls, channel migration processes, and channel pattern.

Source: Legg & Olson (2014)

On the floodplain, channel migration processes and riparian vegetation interact to form channel patterns with distinct landforms and characteristics. For instance, through the process of channel migration, riparian trees can be recruited into channels to create new surfaces where vegetation subsequently germinates (Hickin & Nanson, 1975; Hickin, 1984). Vegetation may also stabilize bank to bank erosion which in turn can influence channel pattern (Thorne, 1990; Abbe et al., 2003; Gran & Paola, 2001; Micheli, Kirchner & Larsenet, 2004; Braudrick, Dietrich, Leverich & Sklar et al., 2009).

Basal Endpoint Control Concept

The basal endpoint control concept according to Thorne (1991), explains the link between sedimentary processes on river banks and those operating in the channel as a whole. In the concept, the river is solely in control for changes in its bank lines even though all the other processes contribute in a way. Thus, after bank erosion and mass failures have delivered sediment input into the system, the balance between the rates of supply from the bank and removal by the flow will determine what happens with the channel platform. There are however three possible states for this balance:

Input > output (impeded removal): which will lead to an increase in basal accumulation thereby decreasing bank angle and height, whiles buttressing the bank. Bank stability is therefore increased and the rates of sediment input and bank retreat is decreased or;

Input = output (unimpeded removal) where there is a balance between processes delivering and removing sediment and so no change in basal elevation or storage takes place over time. The bank retreats by a parallel retreat at a rate determined by the degree of fluvial activity at the base. Basal endpoint control is static and the bank retreat rate is zero if the sediment load at the base is zero or;

Input < output (excess basal capacity) where there is an excess basal capacity to transport sediment than that supplied. This results in basal lowering and under-cutting, increasing bank height and angle whiles consequently decreasing bank stability.

Riparian Vegetation

Riparian vegetation occupies one of the most dynamic areas of the landscape whose distribution and composition reflect histories of both fluvial disturbance from floods and the non-fluvial disturbance regimes such as fire, wind, plant disease, and insect outbreaks as well as human disturbances (Gregory et al., 1991). With the extreme variation in soil properties and topography of valley, riparian plant communities nonetheless exhibit a high degree of structural and compositional diversity (Hawk & Zobel, 1974). They as well contribute large woody debris to channels, a major geomorphic feature streams and rivers (Swanson, Lienkaemper & Sedell, 1976; Keller & Swanson 1979; Bilby 1981). However, the relative influences of large woody debris on the development of geomorphic surfaces decrease from headwaters to large rivers (Harmon et al., 1986; Swanson, Fredriksen, & McCorison, 1982).

Mangroves

Mangrove forests typically are located in the tropical and subtropical regions of the world between approximately 30° N and 30° S and are distributed in the inter-tidal region between the sea and the land (Alongi, 2009; Giri, et al., 2010). Environmental conditions and settings surrounding their growth are comparatively harsh and include high salinity, high temperature, extreme tides, high sedimentation and muddy anaerobic soils. Even though less than half of world mangrove forests now exist, much of what remains is in a degraded condition (Spalding et al., 1997; Spiers, 1999; UNEP, 2004; Mangrove Action Project (MAP), 2005). This degraded condition as posited by Alongi (2002) and Giri et al. (2008) is caused by conversion to agriculture, aquaculture, tourism, urban development, and overexploitation.

These are a threat to the uniquely important ecosystem goods and services provided by mangrove forests including acting as natural barriers, carbon sequestration and biodiversity (Duke, Meynecke, Dittmann, Aaron, Ellison, Klaus Anger, Berger, Stefano, 2007).

As natural barriers, they help stabilize shorelines and for that matter bank lines of rivers and reduce the devastating impact of natural disasters such as floods. They also provide other ecological and economic as well as social needs and such ability according to Beck et al. (2001) stuns from three main factors including their complex physical structure, for example, prop and aerial roots (Lee, 2008; Nagelkerken, 2009). Mangroves, including their associated soils, could sequester approximately 22.8 million metric tons of carbon each year (Giri, et al. 2010).

Forms of Mangroves

Mangroves are dependent on seeds/seedlings for their maintenance according to Tomlinson (1986). However, some types of mangroves for example the A. germinans and L. racemosa are capable of resprouting from stumps, a process called coppicing. Through two unique strategies, mangroves reproduce (Rabinowitz, 1978; Tomlinson 1986); By means of hydrochory (dispersal by water) and vivipary (mangrove embryo germinates while still attached to the parent tree). The R. mangle, for example, may remain attached to the parent tree for 4 to 6 months and attain lengths of 25 to 35 cm at “maturity,” and fall to the ground or into the water where they are dispersed by the tides.

Lugo & Snedaker, (1974) described six mangrove forest types based on size, productivity, and composition. These include riverine (occurring along tidal creeks and extending severally inland), over-wash (lagoon marshes), fringe (low elevation or regularly flooded temperate marshes), basin (occurring behind fringe mangroves and in areas of little water flow so isolated from regular flooding), scrub, and hammock (hypersaline and poor nutrients sites). These forest types reflect differences in geomorphology and hydrology. Unlike other forests such as the rainforest, the strand structure in mangrove forests is relatively simple with a number of strata often reduced to one i.e. the main canopy even though carpet of seedlings may form a second layer (Feller & Sitnik, 1996).

The Erosional Resistance of Alluvial Channels Review

Numerous studies have demonstrated the significant influence of bank and riparian vegetation on the hydraulic geometry of alluvial rivers (McKenney, Jacobson & Wertheimer, 1995; Huang & Nanson, 1997; Millar & Quick, 1998). They appear to exert an important control on the lateral instability and planform channel patterns (Beeson & Doyle, 1995; Nanson & Knighton, 1996; Millar, 2000). According to Mackin (1956: pgs 1717-1718), the essential cause of the drastic difference in channel characteristics in adjoining segments is the difference in bank resistance due to presence or absence of bank vegetation. Bank resistance here refers to erosional resistance.

Bank resistance to erosion is acknowledged as an important factor controlling meandering and braiding (Mackin, 1956; Brotherton, 1979; Ferguson, 1987). The erosional resistance of alluvial river banks is determined by the type of bank sediment, together with the density and type of bank vegetation. Rivers with less resistant banks are typically wider and shallower than an equivalent river with more resistive banks. Bank vegetation can increase the stability of bank sediment by reducing the near-bank velocity and effective bank shear stress (Ikeda & Izumi, 1990); increasing the bank strength through binding of the sediment by root masses (Millar & Quick, 1993); and enhancing interstitial deposition of fine wash load sediment (Xu & Shi, 1997).

Field observations suggest that the magnitude of planform response to changes in bank vegetation varies greatly. That is, whiles some rivers are relatively insensitive, others may undergo complete planform metamorphosis (Mackin, 1956; Trimble, 1997).

The influence of bank vegetation has been described as scale-dependent. Studies of small streams less than 10m in width indicate that grass-covered banks are, in general, more stable and result in narrower channels. In contrast, Andrews (1984) and Hey and Thorne (1986) studied the influence of bank vegetation on larger rivers and concluded that rivers with forest-covered banks are, in general, narrower than those with grass-covered banks. Thus, in a study by Miller (2000), rivers with thin or sparse bank vegetation were expected to develop regardless of the condition of the bank vegetation. Rivers with densely vegetated banks comprising those with "thick" bank vegetation indicated relative insensitivity to changes in bank vegetation. Thus, destruction of riparian vegetation may result in widening of the channel (Millar & Quick, 1993) but would not be expected to precipitate major destabilization or planform metamorphosis.

In another study by Konsoer et al. (2016), two main ways were described in which the characteristics of river banks could influence erosion were highlighted: i) through material properties that affect resistance to erosion from fluvial action and mass failure, and ii) through form roughness that can affect the near-bank, three-dimensional flow structure and thus the shear stresses acting upon the channel boundary. Among the mechanical properties affecting the river bank included the grain-size distribution of the bank sediments which according to Parker, Simon & Thorne (2008) determined the necessary fluid shear stress required to entrain and transport sediment within a reach; the relative amount of fine sediments, particularly clay-sized particles which influenced the cohesion of bank materials and thus the resistance of these materials to erosion (Pizzuto, 2009); as well as riparian vegetation which could have an effect on the erosion-resistance properties of the banks by increasing tensile strength through root-reinforcement and by increasing cohesion through soil development (Van De Wiel & Darby, 2007; Pollen-Bankhead & Simon, 2009; Walker et al., 2010).

Theoretical Frameworks

General Systems Theory

The concept of "Systems" is not new (Von Betalanfy, 1950; Chorley, 1962.) Von Betalanfy (1950), defines a system as "a complex of interacting elements" whiles most geomorphologists define it similarly, as a (complex) whole that exhibits a specific structure of single elements and the relationships between these elements (Chorley & Kennedy, 1971; Bull, 1991; White, Mottershead & Harrison, 1998; Huggett, 2003; Werner & Mcnamara, 2007).

Physical phenomena occurring in nature are mostly and possibly viewed in two separate systematic frameworks; the closed system and the open system (Strahler, 1950; 1952). Von Bertalanffy (1951) distinguishes between closed and open systems on two main bases:

- They possess clearly defined closed boundaries, across which no import or export of materials or energy occurs
- With a given amount of initial free, or potential energy within the system, they develop toward states with maximum "entropy" which is an expression for the degree to which energy has become unable to perform work.

This view of systems immediately precludes a large number, perhaps all, of the systems with which natural scientists are concerned about, and certainly, most geographical systems are excluded on this basis.

Open systems on the contrary, according to Keiner and Spiegelman (1945) need energy supply for their maintenance and preservation and so are in effect maintained by a constant supply and removal of material and energy (Von Bertalanffy, 1952). Open systems are capable of behaving "equifinally" in the sense that different initial conditions can lead to similar end results (Von Bertalanffy, 1950, 1952). They also have the ability to attain a “steady state” wherein the import and export of energy and material are equated by means of an adjustment of the form or geometry of the system itself (Von Bertalanffy, 1950).

This form adjustment principle of open systems has long been recognized by Gilbert (1880) as very important in landform development as presented below:

“For in each basin, all lines of drainage unite in the mainline, and a disturbance upon any line is communicated through it to the main line and thence to every tributary. And as a member of the system may influence all the

others, so each member is influenced by every other. There is an interdependence throughout the system" (Gilbert, 1880).

This character of steady state or dynamic equilibrium was as well presented in a geomorphic statement by Mackin (1948):

"A graded stream is one in which, over a period of years, the slope is delicately adjusted to provide, with available discharge and with prevailing channel characteristics, just the velocity required for the transportation of the load supplied from the drainage basin. The graded stream is a system in equilibrium; its diagnostic characteristic is that any change in any of the controlling factors will cause a displacement of the equilibrium in a direction that will tend to absorb the effect of the change".

From the above, the controlling factors of the drainage basin can be categorized into those controlled by the river itself including; channel slope which can be adjusted by erosion and deposition; and its transverse channel characteristics including channel depth and width. A stream system nevertheless cannot greatly control its discharge, which represents the energy and mass externally supplied into the open system. Neither can it completely control the amount and character of the debris supplied to it, except by its action of abrasion and sorting or as the result of the rapport which seems to exist regionally between stream-channel slope and valley-side slope as presented by Strahler (1950).

Geomorphic Systems Theory

In analyzing environmental systems, White, Mottershead, and Harrison (1992) make use of the systems approach and make very central matter, force and energy. Geomorphology as such has been put into a similar framework.

Howard (1965), thus indicates that the most general model for natural phenomena is the system and geomorphic systems have been described as open systems inasmuch as they exchange both mass and energy with their surroundings (Chorley, 1962). Therefore, in an attempt to rationalize Geomorphology as a discipline to give it some coherence in terms of the systems theory, Chorley and Kennedy (1971) recognize three main types of geomorphic systems namely:

- Morphological systems which comprise a system with formal instantaneous properties integrated into recognizable operational parts of physical reality, with the strength and direction of connectivity revealed by correlation analysis. In Hugget (2007), morphological systems interrelate in a meaningful way in terms of system origin or system function;
- Cascading systems are made up of subsystems in a succession dynamically linked by the flow of mass or energy so that one subsystem's output becomes the input of another subsystem. They are also described as interconnected pathways of transport of energy or matter or both, together with such storages of energy and matter as may be required' (Strahler, 1980);
- Process-response systems emphasize the processes and resulting forms when the morphological and cascading systems traverse. They are described in Hugget (2007) as energy-flow systems linked to a form system so that system processes have the ability to alter the system's form and, in turn, the changed system form alters the system's process.

A Geomorphic system's state can, therefore, be characterized by such descriptions; its composition and organization as well as the flow of energy and mass. However, these characteristics are measured by some variables or parameters some of which are internal and external to the system (Howard, 1965). They are mostly described as passive and determinate as they mostly gain and lose their mass and energy to the external sources and so most non-random changes in time and space are attributable to external factors (Geiger, 1959); they also mostly respond as an organic whole as a change in an external variable usually cause re-adjustment of all system parameters (Hall & Fagen, 1956).

Concept of Equilibrium in Geomorphic Systems

The concept of equilibrium in geomorphic systems relates to the adjustment of the internal variables of a system to its external conditions and these are measured by two main approaches:

a. Constant external conditions in time and space imply constant internal conditions of the system; and

b. Changes in the value of an external variable through time and space imply changes in the correlational value between the external variable and the systems properties such that, a low variance in correlation implies low sensitivity and the reverse is true. Any of such combination can result in a unique equilibrium state as given by Chorley and Kennedy (1971);

- Static equilibrium occurs when a system is in a balance over a time period and no change in state occurs;

- Stable equilibrium records a tendency to revert to a previous state after a small disturbance;
- Unstable equilibrium occurs when a small disturbance forces a system towards a new equilibrium state where stabilization occurs;
- Metastable equilibrium arises when a system crosses an internal or external system threshold thereby driving it to a new state;
- Steady-state equilibrium obtains when a system constantly fluctuates about a mean equilibrium state;
- Thermodynamic equilibrium is the tendency of some systems towards a state of maximum entropy, as in the gradual dissipation of heat by the Universe and its possible eventual ‘heat death’ and in the reduction of a mountain mass to a peneplain during a prolonged period of no uplift;
- Dynamic equilibrium may be thought of as balanced fluctuations about a mean state that changes in a definite direction (a trending mean).
- Dynamic metastable equilibrium combines dynamic and metastable tendencies, with balanced fluctuations about a trending mean flipping to new trending mean values when thresholds are crossed.

A second concept fundamental to the concept of equilibrium is the Resistance to change or inertia which Howard (1965) describes as the rate of change of an external variable compared to the capacity of a system’s adjustment. This concept determines the behavior of the system and common external variables may include stratigraphy (which serves as the source of mass for the system); lithology and structure (which defines the slope, drainage densities and the drainage configuration of the system depending on its homogeneity or heterogeneity); climate (of less intensity but great regularity) and topography.

The concept of equilibrium is further complicated by Secondary Responses or Feedback to changes in external variables. That is, the rate and path of adjustment may lead to a secondary or tertiary effect dominating the system as a result of the sensitive relationship of the system's components. Such secondary or tertiary effect emanates from the adjustment of the grossest structural features of the system according to Bradley and Calvin (1956).

Some system response to changes may also involve the Threshold or Discontinuity principle which separates two different system economies or states (Howard, 1965). Differently put by Hugget (2007), it marks some kind of transition in the behavior, operation, or state of a system. Schumm (1979) made a distinction between external and internal system thresholds. Whiles a change in an external variable forces a geomorphic system to cross an external threshold, only a fluctuation in an internal variable of a geomorphic system may lead a system across an internal threshold and its reorganization. Thus, no change in an external variable is required for a geomorphic system to cross an internal threshold.

The Principle of Time is the last complexity exerted on geomorphic systems. This according to Howard (1965), relates the relative intensity of the action of an external variable to the length of time upon which it acts. Wolman and Miller (1960) termed this as the concept of Frequency and Magnitude, i.e. variation in process rates through time. According to Hugget (2007), bigger floods, stronger winds, and higher waves occur less often than their lesser intensity counterparts. And so, relationships between the frequency and magnitude of such geomorphic process usually portrayed on graphs are rightly skewed, with a lot of low-magnitude events occurring than the number of high magnitude events. The frequency of events of a specific magnitude is expressed as the return period or recurrence interval.

Chorley (1962) however argues that the influence of past external variables decreases with time at a rate that is a function of the ability of the system to adjust to those changes. Therefore, the remoter the past, the lesser the inference which can be drawn. This is the Principle of Equifinality which states that,

"*the present state of a system may have been reached through any of an infinity of previous states with a wider range of past states being theoretically possible as the time considered is more remote*" (Von Bertalanfy,1956).

Critique on the Systems Approach to Geomorphological studies

From the geomorphological point of view, the complexity exhibited by interacting elements whose behavior are independently different from each other defines a system (Hugget, 2003; Werner & McNamara, 2007). Again, from this same point of view have geomorphic systems been defined or characterized as open systems based on the inflow and outflow of mass and energy which are mostly externally supplied to the system but however exerts great influence on the structure and behavior of the system (Bertalanfy, 1950). Thus, a system is always striving to adjust its internal structure to its external influences to attain equilibrium. It is this equilibrium which seems to be challenged by the openness of the geomorphic system because of the constant in and outflow of mass and energy. Hence, as stated by Von Elverfeldt (2012), equilibrium and for that matter stability cannot be attained and it is all going to be a matter of landform constantly evolving. Nonetheless, since geomorphologist mostly make use of the concept of scale, graded and steady time, most of these equilibria notions are as well framed in relation to these concepts whiles these concepts contrast non-linearity and other emergent concepts of systems (Keller & Ting, 1966).

In another explanation, a system is a "complex whole" or has unity irrespective of the complex independence of the various elements as in the end, a change somewhere affects a portion or the entire system. A vital issue rarely discussed in the use of such theory is how the system has been delineated and for that matter disintegrated from its surroundings. Even though, Honig (1999), emphasized on adequately delineating a system to distinguish it properly from its surroundings, the criteria for such adequate delineation and distinction is still unclear. Von Elverfeldt and Glade (2011), advocate for the system to be known or analyzed in advance for the interactions to be known so that delineation can be done properly. However most often in geomorphological studies, such is not the case. Rather, a system is defined based on the identical physical properties and on such basis, it is distinguished from its surroundings. Such a process of delineation with no coherent guiding principles has been described as being subjective based on the researcher's focus, interest or expertise (Baker & Pyne, 1978).

One central concept in the geomorphic systems theory is the concept of equilibrium which is attained when the input of mass and energy is balanced by the self-adjustment property of a system. However, aside these two namely: mass and energy, the threshold concept also associated with the geomorphic systems brings to bear about the fact that there is also some inner disposition of the system which permits the system to react to such adjustments. These are the intrinsic thresholds as described in Schumm (1979).

Chaos Theory

Chaos is usually explained as a mathematical property of dynamical systems. These dynamical systems are commonly defined as deterministic systems exhibiting some unique evolution in which a given state is always followed by the same history of state transitions. Kellert (1993) therefore defines chaos theory as “the qualitative study of unstable aperiodic behavior in deterministic nonlinear dynamical systems”. The definition, however, limits chaos to be a property of mathematical models and so the import for actual physical systems becomes subtile.

But in Morrison (1988), linear systems do not exist in nature. Non-linearity, though does not have an all-inclusive definition, has been explained as a system whose output is not directly proportional to its input, or one in which a change in one variable does not produce a proportionate change/reaction in the related variables (William, 1997). Thus, non-linear systems may differ from linear systems in three main ways according to Campbell (1989):

- In terms of behavior over time i.e. maybe regular at first but often change to erratic looking;
- In terms of response to small changes which may often be greater than the stimulus; and,
- In terms of their persistence to local pulses which may be highly coherent for long times, or even perhaps forever.

Such complex nonlinear dynamic systems are ubiquitous in the landscapes and phenomena studied in the earth sciences in general and in geomorphology in particular. Fluvial systems as natural systems are thus considered as such. As dynamic systems, the fluvial systems are dissipative, move, change or evolve over time (William, 1997). They, therefore, have force, energy, motion or friction and so lose energy over time thereby always approaching some asymptotic or limiting condition or change, unlike the conservative dynamic systems which have no friction. That asymptotic or limiting state, under certain conditions, is where chaos occurs.

Since fluvial systems exhibit characteristics of nonlinearity, complexity, and dynamism, they have come to be associated with various aspects of nonlinear behavior such as chaos. Even though not all non-linear systems are complex, the nonlinearity of the fluvial system opens possibilities for its complex behavior.

According to Berge (1984), the main causes of chaotic behavior are not fully known or very clear, but three possible causes have been proposed:

- An increase in a control factor to a value high enough that chaotic, disorderly behavior sets in. Berryman and Millstein (1989), for example, believe that human interventions or influences in natural landscapes may cause them to become chaotic even though they do not normally do.
- Also, the nonlinear interaction of two or more separate physical operations is proposed as being a possible cause of the chaotic behavior.

- And lastly, the effect of an ever-present environmental noise on otherwise regular motion (Wolf 1983).

The chaos theory, therefore, has three basic principles mainly

- simple dynamic systems in which the nature of changes can be specified with well-defined equations are seldom predictable;
- some systems display sensitivity to initial conditions, i.e. small differences in their state at one time produce great differences in a subsequent state;
- thirdly, the seeming randomness that results from the two may be quite ordered and their patterns may reveal physical truths.

Analyzing Chaotic Systems

In analyzing chaotic systems, there are two main descriptors namely the phase space dimension and the strange attractors. According to Williams (1997), the "phase space" or "state space" is an abstract mathematical space in which coordinates represent the variables needed to specify the phase (or state) of a dynamical system i.e. the instantaneous states that the system can have. Since in the real life a graphical representation can have at most three coordinates, chaotic systems are viewed in terms of the variables (which may be more than three) and so not in graphical terms but in mathematical terms. Chaos theory, therefore, deals with two main types of phases, after William; the standard phase space and the pseudo phase space.

The standard phase space represents an abstract space in which coordinates represent the variables needed to specify the state of a dynamical system at a particular time. Thus the plotted point neatly and compactly defines the system's condition for some measuring occasion. In such a case, a line can be connected through the plotted points in their chronological order to show the temporal evolution more clearly on the graph i.e. the sequence of measured values or list of successive iterates which describes a time path or trajectory.

A pseudo phase space plot can be represented with a map or a lag space plot. A map according to William (1997) is a function whose output is dependent on one or more input or independent variables. Thus, a map or function is an equation or rule with specifications on how a dynamical system evolves forward in time by turning one number into another and specifying how x, via a discrete step, goes to a new x. In the lag space plot, the axis of coordinates represent successive values of the same physical feature and it mostly uses a constant time interval (a "lag") between successive measurements, thus its name a lag space plot.

In the concepts of standard phase space and pseudo phase space, the application applies to any number of coordinates or dimensions, not just to three or fewer. The number of dimensions in any one pseudo phase space analysis is called the embedding dimension. Embedding a time series is a basic step in most types of chaos analysis.

An attractor is a dynamical system's set of stable conditions or the system’s behavior over the long term. A chaotic attractor is, therefore, a complex phase space surface to which the trajectory is asymptotic in time and on which it wanders chaotically or an attractor that shows extreme sensitivity to initial conditions (Grebogi et al., 1982; Eckmann & Ruelle, 1985; Holden & Muhammad, 1986).

Conceptual Framework

Human Impact Model

The Human Impact Model is a concept put forward by Loczy (2008) and it reflects the attitude that human interventions come 'from outside' into the geomorphological systems, much like external disturbances. In this model, the geomorphic evolution is influenced in three main ways by the human society;

a) Directly, producing landforms through activities such as excavations, constructions or hydrological interventions;
b) by affecting some geomorphic processes such as accelerating soil erosion;
c) thirdly indirectly, by influencing the biophysical conditions which control geomorphic processes (e.g. climate change induced by human activities).

In this model, the human influence or intervention is considered external to the biophysical environment. This has raised the questions based on the principles of phenomenological philosophy formulated by Abram (1996) because according to Urban (2002), the co-evolvement of humans with the biophysical environment is not new, and so there is the need to integrate them with any geomorphological agent.

The main strength of this model lies in the fact that it recognizes that human activity can influence all the aspects of the physical environment; from the traditionally inherited form to the processes and characteristics.

However, this model assumes that the influence exerted by humans are external to the system thereby implying, the vulnerability of natural systems to human interventions. As such interventions have brought about a catalog of environmental disruption such as either making systems "erodible or erosive" or "leading to accumulations or removal".

But the relationship between people and the natural environment has been recognized to be much more complex. In fact, McNeely (1994) suggests that the impact of humans is not simply a process of increasing change and destruction in response to population growth and economic expansion.

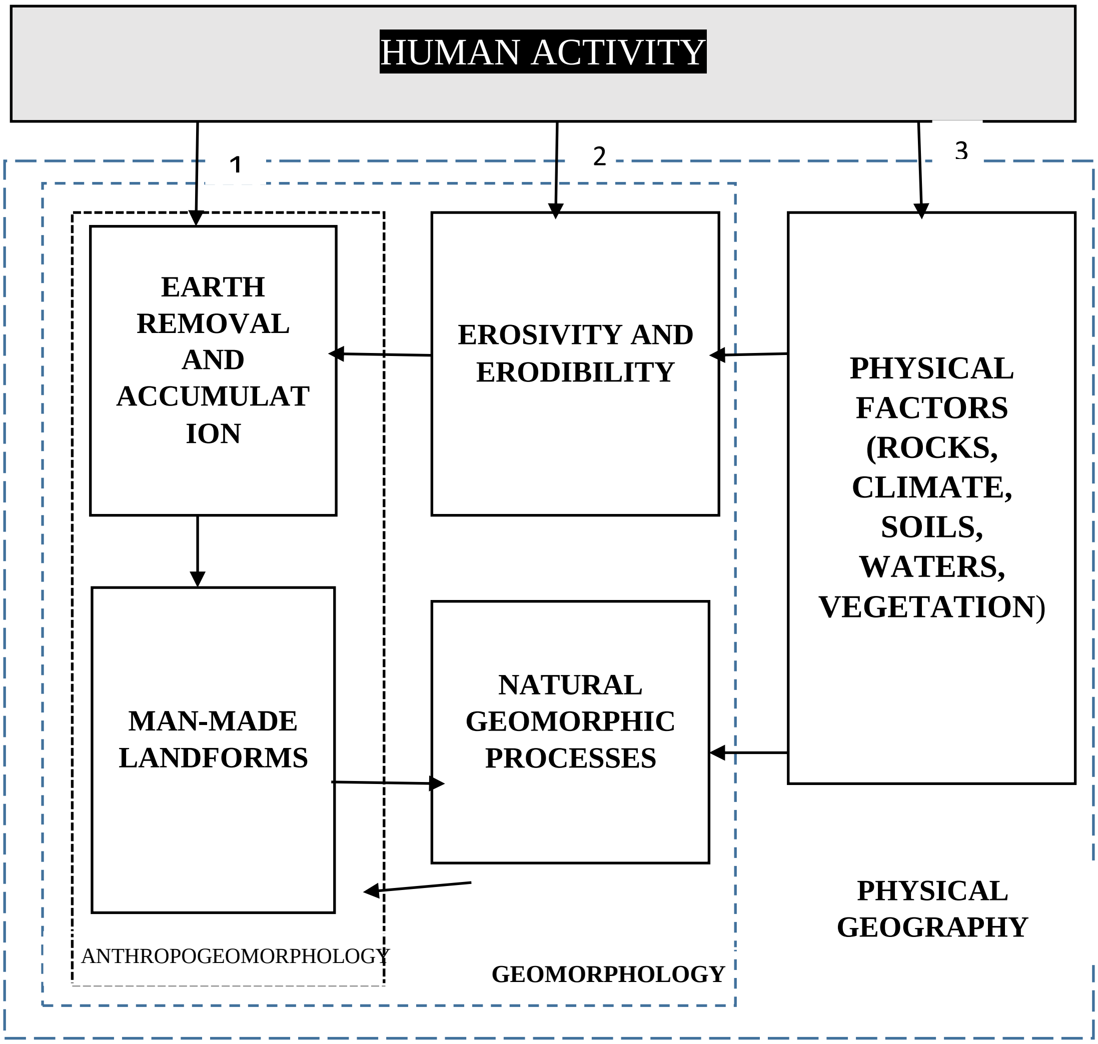


Figure 7: The 'Human Impact' model

Source: Loczy (2008)

According to Gober (2000), geography as a major science has been compartmentalized into various sub-disciplines with little synthesis across these boundaries. However, as a discipline it has had that theoretical uniqueness, distinctiveness, and coherence through the emphasis it places on transcending the traditional boundaries existing between the natural sciences, social sciences and the humanities, that is integrating the physical and human aspects in reality (National Research Council, [NRC], 1997). Research pathways now are focusing on the linkages between the biotic, social and environmental dynamics according to Gober and this is the Comprehensive and Integrated Approach (NRC, 1997a).

Such approach integrates the sociocultural and biophysical process into a single framework whereby the social and economic aspects of human interaction with the environment are highlighted (Kolb, 1998). The visible as stated by Merleau-Ponty (1968) is pregnant with the invisible which at the human - environment interface comprehends those cultural and biophysical processes creating and altering the visible landscape. Thus, to comprehend fully the visible relations, one must go into the relation of the visible with the invisible.

Underlying the conceptual framework by Urban (2002) is an analysis of the philosophical and theoretical foundations behind the separation of humans and society from the biophysical geomorphic system and the reconstruction of the system to include humans and human agency. The model draws on a critical realist perspective grounded in phenomenology to define biophysical landscape as the “articulated moment” resulting from a system of anthropic, physical, and chemical impulses interacting with the material reality of the environment and each other (Schein, 1997). The model is thus primarily based on the following assumptions:

i. humans can operate as both internal and external components of local geomorphological systems;
ii. human behavior is an effective agent of biophysical change;
iii. human behavior is influenced by the biophysical environment through the act of perception, personal experience, and the generation of local and scientific knowledge;
iv. Linking human agency to biophysical processes is as much an exercise in theoretical geomorphology as it is in applied geomorphology.

The Biophysical landscape in the center is described as a non-static form or a transitory artifact of past processes portraying the existing conditions at that given time and also interrelating the various dynamic processes that are constantly adjusting the observed form. Thus, according to Venn (1971), there is an overlap between the purely biophysical environment and culture or society and this results in the creation of an area which contains the physical structure of the environment. The physical environment, therefore, becomes more or less like the cultural landscape since it is a reflection of the behavior or deeds deemed to be ethically right by the local community (Greider & Garkovich, 1994; Rhoads, David, Micheal & Edwin, 1999). Depending on the local socio-cultural dynamics in operation within the local community, there will be varied forms and extents of human interactions from place to place.

The external cultural inputs comprising perception, valuation, and meaning assignation to the left of the model reflects processes emanating from a society which may ultimately influence the physical state of the landscape (Aitkin, 1992). The effects of the human agency on the environment are thus those related to or fixed on the direct modification of the environment so as to make simple the relationship between behavior, environment and cybernetic feedback.

The external biophysical inputs to the right, on the other hand, are the traditional physical, biological and chemical forces whose effect generate changes or lead to morphologic stability as put by Gregory (1985). These plus the human behavior joined together turns the biophysical system into a control system.

As a control system, it utilizes cybernetic feedback in order to maintain or adjust the human behavior towards the environment. Feedback mechanisms may either undermine or dampen the stability of the system depending on the nature, extent, and magnitude of the impact as well as the sensitivity of the environment (Downs & Gregory, 1993).

As such, knowledge of the physical environment depends on what is perceived and experienced and then what is informed by the scientific knowledge. This local and scientific knowledge according to Urban (2002) can affect the physical landscape only when they are contextualized and interpreted by a complex of past perceptions, experiences, and valuations. And through both positive or negative feedback loops, the traditional characteristics of the biophysical environment will feed into the biophysical output through the kind of fluvial sediment and water.

Strengths of the Human Agency Model

The inclusion of the external cultural inputs as well as the socio-cultural context in this model is very vital to understanding the dynamics of river morphology. This is because cultural landscapes are intended to increase awareness that heritage places (sites) are not isolated islands and that there is an interdependence among people, social structures, and the landscape as well as associated ecological systems (Lennon & Taylor, 2011). This gives an indication and highlights the fact that deep cultural associations of traditional communities with the natural environment has implications for inscriptions on natural systems.

Again, culture is expanded to involve the appreciation of the inter-relationships through time among people, events, and places as well as the associated intangible (spiritual values) and tangible values. Recognition of such a relationship has implications for management.

In Livingstone (1992), there is the mention of Historical Particularism as a banner or mode of conceptualizing the environment. This model embraces the idea that different cultures adjust differently to similar environments and so the need to understand the cultural traits of societies – their behavior, beliefs, and symbols – and examining them in their local context.

Thus, such acknowledgment gives a reflection of specific techniques of sustainable land-use in relation to the characteristics and limits of the natural environment they are established in, and a specific spiritual relation to nature (UNESCO, 2017). In Lennon and Taylor (2011) such an approach does not only give the intellectual basis for history but also one with a temporal and spatial perspective.

The isolation of culture and nature in studies of natural systems and scientific studies is dubbed as the ideal situation for studies in the wilderness. Brown, Mitchell, & Beresford (2005) stress that landscapes shaped by the interaction of people and nature are universal and conserve nature. World Heritage identifies three main categories of the cultural landscape:

a) landscapes designed and created intentionally by man;

b) organically evolved landscape which is a category which sub-divides into two: (i. a relict or fossil landscape; and ii. a continuing landscape), and

c) associative cultural landscape.

The 2001 UNESCO Universal Declaration on Cultural Diversity, therefore, acknowledges that there is a fundamental role of protecting the human rights of the indigenous people or communities and this includes respecting the traditional knowledge and its contribution to environmental protection and management of natural resources as well as the synergy possible between modern science and local knowledge.

The main weakness of this model has to do with the less emphasis on the direct ways in which man can affect the landscape as well. Even though it is much recognized that this issue of direct influence on the landscape can be indirectly experienced from culture, there are other intentional or unintentional forces exerted as well which has direct and gross implications on the river morphology.

Conceptual Framework for the Kakum River Basin

Figure 9 is a conceptual framework adapted and modified after Loczy (2008) and Urban (2002). In this framework, River morphology which is the natural form of the river's landscape is controlled by human activity (behavior) as well as the geomorphic context of the river itself. The geomorphic context is the inherited context or characteristics of the river including its geology, climate, soils, vegetation, and tectonics while the human activity or behavior is made up of direct interventions in the river landscape as well as the socio-culture context (norms, values) of the human communities in the landscape and how these impacts the river morphology indirectly. The sociocultural context is influenced by their perceptual, experiential or scientific knowledge.

These forms of knowledge determine the kind of relationship the communities will have with the river's form or function. Commonly, direct activities by humans will either aggrade or degrade the river's morphology or make the river's materials erodible or the river itself erosive.

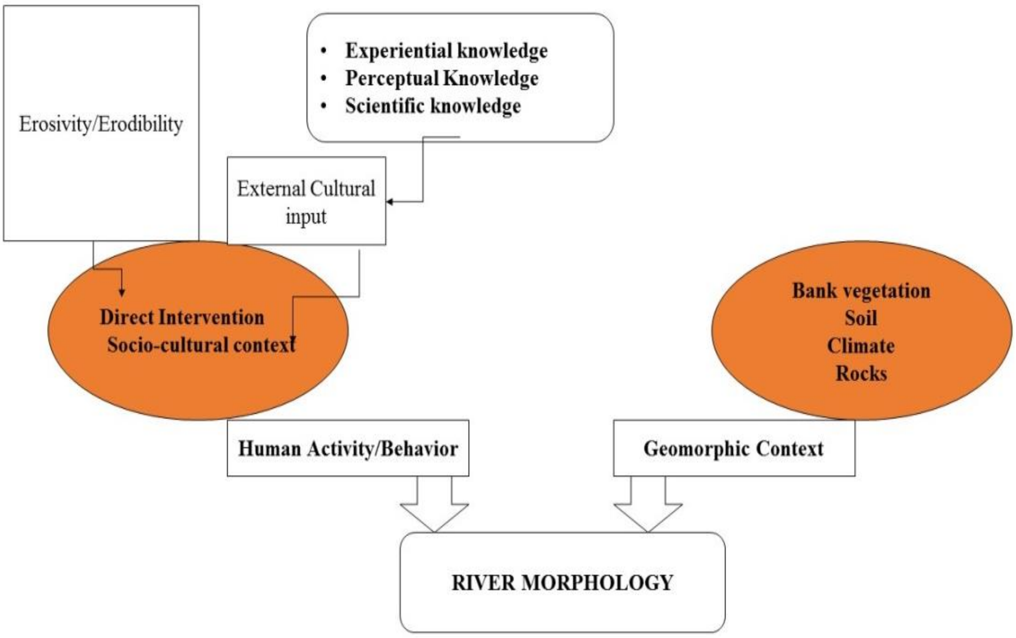


Figure 9: Conceptual framework adapted and modified after Loczy (2008) and Urban (2002).

Source: Loczy (2008) and Urban (2002)

Comprehension of this model has the combined advantage of strengthening the weaknesses of the first two models by the inclusion of culture as well as the direct ways in which the other factors can affect the river morphology.

CHAPTER FOUR

MATERIALS AND METHODS

Introduction

This chapter is devoted to the materials and methods used in data collection, processing, and analysis. It begins with the research design and research philosophy which gives the blueprint of the study. The research philosophy, as well as the data types and sources for the work, are also given in this chapter. Other areas covered in this chapter include the reconnaissance survey and the selection of sampling stations as well as a description of how the sediments were sampled. The various analysis that have been done of the data and sediments have also been discussed including the geomorphic analysis, Chemical analysis, and Land Use Analysis.

Research Design

The study employed the case study design as the study demands intensive or detailed observation and measurement to achieve its study objectives. According to Yatsu (1992), intensive research may involve a detailed study of a single, or a small number, of cases with the main objective of providing an explanation of the mechanisms generating the observed patterns in an extensive investigation. Yin (1984) also defines the case study research method as an empirical inquiry that investigates a contemporary phenomenon within its real-life context; when the boundaries between phenomenon and context are not clearly evident; and in which multiple sources of evidence are used. Even though the case study design has often been described as a qualitative research method, most statements about methodology are no more than models themselves - that is, mental constructs that attempt to represent a degree of understanding of the process whereby knowledge is acquired, and judged as being adequate for some purpose (Richards, 1996). It is, therefore, important to acknowledge the range of circumstances and conditions within which a particular methodology is both developed and applied.

The case study design provides a detailed examination of an event or series of related events which exhibit the operation of some identified general theoretical principle (Mitchell 1983; Ragin & Becker 1992). Critics of the case study method believe that the study of a small number of cases can offer no grounds for establishing reliability or generality of findings. Of course, representativeness or empirical extrapolation using statistical inferences are not possible, however, generalization depends on the cogency of the theoretical reasoning (Mitchell 1983). However, this theoretical reasoning identifies intellectual structures that seek to represent natural mechanisms, and the degree of generality of these structures may vary. Thus, it is not the empirical evidence of form or product that is extrapolated, but the theoretical understanding of processes that allows explanation of the behavior of the systems of which the case study is representative. This problem illustrates the importance of dealing with nonlinearity on a case-by-case basis.

Research Philosophy

Geomorphology as a discipline has received a lot of controversies with regard to being scientific or historical (Watson, 1969; Baker & Twidale, 1991). However, contemporary Geomorphologists confidently describe the discipline as a physical science whose roots are firmly embedded in the philosophical foundations of physics, chemistry, and geology. With such an idea as being empiricists, many researchers in this field ground their works in the philosophy of logical positivism or critical rationalism (Harvey, 1969; Haines-Young, & Petch, 1986)). With logical positivism, scientific knowledge is one grounded in direct veridical phenomenal experience and verifiability theory of meaning, according to which the meaning of a scientific statement is determined by a test condition under which it can be verified or disconfirmed (Rhoads & Thorn, 1994). Thus, development of theories was an inductive upward growth process from observational facts and so knowledge was accessible, independent of theory.

This study, however, is grounded in the philosophy of Critical Realism espoused by Charles Piece and Karl Popper. Critical Realism which is regarded as the scientific realism has the ontological and epistemological components and adopts that the main aim of science is to seek truth and not merely solve problems as in the view of social constructivist and post logical empiricists (Rhoads & Thorn, 1994). According to Boyd (1983) and Niiniluoto (1984), critical realism has four main assumptions;

- Terms in scientific theories that describe the unobservable entities or causal mechanisms should be interpreted realistically; these terms refer to phenomena that genuinely exist.
- Reality exists independent of human thought and the description of such reality embodied in scientific theories is largely independent of theoretical commitments.
- The method of science provides a means for determining the approximate truth of all aspects of scientific theories including a statement about unobservable.

- The historical progress of science consists of successive theories that become more truth-like over time, with later theories building on the knowledge embedded in previous ones.

Theories are therefore very essential to critical Realists because to them, the great empirical success achieved by science simply implies that the theories on which they are based on are at least approximately true, otherwise such success must be viewed as miracles (Rhoads & Thorn, 1994).

Even though the notion of radical conceptual shifts by the social constructivist was a great threat to the image of scientific progress in realism, a causal or referential theory of meaning was adopted to surmount this issue. In this, the meaning of a theoretical term that describes an unobservable entity is determined by an introducing event which pushes scientists in the appropriate causal relationship with the entity and not by the proportion of entity which depends on the theory (Putnam, 1973) in (Rhoads & Thorn, 1994).

The philosophy of realism implies a structuring of the world in which observable events are contingent on appropriate circumstances for mechanisms to act. Methodologically, this means that interpretation of the nature of mechanisms from observation of events demands an understanding of the role played by local conditions in time and space. Thus, in using the realist philosophical approach one's centrality focuses on the view that real explanation needs to penetrate behind the external appearances of phenomena to identify basic causal mechanisms.

Spatio-temporal domains of specific processes are usually addressed by using realism and relies heavily on the collection of high-quality data to assist in the understanding of fluvial processes. Richards (1990) has therefore proposed that geomorphologists should consider adopting a realist approach following recent methodological developments in geomorphology and the associated shift from extensive to intensive research design.

Data Types and Sources

Data used for this study is derived from both the primary and secondary sources. The primarily sourced ones comprise those derived from direct fieldwork activities (field measurement, field observation, field data collection) and laboratory analysis. The field measurement involved measuring some hydraulic parameters mainly the depth and width of some river cross sections. Field observations were undertaken to attain a level of generality by locating major characteristics/elements within the basin including vegetation, geologic formation, sediment as well as distinct subunits in the channel. Again, field observation assisted in cross-checking results of some analysis. Laboratory analysis was carried out for the soil nutrients, particle size distribution, heavy metals at the Soil Science laboratory of the University of Cape Coast, School of Agricultural science.

In addition, Geographic Information Systems and remote sensing tools were used to analyze topographic data which is precisely the Aster Gdem. The most widely used data structure used to store and analyze information on topography in the GIS environment is the Digital Elevation Model, (DEM). In this work, the Aster Global Digital Elevation model (GDem) with a 30m resolution was used since it has an overall accuracy of 17-m at 95% confidence level as compared to the Shuttle Radar Topographic Mission (SRTM) which has a resolution of 90m. Again, the Aster Gdem is known to be comparatively able to help in the performance of more advanced analysis as far as hydrological studies are concerned. It will thus be downloaded from the United States Geological Survey (USGS).

Land use was analyzed from two free Landsat images of the years 1991 and 2016 and they were downloaded from the United States Geological Survey (USGS). Other additional secondary datasets to compliment the use of the above-mentioned were the soft copies of topo-sheet as well as ortho-photos which were obtained from the GIS, RS Cartographic Unit of the Department of Geography and Regional Planning. Geological Map of Ghana was also acquired from the Geological Survey Department, Ghana. Below is a summary of the type, source, and analysis carried out per each of the objectives set out by the work.

Terrain Preprocessing and Generation of Basins

The Aster DEM served as the main input data into the ArcGIS version 10.3 to delineate the basins. Before any other method could be employed a clear definition of the basins was necessary and so it was the very first method employed before any other form of analysis was carried out. The approach involved filling of sinks to remove small imperfections in the data. This function fills the sinks in a grid. If a cell is surrounded by higher elevation cells, the water is trapped in that cell and cannot flow. The Fill Sinks function modifies the elevation value to eliminate these problems. Flow direction was also created to direct flow to the steepest downslope neighbour of the raster cells. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell. Flow accumulation was then calculated from the flow direction grid. The flow accumulation grid records the number of cells that drain into an individual cell in the grid. From the physical point of view, the flow accumulation grid is the drainage area measured in units of grid cells. The flow accumulation and basins were generated thence from the flow direction. The result was a set of rasterized basins which were converted to shapefiles.

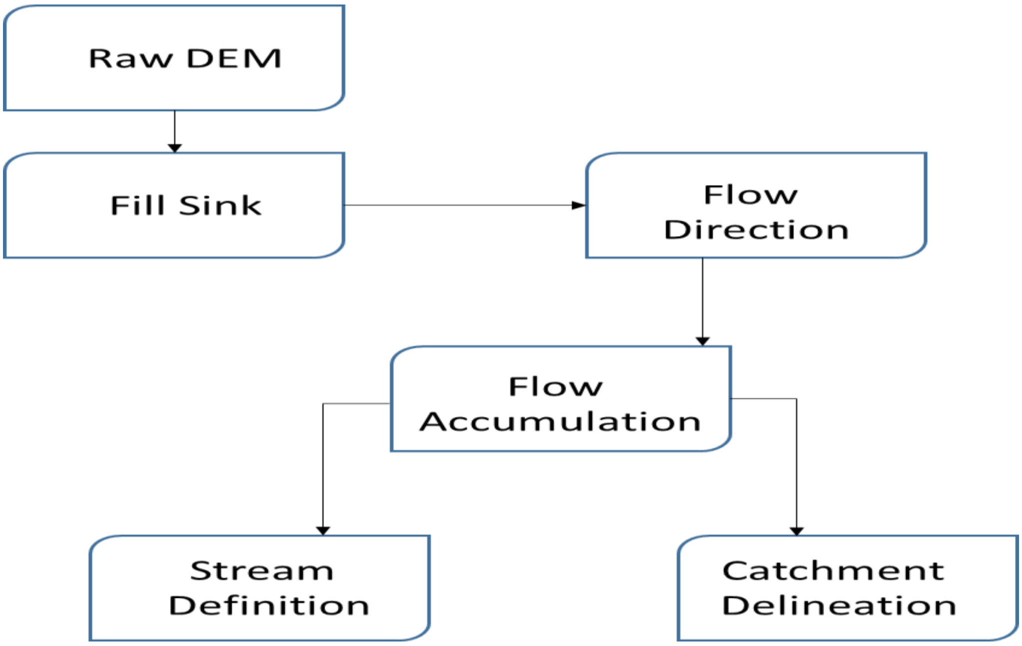


Figure 10: Flowchart of terrain preprocessing and generation of basins.

Source: Author’s Construct, 2017

Site Selection

In order to explain the dynamics of the river which is very unique to the different sections of river, the Kakum river basin was divided into three main sections; the upper, middle and lower section so that the dynamics of the channel and its morphology were assessed as one moves downstream from one section to the other. Due to the different characteristics in terms of hydraulics, bed composition, organic debris, shear stress and other related influences, these three broad sections were further divided into much smaller scales which is the channel unit. According to Gregory (1977) and Thorne

(1990), such small-scale studies are able to generate different styles of adjustments and channel typologies to variable impacts. Again according to Lane and Richard (1996), researches in fluvial geomorphology recently is witnessing a shift towards a full explanation which involves how river channels change through time and space as they are subjected to temporal fluctuations in governing process variables including discharge and sediment supply from upstream.

Reconnaissance Survey and Sampling Stations Selection

In order to familiarize with the nature of the basin, a series of reconnaissance surveys were done over almost the entire course of the river on which this study covers. Three different trips were organized on different days to the various sections of the river. On 22nd November 2016, the first inspection was done at the Brimsu dam and the lower sections of the river towards the confluence and estuary of the Kakum. On the 23rd and the 25th April 2017, a reconnaissance survey was extended to the middle and upper sections of the river and communities visited included Sorodoful, in the middle as well as Nkwantanan and Yebi, in the Upper sections. During such visits, community leaders and stakeholders were called upon so that the necessary introductions were made and permissions sought before actual field work begun.

Based on these familiarization trips as well as the DEM, the entire river was divided into seventeen (17) channel units; seven (7) in the upper section, five (5) in the middle section and five (5) at the lower section. Below is a DEM on how the various sectional divisions were arrived at.

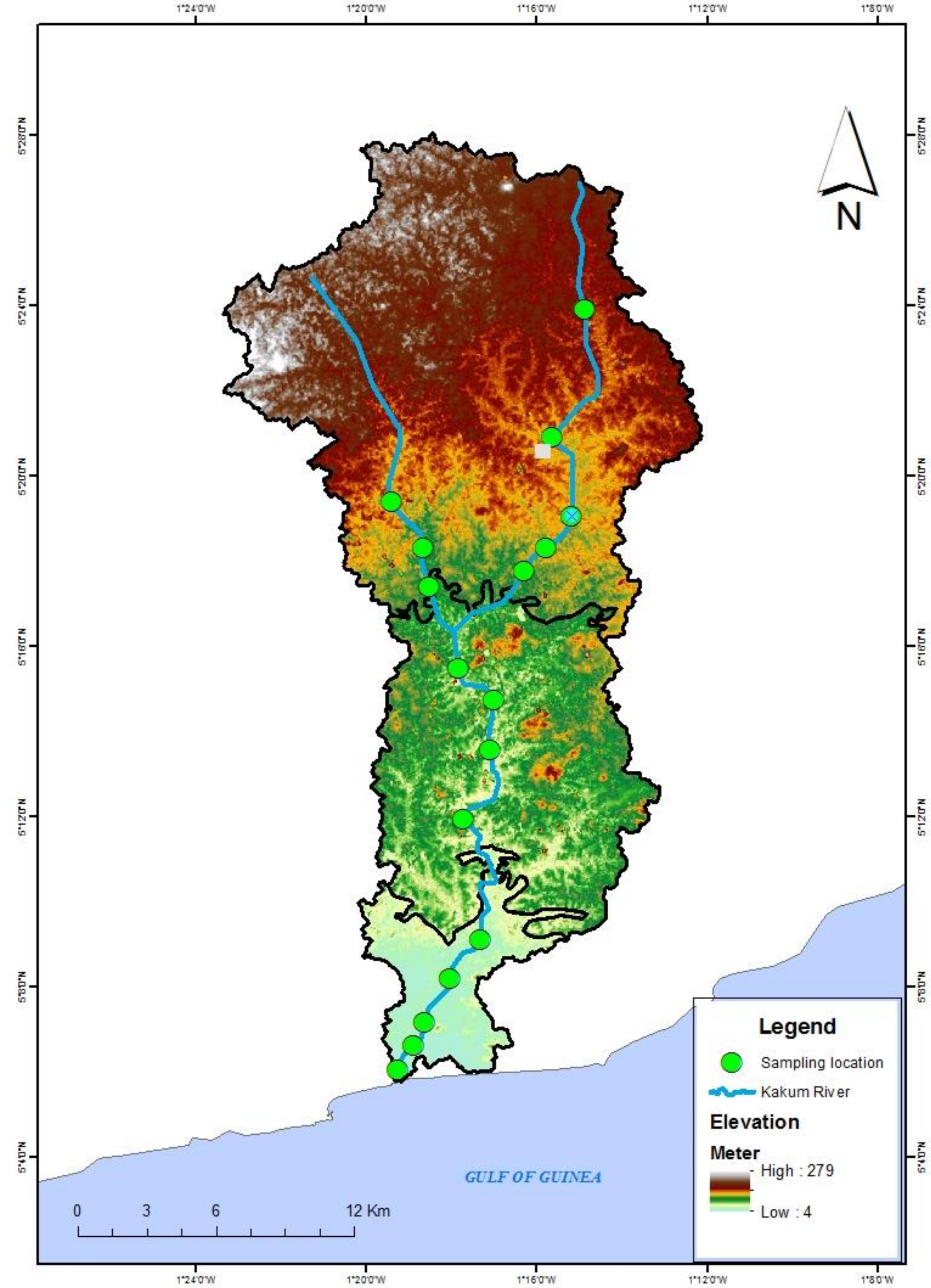


Figure 11: Digital Elevation Model (DEM) of river sections

Source: DGRP GIS Unit, 2017.

These locations were thus purposively sampled based on their characteristics which distinguished them as channel units distinct from each other but related to one another. Below is a table of the sample locations;

Table 3: Location of Sampling Stations

Section	Towns	Location	
Upper		*Latitudes*	*Longitudes*
	1. Asuansi	5°17’29.772”N,	1°15’59.212”W
	2. Nsain	5°17’40.446”N,	1°16’59.350”W
	3. Kokoado	55°17’29.364”N,	1°15’59.860”W
	4. Obosando	05°17.216’N	01°16.312’W
	5. Yebi	05°17.177’N	01°16.408’W
	6. Bun Kofi	05°17.177’N	01°16.568’W
	7. Kokod3	05°16.952’N	01°16.653’W
Middle Section			
	1. Aboenu	5°13’32.756”N,	1°16’55.274”W
	2. Kawanotum	5°17’40.446”N,	1°16’01.350”W
	3. Sorodoful	5°12’31.596”N,	1°17’04.926”W
	4. Apewosika	5°12’31.240”N,	1°17’02.100”W
	5. Abaasa	5°12’37.650”N	1°17’49.656”W
Lower Section			
	1. Brimsu	5°09’12.804”N,	1°17’11.698”W
	2. Esuekyir	5°08’52.140”N	1°17’20.826”W
	3. Kwaprow	5°07’35.790”N	1°18’09.120”W
	4. Ahiaboboe	5°05’56.430”N	1°17’07.326”W
	5. Ahiabo.	5°05’56.430”N	1°17’07.326”W
	6. Mangroves	5°05’56.431”N	1°17’07.327”W

Source: Field survey (2017)

River Sediment Sampling

A period of six weeks was used for the collection of river sediment samples i.e. 12/05/27-28/06/2017. Sampling started from the upstream towards the downstream direction. In each location, the coordinates were taken using a hand-held GPS. Simple hand-held sampling tools such as a trowel, hammer, plastic bucket, polyethylene bags, and measuring tape, masking tape, permanent markers, and field notebook were sent to the field. The hand trowel was used in picking the samples while a hammer was used to detach some rock samples. The sediment samples were collected in the poly-ethane bags which were properly labeled.

Two set of sediment samples were collected from each of the locations but for the upper section, there was a third sample set which consisted of some detached rocks from the huge formations which at the time of data collection were subunits. For the middle course, no such features were found and sampled. Also, in the upper section, some few areas rarely had sediments to be collected and so only some little sediments could be gathered, for instance at Asuansi and Obosando.

However, rock samples were detached from the formations found within the sampling locations. The two main samples were taken within the channel depending on accessibility and sediment availability.

Also, some hydraulic properties of these sampling locations including the width and depth of flow were also taken. For the width, a 100m tape measure was used and for the depth, a stick was dipped into the river at about three different locations and measured on the tape for the average depth of the station to be taken. All the samples were transported to the soil science laboratory of the Soil Science Department in the University of Cape Coast for particle size determination, nutrient and heavy metal analysis. Below are some pictures during some sampling and measurement sessions.

Plate 2: River sediment collection

Source: Field survey (2017)

Aside from the collection of samples and measurement of some hydraulic properties of the river, detailed field observations were carried out as well as taking of photographs. In order to geomorphologically distinguish among the various sections of the Kakum River, critical field observation was done.

Water Quality Sampling

Samples of the water from each sampling location were collected into a 750ml bottle and sent to the laboratory for water quality analysis. This with the soil sampling from the adjacent lands comprised the third field data collected within 12th to 13th October 2017. Below are some pictures during picking the water samples.

Plate 3: Water sample collection

Source: Field survey (2017)

Soil Sampling

Aside from taking the sediment samples from the river bed, soil samples were also taken from the adjacent lands, precisely about 20m from the channel to examine the effect of the processes that go on within the adjacent lands on the water and sediment characteristics. A period of three days was devoted to taking these soil samples. Within the three days beginning on the 12th to 14th October, a day was spent in each of the sections or courses of the river and tools used included pickaxe, spade, trowel and tape measure.

The procedure involved digging 60cm into the soil and collecting the soil samples at every other 15cm. In other words, four samples were taken from each site 15cm, 30cm, 45cm and 60cm. However, before putting these samples in plastic bags, they first were collected onto a brown paper and properly mixed up with the trowel before finally bagging them in the plastic bags. Thus, with a total of 16 sampling stations, 64 samples were collected in all. Plate 4 shows some pictures taken during this second aspect of field sediment collection.

Plate 4: Soil sample collection

Source: Field survey (2017)

Morphologic Analyses

The methods of analysis employed to evaluate the geomorphology and morphology of the Kakum basin include Morphometric analysis, Photographic Analysis, and Particle Size Distribution analysis.

Morphometric Analysis

Putty (2007), as well as Nag and Chakraborty (2003), defines morphometry as the measurement and mathematical analysis of the surface, shape, and dimension of the earth's surface landforms mostly achieved through the measurement of linear, aerial and relief aspects of the basin and slope contributions. These parameters affect the catchment streamflow pattern through their influence on concentration-time (Jones & Mulholland, 1999). For this study, a quantitative evaluation of the morphometry of the Kakum river basin was undertaken to understand the existing relations among various morphometric parameters. The core purpose is to analyze the morphometry of the drainage basin and the channel characteristics as a major component of the fluvial system, in order to provide an idea about the evolution of the whole landscape by hydrological processes.

Data Processing

To accomplish this, the main data used is the Aster DEM and the soft copy of the survey of Ghana topo-sheets numbered 0502a, 0502b, 0503c and 0502d on a scale of 1:50,000. These soft copies of topo-sheets came in the form of layered datasets for the various attributes of the defining area. For instance, the cultural, hypso, hydro, forest and transport layers for a given area within the dataset. The coordinate system of the above-named topo-sheets was defined and merged as they had not been defined already. The Arc GIS version 10.3 was used to process and analyze this data. The delineated watershed for the Kakum basin was clipped with the merged topo-sheet and the rivers within the watershed extracted.

Two main activities with their embedded sub processes were employed for the basis of the morphometric analysis. These include DEM reconditioning and hydrologic terrain. Since there is the use of vector data (topo-sheet) and the raster data (aster Gdem), the DEM reconditioning adjusts the DEM so that elevations direct drainage towards the vector information on stream position. According to Tabooton (2012), this process is only suggested when the vector stream information is more reliable than the raster DEM information. However in this study, this has been employed because most of the streams in the Kakum basin are ephemeral and so are likely not to have been captured by the DEM, thus combining the two aids in making use of all the rivers within the basin whether perennial, ephemeral or intermittent. Thus, some geo-processing functions employed to accomplish this activity includes converting the vector features to raster, the greater than and the reclassify functions.

In the hydrologic terrain analysis, pits are filled and flow direction as well as flow accumulation calculated. The calculation of flow accumulation gives the result of a raster which allows for the identification of the contributing area at each grid cell in the domain. These have been done however in the processes of delineating the basin. Apart from these, some additional geo-processing functions employed include the definition of an outlet point, stream links, and catchments as well as the stream order which is the very first step in any morphometric analysis.

In ordering streams, there are various methods that could be employed. Some include the Shreve’s method, Gravelius method, Hortons and Strahler’s method. For this study, the Strahler's was employed and this method of analyses a drainage basin, based on hierarchy (Strahler, 1964). Thus, in this method, the classification of streams is based on the number and type of tributary junctions and it has been proven to be a useful indicator of stream size, discharge, and drainage area (Strahler, 1957). The spatial analyst, as well as the 3D analyst extensions, was used to process and analyse the data in the Arc GIS environment.

Statistical Methods

The methodology employed for the computation of the other morphometric parameters are given in Table 4:

Table 4: Summary on Description of Morphometric Parameters

Sl. NO	Morphometric Parameters	Formula	Description	Units	References
Linear Aspects					
1.	Stream Order (u)		Hierarchical rank	Dimensionless	Strahler (1964)
2.	Stream length (Lu))		Length of the major stream	Km	Horton (1945)
3.	Mean stream length (Lsm)	Lsm = Lu/Nu	Lu = Total stream length of order ‘u’ Nu = Total number of stream segments of order ‘u’	Km	Strahler (1964)
4.	Perimeter (P)	P		Km	
5.	Stream length ratio (Rl)	Rl = Lu/Lu-1	Lu = Total stream length of order ‘u’ Lu-1 = Total stream length of its next lower order	Dimensionless	Horton (1945) Sreedevi et al., (2005)
6.	Bifurcation ratio (Rb)	Rb = Nu/Nu+1	Nu = Total number of stream segments of order ‘u’ Nu+1 = Number of stream segments of the next higher order	Dimensionless	Schumm (1956) Horton (1945)
7.	Mean bifurcation ratio (Rbm)	Rbm	Average of bifurcation rations of all orders	Dimensionless	Strahler (1964)
8.	Basin length (Lb)			Km	
9.	Rho coefficient ((ρ)	ρ = Rl/Rb	Ratio of Stream length ratio and bifurcation ratio	Dimensionless	Horton (1945)

Table 4 contd.

Relief Aspect				
Basin relief (Bh)	Bh = H – h	Vertical distance between the lowest & highest points	Km	Hadley & Schumm (1961)
10. Relief ratio (Rr)	Rr = Bh/Lb	mean elevation minus minimum elevation divided by relief	Dimensionless	Schumm (1963)
11. Ruggedness number (Rn)	Rn = Bh x Dd	Bh = Basin relief Dd = Drainage density	Dimensionless	Strahler (1958)
12. Melton's Ruggedness number (MRn)	MRn = H-h/$A^{0.5}$	Basin relief divided by the square root of the basin area	Dimensionless	Melton (1965)
13. Rotundity ratio (R)	$R = 4A/pL^2$	Area and maximum length of watershed	Km	Chorley et al., 1957
Areal Aspect				
14. Area	A		Km^2	
15. Drainage Density (Dd)	Dd = Lu/A	L = Total length of streams A = Area of the basin (km2)	Km km^{-2}	Horton (1932, 1945)
16. Constant channel maintenance (C)	Re = 2√(A / Pi) / Lb	Inverse of drainage density	Km	Schumm (1956)

Table 4 contd.

17.	Circulatory ratio (Rc)	Cc = (0.2821xP) / A $^{0.5}$	A = Area of watershed P = Perimeter of watershed Pi = 3.14	Dimensionless	Miller (1953)
18.	Elongation ratio (Re)	Rt = Dd x Fs	A = Area of watershed Lb = Basin length Pi = 3.14	Dimensionless	Schumm (1956)
19.	Compactness Constant (Cc)	Fs = N/A	A = Area of watershed P = Perimeter of watershed	Km	Horton (1945) Gupta (1999)
20.	Drainage Texture (Rt)	Rt = Dd x Fs	Dd = Drainage density Fs = Stream Frequency	Km	Smith (1950)
21.	Stream Frequency (Fs)	Fs = N/A	N = Total number of streams A = Area of watershed	Km^{-2}	Horton (1932, 1945)
22.	Form Factor (Ff)	Ff = A/Lb2	A = Area of watershed Lb = Basin length	Dimensionless	Horton (1932)
23.	Texture Ratio (T)	T = N1/P	N1 = Total number of first order streams P = Perimeter of watershed	Km^{-1}	Horton (1945)
24.	Shape factor (Sf)	Sf = 1/Ff	Reciprocal of form factor	Dimensionless	
25.	Length of overland flow (Lg)	Lg = 1/Dd*2	Dds = Drainage Density	Km	Horton (1945)
26.	Geometric similarity constant (Gsc)		Ratio of area of watershed to square of maximum length of stream	Km	Strahler (1957)

Table 4 contd.

27. Leminiscate ratio (K)	K = L2 /4A	Iindex of basin shape	Dimensionless	
28. Basin Shape (Bs)	Bs = Lb2 /A	Lb2 = square of basin length A = area of the basin	Dimensionless	Horton (1932)
29. Sinuosity Ratio	Si= Ci/Vi	Channel length/valley length		Mueller (1968)

Source: Author's Compilation (2017).

Focused Field Observation and Photographic Analysis

Evidence and understanding of the various processes shaping a particular segment of the fluvial landscape were sought from focused field observation and photographic analysis. In the focused field observation, two hours were spent at each reach visited and extensively subunits found extensively studied and noted. At the upper course, since during the three visits the river was experiencing low flows, a walk was taken in the river to feel the surface of the rocks, note color differences, as well as other striking features, identified. Also, since an older resident of those reaches was the main field assistant employed, he pointed out some features extraordinary to them and the characteristics they have observed with respect to those subunits.

For instance, at Nkwantanan, the first point of call was a site of fetching water which was just on the roadside. But there, the native and elderly field assistant spoke to us about a point where a huge rock formation crossed the river and was very striking that they named locally “bosando”; there was also another place where about seven persons would stand on each other and would still not be seen on the surface which they named “Bun Kofi”; and another area with a lot of crocodiles they called “Denkyem Bue”.

Plate 5: A native describing and leading researcher to distinct sections of the Kakum River

Source: Field survey (2017)

Based on these highlights, we were led to those areas and photographs taken, and focused examinations done with the senses of touch and sight. Pictures were taken with a field camera of such striking and any other features and when back from the field, these were critically studied along with literature and discussions with authorities (Senior Geomorphologist) to ascertain why and how those could have been as found.

Particle Size Distribution Analysis

Natural hydrologic variability and high flows in particular move and sort sediments selectively eroding and depositing materials in the river channel. Depositional process and sedimentary environments are inferred from such analysis. Among the methods used were the electrical sensing method of Coulter counter, instrumental sedimentation devices like the sedigraph, Laser particle sizer based on forward light scattering and the classical method by sieve and pipette method. Each technique defines the size of a particle in a different way and thus measures different properties of the same material

(Konert & Vandenberghe, 1997). This study employs the classical method to analyze the grain size of fluvial sediment samples.

The use of sieve is affected by the method of calibration of sieves, the shape of the particles, chemical and mechanical stability and uniformity in density and porosity.

The use of the pipette method is based on the following assumptions;

- Sedimentation speed is constant and not too fast. The particle Reynolds number must be smaller than one (Rep <1);
- Particles are spheres, solid and smooth;
- Densities of the particles or between the particles and the wall of the sedimentation vessel;
- Particles do not affect the viscosity of the liquid (Konert & Vandenberghe, 1997).

Pre-processing of Sediment samples

Sediment samples conveyed to the laboratory were wet samples and so had to be dried. But since the weather was not conducive, the samples were forced dry in an oven at a temperature of 50°C and in two days (15th and 16th June 2017) the first 21 samples were ready. A porcelain mortar and pestle were used to gently disaggregate the samples. The dried and disaggregated samples were weighed on a balance and a 2mm sieve mesh was used to separate the gravel portion from the fine earth sediments and each of these weighed separately, bagged and properly labeled with codes. In analyzing the grain size distribution, the standard method of sedimentation and pipetting and mechanical sieving method was employed.

Procedure/Methods

In analyzing the sediments for their particle size distribution, three main reagents were used including Hydrogen Peroxide ($H20_2$), Amyl solution and Sodium Hexametaphosphate ($NaPO_3$) plus Sodium carbonate (NaCl). 20g of the fine earth portion of the samples were weighed into beakers/tubes and Hydrogen Peroxide (H202) added to destroy the organic matter content since it binds the mineral particles especially in clay together. Since the size elements of the mineral particles are of interest and importance this was to be done. Distilled water was added in the presence of Sodium Hexametaphosphate ($NaPO_3$) plus Sodium carbonate ($NaCO_3$) and shaken in a mechanical shaker. The $NaPO_3$ and NaCl constituted the dispersion solution and the essence of the addition of this solution was to disperse the soil by adding sodium ions to increase the exchangeable sodium and also cause repulsion between the particles. The suspension was poured into 500ml cylinders and topped to the level, covered and vigorously shaken as in sedimentation processes.

By the pipetting method, 25ml of silt and clay were pipetted into beakers after 40 seconds and after 5 hours, the clay portion was also pipetted. This principle of sedimentation is based on the settling velocities of particle derived from Stoke’s law for streamlined flow. Thus, a spherical particle settles in a liquid with a sediment velocity which depends on the size of the particle, its density as well as the properties of the liquid. Stoke’s law given by:

$$v = 2gr^2\,(ps - p1)/9\eta$$

Where v - the sedimentation velocity (ms-1) r – Particle radius (m)

g – Gravitational force per unit mass (9.81Nkg^{-1})

Ps – Density of particle (2600kgm^{-3} is the average density for soil particles)

P1- Density of liquid (998kg m^{-3}20°C for water)

η- Viscosity of the liquid (1.002 * 10^{-3}Nsm^{-2} at 20°C for water)

The remaining suspension was washed thoroughly for the sand portion. And using sieves with apertures 212 µm and 63 µm the various sand portions were determined. The coarse sand remained on the 212 µm sieve, medium on the 63 µm and the fine passed through the 63µm. the textural class was determined by the USDA textural equation. Results were input into a gradistat template and the various statistics calculated including Geometric and arithmetic mean, sorting, Skewness and kurtosis.

Chemical Analysis

The main objective of the chemical analysis of the nutrients is in three folds. The first was to evaluate the nutrient composition of sediments along the Kakum River to explain the dynamics in the wig intrusion. With the second aim, water quality was conducted to test for its chemical composition and in the third, the soil samples in adjacent lands were tested or chemically analyzed.

In chemically analyzing the river sediments and the soil samples, the main parameters that were evaluated included Nitrates (NO), Organic Matter, Nitrogen (N), Phosphorus (P) and potassium (K) as well as some heavy metals which included Iron, Copper, and Zinc (Zn). Also, some of the rock substrates in the upper section were sampled and heavy metal analyses were also conducted on them. This could be used to know the origin of the sediments i.e. through weathering of underlying rocks or from adjacent areas. However, because the soil samples were collected in batches, the Nitrate parameter could not be analyzed and so Total Nitrogen was evaluated.

The parameters evaluated to chemically analyze the water samples were basically NO_2, P, Ca, Mg, Ph and the trace metals (Fe, Cu, and Zn).

Fluvial Sediments and Soil Analysis

In analyzing the parameters for the fluvial sediments, samples were taken from the same samples collected for the granulometric analysis. For the purposes of certainty, three replications were done for each sample in analyzing for the nutrients in the river sediments. Since the sediment samples for the upper and middle course were ready before that of the lower section, 21 samples were replicated for the above-mentioned parameters between 12th -28th of June 2017 yielded 63 sample results in all, whiles that of the lower section was done between 29th June-6th July 2017.

In the case of the 64 soil samples taken from the adjacent lands, because they were collected differently they were also analyzed differently. Because of the number involved and the limited nature of the laboratory equipment, two replications could be made instead of the three. Thus in all, there were 128 soil samples that were analyzed. Below are the procedures employed for the analysis of the various nutrients.

Nitrate

- 5g of fresh sediments sample were weighed into centrifuge cylinders and 30ml of distilled water added to each of them and thoroughly placed in the shaker for 15 mins

- The suspension was placed in centrifuge machines and the solution (aliquot) filtered on Whatman filter papers into 25 mls conical flasks
- 10 ml of this solution was pipetted into 50 mls beakers and brought to dryness on a fume hood but not baked
- Using the phenodisulphonic acid method, 1ml of this was added to the cool-dried residues in the beakers and swirled rapidly to bring residue and acid into contact quickly and allowed to stand for 10 min.
- 10ml of distilled water and 3 ml of ammonia (1+1NH40H) were carefully added until pH is between 10 and 11
- Volume was poured into a 25 ml volumetric flask and mix well
- Standards were also prepared and used to determine mg $NO3^{-}$-N in the sample aliquot
- The blank determination was carried in the same way and subtractions were made where necessary.

Organic Matter

- 1.0g and 0.1g of the sand and clay sediments were weighed respectively into 500 ml volumetric flasks.
- 10 ml of Potassium Dichromate solution ($Kr\ Cr\ O_7$) was added to the sediment samples and swirled
- 20 mls of Sulphuric acid was added and allowed to stand for 30 min
- Distilled water was topped to the 200ml level
- 10 drops of diphenylamine indicator ($(C_6H_5)\ 2NH$) was added until suspension showed a dark color
- By titration using 0.5 M ferrous ammonia sulfate solution, values were determined.

Phosphorus

- 2.0 and 1.0g of the sand and clay sediments were weighed into centrifuging tubes
- 30 mls of Bray extracting solution was added to the samples and covered
- Samples were shaken in a mechanical shaker for 30 min and centrifuged for 10 min
- 10 mls of the aliquot was extracted and 3 mls of sulphuric acid was added.
- Distilled water was topped to the 25 ml

Potassium

- 2.5g of air-dry soil was weighed into a 250-mL flask.
- Add 50 mL 1 N NH_4OAc solution
- It was shaken for 4 hours minutes on a mechanical shaker
- The suspension was filtered using a Whatman No.1 filter paper to exclude any soil particles and bring the extract to a 50-mL volume with 1 N NH_4OAc solution.
- Series of suitable K standards were run using a Flame Photometer.
- Measure K in the samples (soil extracts) by taking the emission readings on the Flame Photometer at 767-nm wavelength.

Heavy Metal Analysis

The main heavy metals analyzed in this work include iron (Fe), copper (Cu) and zinc (Zn). This was done for the sediments as well as the rock samples collected from some parts of the upper section. In order to do this for the rock samples, some portions of the rocks were broken and pounded. They were then sieved and the analysis carried out. Below is the procedure employed for the extraction of the heavy metals.

- 10g of soil and grounded rock samples were weighed into centrifuging tubes
- 20 ml of DTPA (Diethylenetriamine Pentaacetic acid) extracting solution added to the samples
- Tubes were stoppered and shaken in a mechanical shaker for 2 hours
- Suspension in tubes was centrifuged for 10min and decanted into 50 ml conical flasks
- Distilled water was added to the 50 ml mark and results were read using the AAS (Atomic Absorption Spectrometer).

Land Use Analysis

Land use/cover mapping involves the conversion of remotely sensed data to thematic data. Thus, the main data used for this is the Landsat TM images and Landsat Etm images. This procedure involves image processing, classification, and accuracy assessment to validate the satellite image interpretation.

Image Processing

The downloaded remotely sensed satellite images were subjected to pre-processing using Erdas Imagine 2013. Radiometric corrections have been performed on the images to remove surface reflectance order to improve the accuracy of the image classification. Haze and noise have also been corrected for in each band of the Landsat datasets. Geometric corrections have been done as well so that the geometric representation of the imagery will be as close to the real world as possible. The geometric correction includes geo-referencing which is a process of relating images to specific map projections. The Landsat images for this study were originally in the global coordinate system UTM zone 30/WGS 84. In process of geo-referencing, they were transformed to a local projected coordinate system i.e. the Ghana Metre Grid. Since the spatial extent of the three sets of Landsat images was far greater than the study area, the images were sub-setted to a smaller area using a bounding polygon of Kakum basin. The subset images were then geometrically registered to each other before all other image analyses were performed.

Image Classification

The overall objective of the image classification procedure is to categorize all pixels in an image into land cover classes or themes (Lillesand, Kiefer & Chipman 2014). In the image classification process, bands 1,2,3,4 of Landsat TM, EMT+ and bands 2,3,4,5 of Landsat OLI/TIRS were used. The present study employed both unsupervised and supervised classification algorithms. An unsupervised classification was done to aid in the exploration of the land use/cover types. High-resolution images from Google Earth, UAV photographs and ground-based knowledge after a detailed field survey were used to select training samples for the supervised classification. Maximum likelihood classifier was selected as the decision rule for the supervised classification algorithms and the categorization of the land cover types was based on the USGS classification system.

Change Detection

Change detection invariably involves the detection of changes in the form of location and extent, and sometimes the identification (Asubonteng, 2007). To identify changes in land use/cover classes in terms of areal extent, spots of change, and the path of change, the post-classification change detection technique, which involves an overlay of independently classified images, was used. Land use/cover change maps were derived for the periods 1990 to 2003 and 2003 to 2015 using the respective land use/cover maps. The land use/cover maps were loaded in combinatorial and spatial analyst tool in ArcGIS 10.3 to indicate changes between both periods in the form of change map and change matrix, which was then used for the analysis.

Changes in the Bankline of the Lower Kakum

Data collection and pre-processing

Riverbank lines for the Kakum river were derived from two orthophotographs of the study area obtained in the 2005 and 2016. The former was obtained from the Department of Geography and Regional Planning (DGRP) of the University of Cape Coast. The latter was collected with the help of Phantom 3 professional Unmanned Aerial Vehicle (UAV). The flight was carried out from the Kakum estuary through to Kwaprow Village. The total imaged area is about 4.8 km2. The resolution of 2016 was sampled from 0.04 by 0.04 to 0.5 by 0.5 and was projected into the same coordinate system using the Ghana Metre Grid projection, along with the World Geodetic System 1984 datum which enabled appending to be done and comparisons made. Using the mangrove vegetation as a border of the land area river banks were digitized from the two orthophotos using ArcGIS Software 10.3.

In addition, ground truthing along the river course was done. The aim was to collect more data and information from the field through field observation and anecdotal information from local people. Interviews were conducted for residents in the communities who have lived around the river for at least 25 years. Most of these individuals were elderly people who had a lot of information about the changes in the river course.

River Bank Erosion Measurement

To analyze the river bank morphology the study employed the Digital Shoreline Analysis System (DSAS) an extension to ArcMap 10.3 TM developed by the USGS. DSAS calculates rate-of-change statistics from several historic river bank lines. First, the software generates transects that are cast perpendicular to the baseline at a user-defined interval. The intersections of transects and the river bank lines along the defined baseline were then used to calculate the rate-of-change statistics. In this study, different transects were cast both at the left and right bank. To assess the dynamics of the morphology of the river, a hypothetical baseline was constructed offshore. In order to calculate erosion/accretion rates and the extent of river bank migration, the net shoreline movement (NSM) and endpoint rate (EPR) statistics were used. A detailed description of these statistics in DSAS has been provided by Thieler et al. (2009).

CHAPTER FIVE

MORPHOMETRY OF THE KAKUM RIVER BASIN

Introduction

This chapter aims at analyzing the hydro-geomorphic attributes of the Kakum river basin. In order to accomplish this objective, the drainage basin morphometry was employed. This methodology made use of topographic maps and Digital elevation model of the study area. Processing methods included DEM reconditioning and hydrologic terrain analysis. Spatial analyst and 3D analyst extensions were tools used to process the data in the Arc GIS environment and the streams were ordered after Strahler (1957). Other statistical morphometric parameters were employed to analyze the linear, areal and relief aspects of the catchment.

Table 5: Results on the Morphometry of the Kakum River Basin

Stream order (U)	Stream Segments (Nu)	Bifurcation Ratio (Rb)	Stream Length (km)	Stream Length Ratio (Rl)
1	27	-	79.8	-
2	13	2.07	48.86	0.612
3	11	1.181	36.14	0.74
Total	51	Rbm: 1.625	164.8	0.6756

Source: Data analysis (2017)

The implication of the Linear Morphometry of Kakum River Basin

Watershed morphology (Basin morphometry) has a profound impact on watershed hydrology (Tucker & Bras 1998). From the Linear point of view, parameters including stream order, stream number, stream length, stream length ratio and bifurcation ratio were analyzed.

Stream Order

Since the primary step in any drainage basin analysis is the order designation, streams in the Kakum basin were ordered based on Strahler's method of ordering and was found that the Kakum is a third order basin with the first order streams being as many as 27 and the third being about 11. It was observed that the maximum frequency occurred with the first order streams and it decreases as the order increases to the third order. Overall, the Kakum has a total stream frequency of about 51.

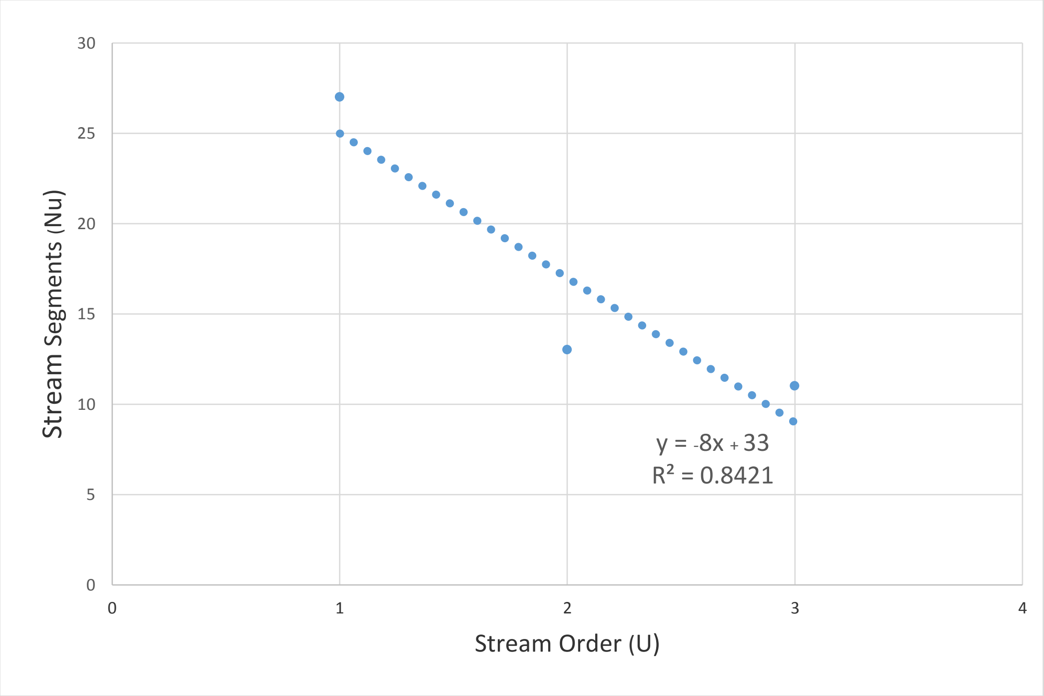


Figure 12: Relationship between stream orders and stream numbers.

Source: Data analysis (2017)

Mean Bifurcation Ratio (Rbm)

The Rb value is not constant between each set of adjacent orders but the variation from one order to the other is small so a mean value can be used given a homogenous geology. Rb values should usually range from 3.0 to 5.0, with values of more than 10 showing the effect of structures (Horton, 1945;

Chow set al., 1988; Romshoo, Bhat & Rashid , 2012). Generally, the rb value from the first to second order was found to be 2.07 and 1.181 from the second to the third order whiles mean bifurcation ratio was found to be 1.625. Even though values, greater than 10 implies the effect of structures, values less than 3.0 have hardly been explained in terms of the effect of geologic structures. However, few studies explain that the drainage basins with such Rb values have been carved naturally by slope and local relief and not influenced by geological structures like lineaments and faults. Thus, a high bifurcation ratio implies a higher flooding potential as a lesser number of streams in the second higher order would have to receive water from a relatively higher number of streams. Based on this attribute, the Kakum basin with a relatively lower mean bifurcation ratio should not be a flood-prone basin.

Stream Length/Length Ratio

In Horton's law of stream length, the mean length of stream segments of each of the successive orders of a basin tends to be roughly direct geometric series, with stream lengths increasing towards higher stream order. This relationship plots as a straight line according to Schumm (1956), Chorley (1957) and Morisawa (1962).

The stream lengths (Lu) have been computed and generally total length of stream segments is maximum in first-order streams and decreases as the stream order increases in the Kakum river basin with first-order stream segments having the maximum length of 79.8km and the third order stream having the minimum length of 36.14 km as depicted roughly in figure 13.

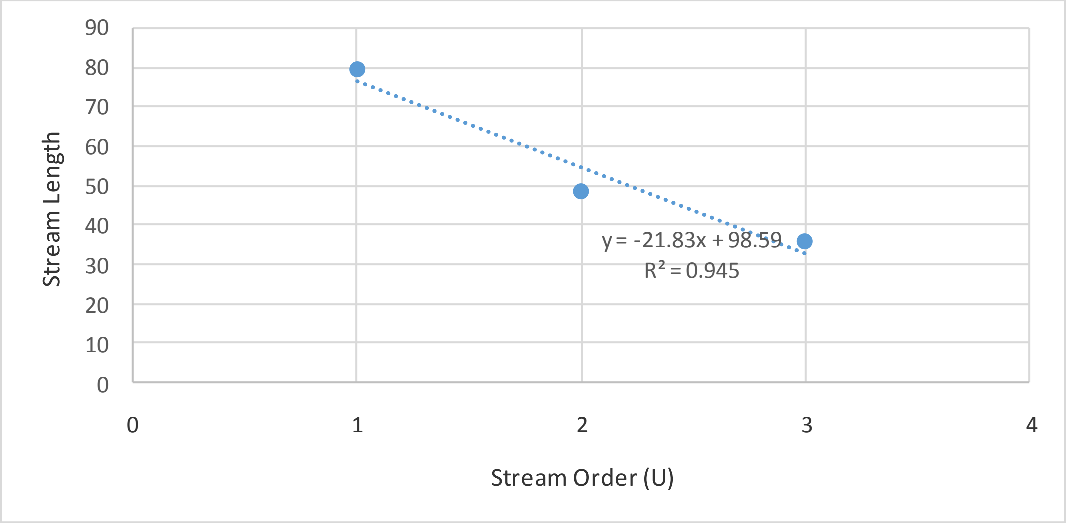


Figure 13: Relationship between stream order and stream length.

Source: Data analysis (2017)

Table 6: Results on Relief Morphometry of Kakum River

Relief Morphometric Parameters	
Basin relief (Bh)	275m
Relief ratio (Rr)	1.025
Ruggedness number (Rn)	14.619
Melton’s Ruggedness number (MRn)	1.883
Rotundity ratio (R)	1.129

Source: Data analysis (2017)

Implication of the Relief Morphometry of Kakum river Basin

The relief properties in morphometric analysis bring into consideration the influence of aspect and height over a large basin area. Parameters considered included Basin relief (Bh), relief ratio (Rr), Ruggedness number (Rn), Melton's Ruggedness number (MRn) and Rotundity ratio (R).

Total Basin Relief/Relief Ratio

The total basin relief of the river Kakum was found to be 275m. This relief is classified as moderately high because, in the study by Sreedevi et al., (2013), a relief of about 100m was considered relatively high. Thus, Patton (1988) characterizes such relatively high reliefs as having steeper hillslopes and higher stream gradients decreasing the time of concentration of runoff, thereby increasing flood peaks.

According to Schumm (1956), the basin relief (H) divided by maximum basin length (Lb) gives the relief ratio and this parameter measures the overall steepness of the drainage basin and is also an indicator of the intensity of erosion processes. The relief ratio has been found to be 1.025 and this characterizes the Kakum basin just as in the study by Golekar et al., (2013) as indicating steep slope and high relief.

Ruggedness Number

This parameter according to Horton (1945) aside from being the product of relief and drainage density also indicates the structural complexity of the terrain. The ruggedness number for this study was found to be 14.619 and such high values of Rn according to Ozdemir and Hassan (2009) are characteristic of basins which are highly susceptible to erosion and therefore susceptible to an increased peak discharge.

Table 7 presents the Areal morphometric results of the Kakum river catchment.

Table 7: Results on Areal Morphometry of Kakum River

Areal Morphometric Parameters	
Area (km^2)	451.47
Drainage Density (Dd) km^2	0.37
Constant channel maintenance (C km)	2.74
Circulatory ratio (Rc)	0.22
Elongation ratio (Re)	0.60
Compactness Constant (Cc km)	2.16
Drainage Texture (Rt km)	0.04
Stream Frequency (Fs km)	0.11
Form Factor (Ff km2)	0.29
Texture Ratio (T)	0.17
Shape factor (Sf)	3.48
Length of overland flow (Lg)	1.37
Geometric similarity constant (Gsc)	0.19
Leminiscate ratio (K)	15.20
Basin Shape (Bs)	3.49

Source: Data analysis (2017)

Implication of the Areal Morphometry of Kakum river Basin

The areal properties in morphometric analysis bring into consideration the influence of the entire basin area. Parameters considered included Basin Area (A), Drainage Density (Dd), Length of Overland Flow (Lg), The Kakum Basin area has been found to be 451.468km^2.

Length of Overland Flow (Lg)

This according to Horton (1945), is the length of water over the ground before it gets concentrated into definite stream channels and Patel et al. (2012) relate this parameter inversely to the average channel slope. From several authors (Hajam et al., 2013; Altaf, Meraj, & Romshoo, 2013), the higher the value of Lg, the gentler the slopes on which the water flows and the longer the flow path and vice versa. In this study, the Lg was computed as equal to 1.37km. This value as compared to the results of Hajam et al., (2013) and Altaff et al., (2013) is relatively higher and therefore implies that water within the Kakum basin flows over relatively much gentler slopes with longer flow paths.

Drainage Density (Dd)

The Dd is the ratio of total channel segment lengths cumulated for all orders within a basin to the basin area and this parameter was found to be 0.365km/km2 within the Kakum river basin. This parameter gives an indication on the characteristics of the subsurface materials such as the hydraulic conductivity of the soils and their infiltration capacities, as well as the topographic and vegetation characteristics of the basin (Srivastava et al., 2008; Romshoo et al., 2012; and Sreedevi et al., 2013). According to the drainage density categorization by Pater et al. (2012), the Kakum was found to possess a very low drainage density characterized by a poorly drained basin with a slow hydrologic response (Melton, 1957).

Therefore, with Dd being inversely related to the hydraulic conductivity of the underlying soil according to Sreedevi et al. (2013), it implies that the Kakum basin possesses a fairly good infiltration capacity and thus a low storm response. The Kakum basin in this regard can be described after Romshoo et al. (2012) as being composed of permeable subsurface materials, good vegetation cover and low relief, which results in more infiltration capacity and can be good sites for ground water recharge.

Stream Frequency (Fs)

Stream frequency is related to permeability, infiltration capacity and relief of watersheds (Montgomery and Dietrich 1989, 1992) with a relatively higher stream frequency pointing to larger surface runoff, steeper ground surface, rocky terrain, and very low infiltration capacity (Vittala et al., 2004; Romshoo et al., 2012). In this present study, the Fs has been computed as 0.113 and such low Fs in indicative of a lower surface runoff and a much gentler slope in a less rocky terrain.

Shape Parameters

The calculated Form factor of the basin is 0.287 which was based on the range given by Horton (1945) implies a relatively elongated basin with such a low value as in Babu et al. (2014) and Chopra et al. (2005). Such a basin possess lower or flatter peak flows of longer duration and are easier to manage than those of circular basins, according to Gajbhiy (2014).

The elongation ratio which in Singh and Singh (1997), indicates relief and steep slope, has been computed as 0.604 and based on the categories given by Schumm (1956), this value designates the Kakum basin as less elongated even though the Form factor describes it as relatively elongated. The categories are namely: Circular (> 0.9), Oval (0.9 to 0.8), Less elongated (<0.7). It is nowhere close to being circular and as such not as capable for the discharge of run-off as in the case of a circular basin. A circular basin is more capable of discharge of run-off than an elongated basin.

The circularity ratio according to Babu et al. (2016) indicates as well the shape of the basin and whether or not the basin is structurally controlled. In Sreedevi et al. (2013), this parameter also tells of how quickly excess water is taken away from the basin in the form of infiltration and according to him basin with Rc values closer to 1 are much circular and can quickly remove water through infiltration. By this too, it takes a relatively long time for the basin to experience excess water at basin outlet. The Rc value computed for the Kakum basin is 0.215 which is less than even 1/2 and so not close to 1. The Kakum basin thus is not at all circular.

Compactness coefficient (Cc) expresses the relationship of a basin with that of a circular basin having the same area (Gravelius, 1914). The Kakum river basin has been found to have a Cc of 2.16. However, Altaf et al. (2013) express that when Cc=1 there is an indication that the basin completely behaves as a circular basin and thus yields the shortest time of concentration before peak flow occurs in the basin. But with a Cc>1, there is an indication that the Kakum basin deviates from being circular in nature and so the basin is expected to experience the longest time of concentration before peak flow occurs in the basin.

Constant of Channel Maintenance (C)

Schumm (1956) expresses that this parameter is dependent on the rock type, permeability, climatic regime, vegetation cover, and relief as well as duration of erosion and decreases with increasing erodibility. According to Altaf et al. (2013), it also signifies how much drainage area is required to maintain a unit length of a channel. The C for the Kakum river basin has been computed as 2.74. Bhagwat et al. (2011) explains that such a was suggest more area is required to produce surface flow. Again, Altaf et al. associate such high values with basin characterized with resistance soils, vegetation, and comparably plain terrain, thus low structural disturbance, high permeability, moderate to gentle slopes and low surface runoff.

Sinuosity

Calculated sinuosity has been computed as 2.12 for the Kakum river basin. Based on the computed values, since sinuosity values greater than 1.5 are considered as meandering, the Kakum river can be described as such too. Confirming its local name, “Kwesi mponponee”.

Conclusion

By the use of remote sensing and GIS technology, the hydrological characteristics of the drainage network of the Kakum basin have been brought to bear. The computed linear, relief and areal morphometric parameters have characterized the Kakum river basin as having a relatively gentler slope. It is this local topography and lithological structures which have carved the pattern of the Kakum and not geological structures like lineaments and faults. With such influence, the Kakum river basin under normal circumstances should not be flood-prone since it possess good vegetation, resistant soils and comparatively a plain terrain and so permeability and flow length should be high thereby reducing early peaking of its storm hydrograph.

CHAPTER SIX

MORPHOLOGY OF THE KAKUM RIVER

Introduction

This Chapter aims at assessing the morphological variations of the various sections of the Kakum river. For this, the river styles methodology was employed. River Styles methodology is a nested hierarchical classification system that looks at the landscape and rivers at four scales – catchment, landscape units, river styles and geomorphic units. Landscape units define the landscape in terms of large easily recognized features such as a plateau, an escarpment or a lowland plain. River styles are reaches of river that have characteristic channel geometry, planform, and assemblages of geomorphic units. Geomorphic units are features of the channel and floodplain that can be related to the processes that produced their form.

Thus, in studying the morphology of the reaches, categories of channel bedform types were determined in the field by comparison with photographs and physical descriptions of each bedform type as discussed in the literature (i.e., Montgomery & Buffington, 1997; Thompson & Townsend, 2006; Wohl & Merritt, 2008).

The Grain size distribution of the various reaches was also done by field sampling of the rivers sediments and laboratory analysis using the classical method of a pipette and Sieve. The results for this objective are thus presented under two sections including bed-form variations in the various reaches of the Kakum River and the Grain size distribution.

Bed-form Morphology in the Upper Reaches

Bed-forms of three channel units of the various sections of the river were studied to provide the building block upon which the larger reach scale bed-form can be described. These were evaluated based on the bed-form categories given by Montgomery and Buffington (2007).

From almost the entire basin scale within the Kakum river basin, bedrock channels and alluvial channels have been distinguished from the perspective put forward by Massong and Montgomery (2000). The bedrock channels were the channels with at most a thin alluvial cover, whereas the alluvial channels were those that occupied broad alluvial valleys. In plates 6-8 are figures of the bed-forms of the channel units of the upper reach scale.

Plate 6: Bedrock channel with thick vegetation on banks (Kokoado, upper section)

Source: Field survey (2017)

In Kokoado, a bedrock channel was identified with no alluvium but a very broad bedrock exposure formation characterized by terraces giving it a step-like look. In times of high flows, this entire broad bedrock is covered, however, during low flows, only the portion in view is covered with water. Some water may also stand in the form of puddles on the uncovered sections.

Plate 7: Exposed pegmatite bedrock channel with thick vegetation on banks and cracks with vegetation (Kokoado, upper section)

Source: Field Survey (2017)

Plate 8: Bedrock outcrop and pools of water, a condition for water- layer weathering at Obosando (upper section)

Source: Field Survey (2017)

Plate 9: Granite outcrops and boulders with trapped pebbles covered by bamboo leaves at Obosando (upper section)

Source: Field survey (2017)

Again in the upper section, the bedform of Bun Kofi was identified as bedrock Channel as depicted in Plate 9. This channel was confined with almost steep sides and some very little outcrops of rocks on the bed. However, during periods of high flow these outcrops are entirely covered and do not generate turbulence as in the first two sub-reaches of the upper catchment. Alluvium in this reach was also thinly trapped behind the few rock outcrops and on the valley sides were covered with leaves.

Plate 10: Outcrops of granites with pool of water and bamboo litter covering the upper section of the valley at Bun Kofi (upper section)

Source: Field survey (2017)

Plate 11: Bedrock channel at Auansi with thick vegetation on river banks and a disappearing pool of water into the thick vegetation (upper section)

Source: Field survey (2017)

Within the Kakum river basin, the distribution of bedrock channels occurs in the Upper Reaches. These channels exhibited both without alluvial cover as in Kokoado, Yebi Asuansi and Obosando as well as those of thin alluvium as found in Bun Kofi. Bedrock channels are mostly characterized by relatively high relief, high uplift rates and steep slopes, rapid local warping or faulting, resistant bedrocks and low sediment yields as suggested by Howard (1998). The main characteristics of the bedrock channels within the Kakum basin were found to include resistant bedrock, low sediment yields, and steep slopes were however found at Asuansi, rather than any of the other channels.

The thin veneer of sediments cover in some of these reaches is mainly due to the scouring, plucking and abrasion that occur during high flow periods as explained by Howard & Kerby (1983). One very profound and unique characteristic of the bedrock channels here is the thick vegetation on its banks. The riparian plant communities and the vegetation along the bedrock channels exhibit a high degree of structural and compositional diversity (Hawk & Zobel 1974). As a result, the effect of the contribution of this thick vegetation to woody debris and logjams in the Kakum river channel is also variable.

By critically examining the morphologies of these bedrock channels, it was realized that even though some of the woody debris and logjams were constantly supplied to the channel, none of these had affected the morphology of the bedrock channels. In order words, the existing bedrock morphology of the upper reaches does not seem to have been forced by the presence of the thick vegetation on the banks.

Plate 12: Exposed bedrock with uprooted raffia palm (woody debris) during a low flow season at Yebi (upper section)

Source: Field Survey (2017)

Plate 13: Exposed bedrock and boulders with trapped timber log (woody debris) at Kokoado (upper section)

Source: Field survey (2017)

However, a very important effect of the vegetation on the bedrock was seen in the supply of materials via weathering, color, and striations imprinted on the bedrock.

Plate 14: Root of silk cotton tree cracking the exposed pegmatite weathering at Kokoado (upper section)

Source: Field survey (2017)

By means of plants root activity, some of the adjacent rocks were being disintegrated and supplied to the channel as boulders. There were pieces of evidence of lichens and microfilms which also attack the bedrock and some of the boulders and weaken them to be acted upon easily by other weathering factors.

Plate 15: Biological weathering by lichens (upper section)

Source: Field survey (2017)

However, during low periods of flow and in the dry periods, these microfilms die by drying and their lower parts get imprinted onto the bedrocks as shown in the Plate 16.

Plate 16: Cracks, striations and potholes in bedrock at Obosando (upper section)

Source: Field survey (2017)

Again, due to the falling leaves and branches of the vegetation, the surface of the bedrocks have a dark coloration signifying the decomposition of organic matter. Consequently, in the bedrock channels of the upper reaches of the Kakum basin, weathering by biological means is very prominent.

Aside from this, weathering by physical and chemical means is very pronounced. Many of the exposed granitic bedrock and adjacent rock surfaces essentially consisted of a skin multilayer of thin laminae, flakes or scales, while other areas had pseudo beddings, polygonal cracks, displaced blocks as well as split rocks and other related forms as studied by Campbell and Twidale (1995) and shown in the Plate 17.

Plate 17: Chaos of granite boulders with cracks at Obosando (upper section)

Source: Field survey (2017)

Plate 18: Kakum river flowing under a dry-surfaced boulder at Kokoado (upper section)

Source: Field survey (2017)

Plate 19: Heavily faulted and cracked bedrock in the upper section of the valley at Kokoado (upper section)

Source: Field survey (2017)

Plate 20: Chaos boulders at Kokoado (upper section)

Source: Field survey (2017)

Alluvial Reaches of the Kakum River Basin

The Kakum river also exhibits alluvial characteristics at certain reaches along its profile. Apart from the bedrock channels that dominated the upper section, some other forms of alluvial morphologies were also identified including cascades and pool-riffle reaches.

Plate 21: Exposed boulders and granite bedrock in river valley channel at Yebi (A cascade channel in the upper section)

Source: Field survey (2017)

Plate 22: Pool- riffle channel at Kokode (upper section)

Source: Field survey (2017)

A fact which is very evident is that the alluvial reaches of the upper Kakum are made up of relatively bigger alluvium. Thus, in the cascade reaches, mainly boulders were found while in the pool-riffle channel mainly gravels were found. Another sight along these two alluvial channels was the fact they were also densely vegetated along their banks even though the vegetation along the pool-riffle had been degraded through human activities as a lot of farms existed along that stretch.

In the middle section, two different alluvial channels could also be identified namely a Plane channel (at Kawanotum and Aboenu) and a lake with instream vegetation inhabiting most part of it. The planar channel is confined as shown in the plate 23 with a bit of dense vegetation on the left bank and a lot of bamboo on the right bank

Plate 23: Deep stagnant pool of water surrounded by bamboo trees channel at Kawanotum (Plane channel in the middle section)

Source: Field survey (2017)

The Lake morphology has been created as a result of the Brimsu dam on the Kakum river and this transcends almost throughout the middle section (Sorodoful, Apewosika, Abaasa, and Brimsu). One unique characteristic of this lake morphology is the thick secondary vegetation cover along the banks as well as thick "wigs" of macrophytes deeply rooted and covering the lake across almost the entire area.

Plate 24: Lake morphology at Sorodoful (middle section)

Source: Field survey (2017)

The lower catchment of the Kakum the downstream of the dam area to the estuary has some kind of heterogeneous characteristics as the river flows through the urban or very populated areas. Thus, unlike the upper sections where the river lies far away from the human populace, in the lower section, it is the reverse; very close to settlements. At some points in Esuekyir, sand mining practices had deepened the channel so much that no samples could be taken from there since it was very risky. At Kakumdo, the channel had been tampered with as the river’s course had been straightened and enlarged and a similar thing had been done Kwaprow.

But after Kwaprow through Akotokyiri downstream, the river flows through a swampy area with various characteristics till it gets to the estuary. Here the floodplain broadens very well with assorted vegetation types. The riparian vegetation is made up of mangroves and grasses. Right after Akotokyire, the forest is purely grassy until it gets to about 150m after which the mangrove forests are prevalent.

Plate 25: Mangroves and grasses (lower section)

Source: Field survey (2017)

At some point also the grass covers the banks of the river while mangroves are at the back or behind the grasses.

Plate 26: Grasses on the banks (lower section)

Source: Field survey (2017)

The forest from this section, until it gets to the estuary, displays a variety of features. Downstream of Akotokyire a vegetation of Royal Palms and other assorted plants with almost equal heights emerge at both banks forming some canopy on the riversides.

Plate 27: Mangroves on the banks (lower section)

Source: Field survey (2017)

They are interspersed with some thickets, royal palms as well as some tall and short grasses.

Plate 28: Mangroves on the banks (lower section)

Source: Field survey (2017)

At this point also, there are pieces of evidence of degradation by means of burning for agriculture and cutting of mangroves for other purposes.

Plate 29: Degradation along the banks (lower section)

Source: Field survey (2017)

Plate 30: Degradation and forced deposition along the banks (lower section)

Source: Field survey (2017)

Their scene is a bit different as one gets closer to the confluence of the Kakum and Surowi rivers. At this point, the mangrove forest exhibit about three different characteristics. There are the very tall ones whose younger ones emerge from the stem and drop to the ground with apparently long roots, the intermediate ones, and the short ones.

Plate 31: Dune ripple channel with vegetation on banks at Ahiaboboe (lower section)

Source: Field survey (2017)

Thus, in the lower section, the main bed-form which was identified was a dune ripple channel as shown below,

Plate 32: Dune ripple with vegetation channel at Ahiaboboe (lower section)

Source: Field survey (2017)

Plate 33: Dune ripple with vegetation at Ahiaboboe (lower section)

Source: Field survey (2017)

Particle Size Distribution

The particle sizes and texture of the samples from the study area were analyzed and the results are presented in the subsequent tables and graphs. The textural classes were determined by the USDA soil texture program which was developed on the soil texture triangle.

Upper catchment

From Table 8, a greater percentage of the sediments collected from the various sampling locations in the upper catchment is sand with some sandy clay loam and sandy loam being identified at Nsain 2 and Yebi 2.

Table 8: Particle Size and Textural Class of Upper Catchment

Sample location	%CL	%SI	%SA	Textural Class
Kokoado-1	0.50	0.46	99.04	Sand
Kokoado-2	0.98	0.48	98.54	Sand
Nsain-1	0.66	1.06	98.28	Sand
Nsain-2	28.19	7.27	64.53	Sandy clay loam
Asuansi	0.79	0.37	98.84	Sand
Obosando	0.16	0.47	99.36	Sand
Kodode-1	1.01	0.42	98.57	Sand
Kokode-2	0.56	0.42	99.02	Sand
Bun Kofi- 1	0.45	0.52	99.03	Sand
Bun Kofi-2	0.32	-0.04	99.71	Sand
Yebi-1	2.15	0.82	97.04	Sand
Yebi-2	16.44	4.18	79.38	Sandy loam

Source: Data Analysis (2017)

Where CL=Clay
SI= Silt
SA= Sand

From figure 14, the chart of the Upper catchment, abrupt descent or depression in the sand graph is where the characteristics of the sand is that of clay loam. This is further buttressed by the peakedness in the graph of the clay and silt. Aside from this particular extreme variation, all the other particle sizes show a close association.

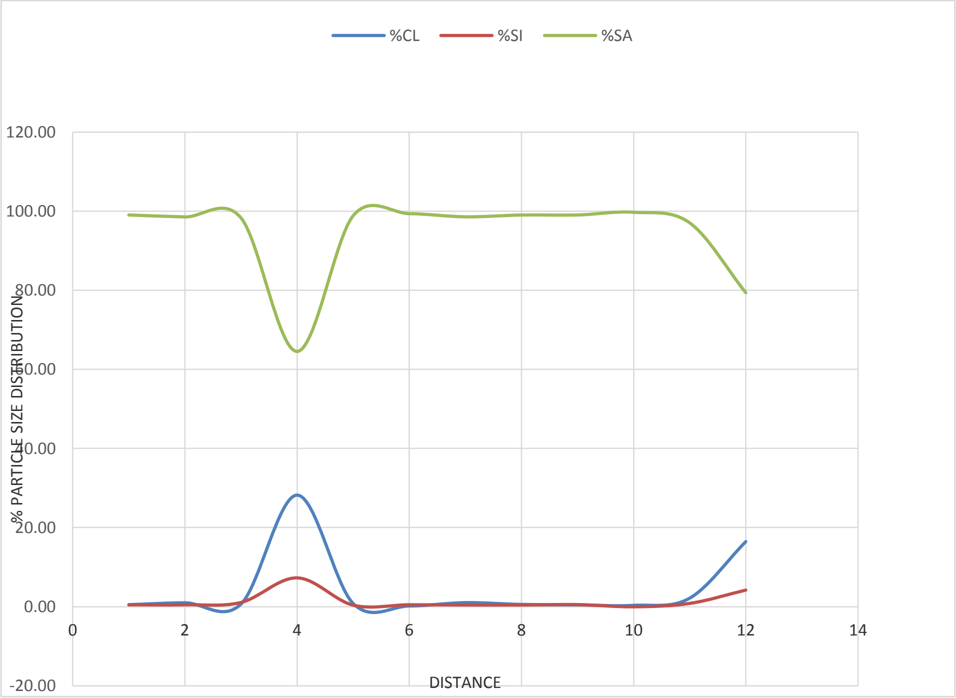


Figure 14: Graph of particle size distribution of upper catchment.

Source: Data analysis (2017)

Where % CL=Percentage of clay

% SI= Percentage of Silt

% SA= Percentage of Sand

Middle Catchment

In the middle catchment, the textural class has also been identified as being sandy in nature almost along the entire stretch with variations in the textural class being recognized at Sorodoful 2, Abaasa and Abaasa Bun. Unlike the Abaasa Bun where both samples show characteristics of Loamy sand, in the other two locations, the samples show characteristics of sandy clay loam. Table 9 summarizes this.

Table 9: Particle Size and Textural Class of Middle Catchment

Sample location	%CL	%SI	%SA	TEXTURAL CLASS
Aboenu-1	4.23	2.34	93.43	Sand
Aboenu-2	0.97	0.40	98.63	Sand
Kawanotum-1	0.86	0.51	98.63	Sand
Kawanotum-2	0.10	0.54	99.36	Sand
Sorodoful-1	45.20	-11.96	66.76	Sandy clay loam
Sorodoful-2	2.25	1.17	96.58	Sand
Apewosika-1	3.42	0.86	95.72	Sand
Apewosika-2	0.86	0.88	98.26	Sand
Brimsu Down	0.43	0.53	99.05	Sand
Abaasa-1	21.47	12.82	65.71	Sandy clay loam
Abaasa-2	1.21	0.91	97.88	Sand
Abaasa Bun-1	9.56	3.49	86.95	Loamy sand
Abaasa Bun-2	12.26	5.30	82.45	Loamy sand

Source: Data analysis (2017)

Where % CL=Percentage of clay
% SI= Percentage of Silt
% SA= Percentage of Sand

From the figure 15 representing the textural classes of the middle catchment, it is shown that the clay percentage at upper middle section is relatively higher that silt as silt records almost a negative value. At the tail of the graphs, the other trough in the sand graph, however, is by both some amount of silt and clay.

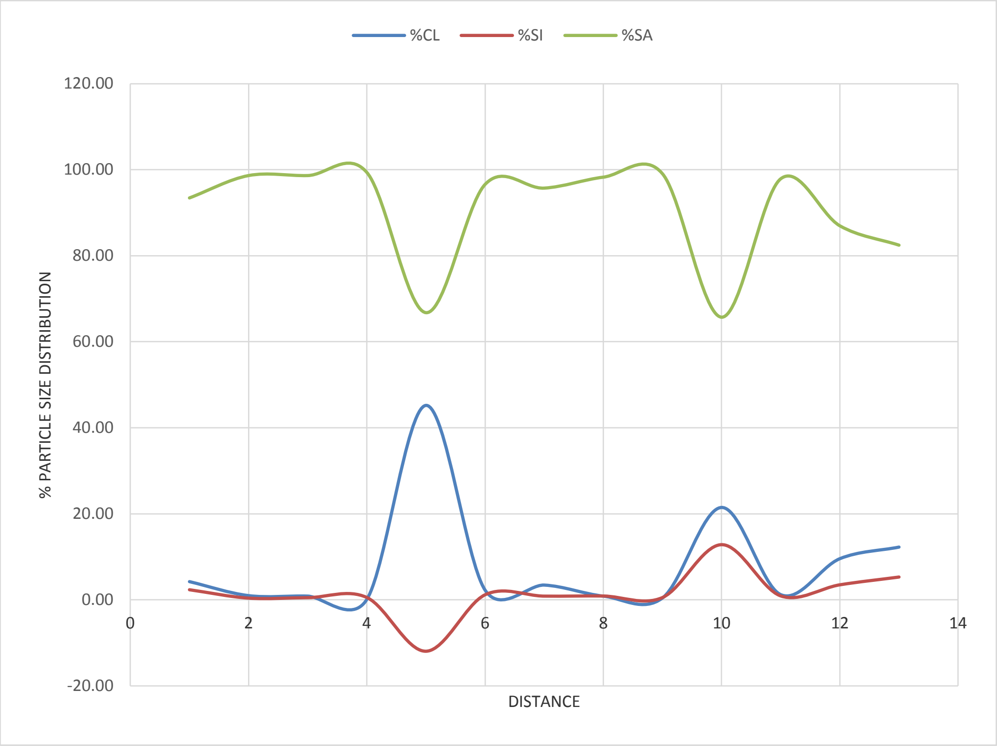


Figure 15: Graph of Particle size distribution of middle catchment.

Source: Data analysis (2017)

Where % CL=Percentage of clay
% SI= Percentage of Silt
% SA= Percentage of Sand

Lower Catchment

As as shown in table 10, the lower catchment did not display apparent variation from the upper and middle catchment in terms of particle size distribution. It is virtually sandy all along. Loamy sand is recorded at Esuekyir but at the Mangroves in Ahiaboboe, the sandy characteristics varied from sandy loam to loamy sand.

Table 10: Particle Size and Textural Class of Lower Catchment

Sample location	%CL	%SI	%SA	Textural Class
Esuekyir 1	4.58	2.92	92.49	Sand
Esuekyir 2	8.27	5.83	85.90	Loamy sand
Kwaprow 1	16.61	-15.46	98.85	Sand
Kwaprow 2	0.98	0.45	98.57	Sand
Ahiaboboe 1	0.20	0.34	99.46	Sand
Ahiaboboe 2	1.08	0.05	98.87	Sand
Ahia-mangrove 1	13.37	5.41	81.22	Sandy loam
Ahia mangrove 2	0.16	19.93	79.91	Loamy sand

Source: Data analysis (2017)

Where % CL=Percentage of clay
% SI= Percentage of Silt
% SA= Percentage of Sand

From figure 16 of the lower catchment, the percentage of silt rises at its upper section whiles that of sand fall before rising again for the silt percentage to attain a negative value with clay maintaining its rise. However, in the downstream section of the lower catchment both sand and clay values fall with silt rising.

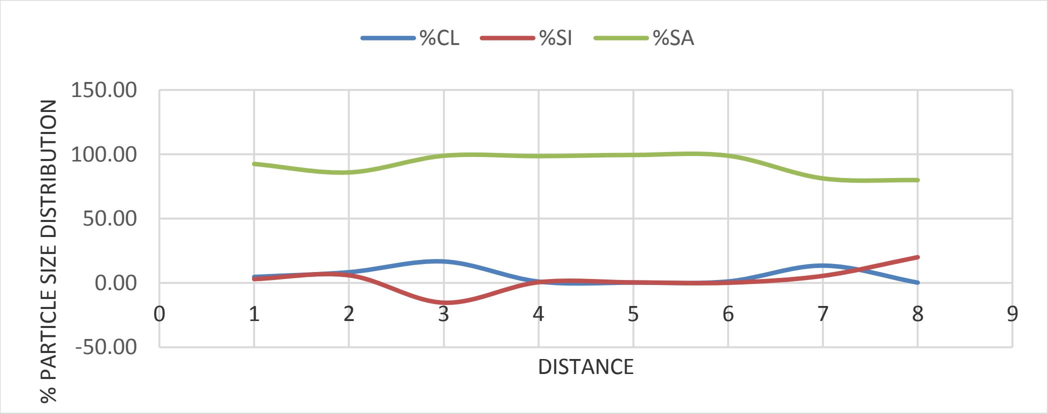


Figure 16: Graph of particle size distribution of lower catchment.

Source: Data analysis (2017)   Where % CL=Percentage of clay
% SI= Percentage of Silt
% SA= Percentage of Sand

Particle Size Distribution Analysis

The particle size analysis has been carried out based on Folk and Ward method and particle size parameters including mean, sorting, Skewness and kurtosis have all been determined. The results are presented in Tables 11, 12 and 13 representing that of the upper, middle and lower catchments respectively.

Table 11: Particle Size Analysis of Upper Catchment

	Geometric Mean (µm)	Logarithmic Mean (ϕ)	Description
Mean (x̅)	1444.3	-0.53	Very Coarse Sand
Sorting (σ)	0.947	-0.078	Very Well Sorted
Skewness (sk)	-1.207	1.207	Very Fine Skewed
Kurtosis (K)	-0.522	-0.522	Very Platykurtic

Source: Data analysis (2017)

From the table on the upper catchment, the sand particles are very coarse but very well sorted and Platykurtic.

Table 12: Particle Size Analysis of Middle Catchment

	Geometric Mean (µm)	Logarithmic Mean (ϕ)	Description
Mean ($\bar{x}$)	1465.2	-0.551	Very Coarse Sand
Sorting (σ)	2.11125	1.087	Poorly Sorted
Skewness (sk)	-0.559	0.559	Very Fine Skewed
Kurtosis (K)	-6.257	-6.257	Very Platykurtic

Source: Data analysis (2017)

Table 13: Particle Size Analysis of Lower Catchment

	Geometric Mean (µm)	Logarithmic Mean (ϕ)	Description
Mean ($\bar{x}$)	1458	-0.544	Very Coarse Sand
Sorting (σ)	2.075	1.053	Poorly Sorted
Skewness (sk)	-0.56	0.56	Very Fine Skewed
Kurtosis (K)	-6.156	-6.156	Very Platykurtic

Source: Field survey (2017)

Discussion

Influences on the Channel Form Dynamics along the Kakum River

According to Gregory et al. (1991), the histories of the fluvial landscape can best be inferred from the distribution and composition of riparian vegetation since they occupy one of the most dynamic areas of the landscape. As such an examination of the variation of the vegetation along the various reaches of the Kakum river is a very important source of information on its dynamics. It has been observed that the riparian vegetation in the upper reaches of the river is much denser comprising very tall and big trees.

Most of these trees are very old since in the Upper reaches, because of the enforcement of the regulation of not cutting trees close to the river is in line. Some very old trees found included “Kwesi Arko Nkatee”, “Dua Annyoo”, “Odum” etc. thus, even though evidence of logging was found within these reaches, most of the logging takes place several kilometers away from the river itself. This accounts for the stability of the reaches in the upper catchment as found by Mackin (1956) that the essential cause of the drastic difference in channel characteristics is the difference in bank resistance due to presence or absence of bank vegetation. The type and density of the bank vegetation which was very close to being of a tropical forest type in the upper reaches could increase the bank strength through binding of the sediment by root masses Millar and Quick (1993). This accounts for the nearly absent wash load as well as the confined nature and narrow width in these reaches. Thus, even the alluvial channels found in the upper reaches were confined as a result of the vegetation characteristics.

Notwithstanding, some few pieces of evidence of degradation were found very close to the reaches in the upper catchment especially at Kokode and Bun Kofi as shown in Plates 34 and 35.

Plate 34: Evidence of forest degradation in Kokode (upper section)

Source: Field survey (2017)

Plate 35: Evidence of forest degradation at Bun Kofi (upper section)
Source: Field survey (2017)

Interestingly, the magnitude of the planform response to changes in bank vegetation varies greatly, with some rivers being relatively insensitive as observed by Trimble (1997). The scenario/situation in these two reaches of the Upper sections confirms the observation of Millar and Quick (1993) that rivers with densely vegetated banks comprising those with "thick" bank vegetation indicated relative insensitivity to changes in bank vegetation. However, unlike in the study by Miller and Quick, the destruction of this riparian vegetation have not actually widened the channel or precipitated any major destabilization or planform metamorphosis at these reaches.

The situation in the middle and lower reaches are however different. In the middle section, the vegetation is mainly a secondary forest of very thin trees with very tiny leaves. These trees have however grown to considerable heights but per their nature, they cannot be as big as those found in the upper reaches. Again with this kind of vegetation and due to the presence of the dam causing the lake, the banks keep widening and deepening as a result of the sparse bank vegetation (Miller, 2000). In other words, the banks of the middle section are very sensitive and so during the rainy season, the channel widens and gradually it has attained its current width even though it could be crossed like a big gutter initially. For about ten years, there has been a prohibition on the felling of trees near the river, nonetheless, the trees which have been used for such afforestation cannot strongly bind the soil. Thus the lake morphology and the banks of the middle section of the Kakum river influence the channel in two ways, as put by Konsoer et al. (2016) and Walter et al. (2010); i) the lake is acting as a temporal base level in which most of the sediment carried from the upper reaches are being deposited and this gives material/sediment with properties that affect resistance to erosion from fluvial action and mass failure ii) secondary riparian vegetation decreases the erosion-resistance properties of the banks by decreasing the tensile strength through the kind of root-reinforcement and by decreasing cohesion through soil development.

In the lower reaches, the main vegetation found along the banks are the mangroves interspersed with grasses. Observations made from the field confirms the findings of Spalding, Blasco and Field (1997), Spiers (1999), UNEP (2004) and MAP (2005) that much of what remains of the world’s mangrove forests now is in a degraded condition. Again, as identified by Alongi (2002) and Giri et al. (2008), the degradation of the mangrove forest at the lower reaches of the Kakum river is mainly caused by conversion to agriculture, overexploitation for housing development. Plate 36 shows evidence of mangrove degradation in the lower section.

Plate 36: Evidence of Mangrove Degradation (lower section)

Source: Field survey (2017)

As a result of these means of degradation of the mangrove forests, most parts of the lower banks are now covered by grasses and very few areas by the mangroves. This thus threatens the unique and important services provided by the mangrove forests as elaborated by Duke et al. (2007), as acting as natural barriers among others. A similar observation to that of, Andrews (1984) and Hey and Thorne (1986) a similar observation was made in this study that grass-covered banks tend to widen than with forest-covered banks. Plate 37 shows a grass-covered bank in the lower Kakum which is gradually widening.

Plate 37: Grasses covering river banks (lower section)

Source: Field survey (2017)

Based on the results on the particle size distribution and the variations in the morphologies of the various sections of the Kakum river basin, the diagnostic features of the various reaches within the Kakum river basin was summarized in Table 14 after the classification by Buffington and Montgomery (1997).

Table 14: Diagnostic Features of the Channel Reaches in the Kakum River Basin

	Bedrock	Cascade	Pool Riffle	Plane	Lake	Dune Ripple
Bank Vegetation	Forest	Forest	Secondary	Secondary	Secondary	Mangrove Forest
Typical Bed Material	Rock	Boulders	Cobble-gravel	Sand	Fine Sand	Sand/Silt
Typical Bank Sediment	Rocks	Boulder/Gravel/Cobles	Sandy-gravel	Fine Sand-Silt	Fine Sand-Silt	Silt-Clay
Dominant Sediment sources	Weathering	Hillslope/DebrisFlow/Fluvial	Fluvial	Fluvial/Bank Failure	Fluvial	Fluvial/Bank Failure
Sediment Storage element	Pot-holes	Under/Behind Obstructions	overbank/Bedforms	Bedform	Overbank	Overbank /Bedforms
Typical Confinement	Confined	Confined	Unconfined	Confined	Unconfined	Unconfined
Sediment Transpore Regime	Bedload Dominated	Bedload Dominated	Bedload to Saltation/Suspension	Suspension	Suspension	Suspensiom
Channel Stability	Long periods	Long periods	Relatively stable	Relatively stable, but subject to major floods causing lateral channel instability	Highly unstable: Laterally & Vertically	Laterally unstable due to scour and channel widening

Source: Author's Compilation (2017)

Summary

Reach morphologies, processes, and environments allow reach-specific prediction of the likely degree and style of response of the river to a particular perturbation. The Kakum exhibits both bedrock and alluvial channel characteristics. The bedrock characteristics are very predominant in the upper reaches whiles the alluvial channel characteristics is very pronounced in the middle and lower reaches. One very unique characteristic of the basin is, flowing through both tropical and mangrove forests in the extreme sections. These striking vegetations play a significant role on the supply of materials as well as the stability of the Kakum river in general. The presence of large woody debris in the upper reaches does not affect the morphology of the upper reaches in any way. The middle and immediate upstream of the lower sections are very much unnatural due to human interventions such as the dam, bridges at both Esuekyir and Kwaprow.

Indeed, the soico-cultural context of humans influence their behavior towards such natural systems. This, as portrayed in the conceptual framework is influenced by all the sources of knowledge. The construction of dams, bridges as well as straightening and desilting of the river are known to solve some societal issues. Again, the overexploitation of the mangroves downstream of the Kakum for housing purposes is mainly to satisfy a cultural belief of the riparian resident human communities who are known for such buildings. Such is not the case of the upper reaches and so their resilience and insensitivity to plan-form metamorphosis as they are laterally confined with large and relatively immobile clasts making channel incision or bank cutting unlikely.

On the contrary, the middle and lower sections are likely to be more responsive and sensitive to altered discharge and sediment supply. This is due to their human influence and their relative bank instability suggesting that there is a systematic downstream increase in response potential to altered sediment supply or discharge (Montgomery & Buffington, 2007).

CHAPTER SEVEN

LANDUSE /LAND COVER (LULC) INFLUENCES

Introduction

This chapter aims at evaluating the impacts of Land Use and vegetation on the morphology of the Kakum river channel. To realize this objective, the United States Geological Survey (USGS) LULC classification system was employed to classify this parameter on two images of different years (1991-2016) of the same area. This generated a conversion table and map of the form of Land use in the study area.

Again, river sediments, water sediments and adjacent soil samples along the river were collected and analyzed in the laboratory to also assess if perhaps, the land use and adjacent riparian vegetation also affected these samples. This also could help assess the Kakum as a cascading channel and also determine the direction of movement. The General Analysis of Variance in GENSTAT was employed to analyze the second aspect of this objective.

In table 15 is the USGS classification system of Land use/Land cover and a general description of what they include.

Table 15: Description of Land Use/Land Cover units

Land cover/use	General description
Water	Water as includes all areas within the landmass that persistently are water covered. Categories include stream, lakes, reservoirs, bays and estuaries.
Closed forest	Forest lands have a tree-crown aerial density (crown closure percentage) of 10 percent or more, regime. Categories include deciduous, evergreen, and mixed.
Open forest	Forest lands have a tree-crown aerial density (crown closure percentage) of 5 percent. It include areas that depict sparsely located trees, shrubs and patches of bare soil. Areas of extensive grass cover and isolated thickets are classified under this category.
Built-up	Built-up comprised of areas of intensive use with structures. In this category include, community service areas (parks, playing grounds, lorry parks), residential areas, commercial and industrial areas. Also includes lands cleared in readiness for development.
Rangeland	Rangeland is comprised of areas where the potential natural vegetation is predominantly agriculture, grasses, and grass like plants, forbs, or shrubs.

Source: USGS classification system, 2007.

Results of Land Cover Classification of the Kakum river basin

State of Land Use/Land Cover classes in 1991 and 2016

In 1991, the most predominant land cover class in the Kakum Basin was open forest which occupied 58.14 % of the area, followed by the closed forest with 26.03 %. The closed forest occupied the North-western corner of the study area whiles the open forest almost occupied the other sections of the study are except the southern section which was practically covered by rangeland interspersed with built up occupying 13.78% and 1.51%

respectively. Water had the least area of occupancy in 1991 within the study area and represented only 0.54%. Table 16 and Figure 17 vividly display these in summary

Table 16: Surface Area and Changes in Land Cover units (1991 and 2016)

Land-Cover	Area in 1991 (sq./km)	%	Area in 2016 (sq./km)	%	Area Changes from 91-16 (sq./km)	% Change
Closed Forest	117.76	26.03	104.91	23.19	-12.85	-2.84
Built-Up	6.83	1.51	91.98	20.33	85.15	18.82
Open Forest	263.04	58.14	150.24	33.21	-112.81	-24.93
Range-Land	62.34	13.78	103.84	22.95	41.50	9.17
Water	2.45	0.54	1.46	0.32	-1.00	-0.22
Total	452.42	100	452.42	100		

Source: Image analysis, 2016

The most predominant land cover classes in this year were also the open and closed forest covered about 33.21% and 23.19% respectively. Even though the area being occupied by the closed forest has almost remained unchanged, that of the open forest had lost much of its land area to concentrate right below the closed forest. Built-up and rangeland have close proportions of about 20.33% and 22.95% of the total surface area. While water still occupied the least area of 0.32 % this time around.

Table 16 shows the surface and percentage areas of the various land cover classes for the years under study (1991 and 2001) and the respective changes that occurred over the years. From the Table 16, it can be observed that Open forest land cover class experienced a significant change as its surface area reduced from about 58% to 33% and lost about 24% of its original area by 2016. Nonetheless, other land cover classes including the closed forest and water also experienced some losses of about 2% and 0.2% of their original area respectively. Aside from these losses, the other two classes including built up and rangeland gained additional surface areas of about 18% and 9% of their original areas. In figure 17 is a summary of the percentage areas of the land-cover classes for the years under review in addition to the changes that have occurred over the time.

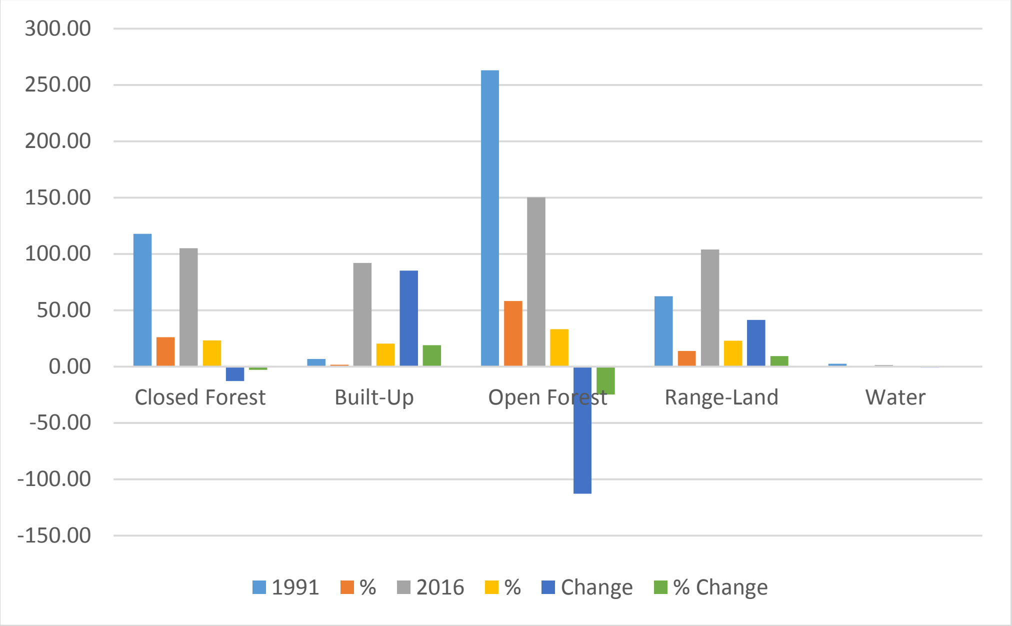


Figure 17: Land cover change and trend from1991 to 2016.

Source: Data analysis (2017)

With distinction being drawn between land cover conversions and land cover modifications, a further analysis was made to define changes that were observed in the LULC analysis. In the case of the former, it is the complete replacement or shift of one cover type by another as in the change in urban extent and deforestation whiles the latter implies more subtle changes that affect the character of the land cover without changing the classification in totality (Lambin et al., 2003). In Table 17 is a change matrix summarizing the extent of changes in the various land cover classes and the classes to which classes they were converted into.

Table 17: Land cover conversion 1991 – 2016

				1991		
		Closed Forest	Open Forest	Built-up	Water	Rangeland
2016	Closed Forest	102.16	2.06	0	0.36	0.05
		86.8%	1%	0	15%	0.1%
	Built-up	0.73	42.26	6.45	0.57	41.95
		0.6%	16%	94%	23%	67.3%
	Open Forest	11.73	131.53	0.13	0.33	6.26
		10%	50%	2%	13%	10%
	Rangeland	2.73	86.04	0.25	0.91	13.91
		2.3%	33%	4%	37%	22.3%
	Water	1.15	0.89	0	0.29	0.16
		1.0%	0.3%	0.0%	11.8	0.3%

Source: Image analysis 2016

With the predominant change affecting the open forest land cover class, it was observed that only 50% of the conversion was directed back to being the open forest. However, about 32% and 16% of the area of the open forest was converted to rangeland and built-up respectively but a slight change in the open forest converted to water. Unlike the Open forest, the closed forest retained about 87% of its area and the largest portion of its conversion went into the open forest with as little as 0.1% converting into the water. In the case of the surface area of water, because it only occupied a smaller area, a little change is very significant. From the Table, it is realized that 37% of the area of water was converted to rangeland whiles as much as 23% was converted into built-up. Only 11% of the water was lost to being water.

It was however observed that about 94% of the area of Built-up was retained whilst some insignificant proportions of built-up was converted into open forest and rangeland with no conversions of this class into water or closed forest. However, in the case of the changes in the Rangeland cover class, just about 22% of its original remained. As much as about 67% of the area of the cover class was converted into built up, whiles only 1% of this conversion went into being water.

In figure 18 is a change map showing original land cover classes and what they have been converted into.

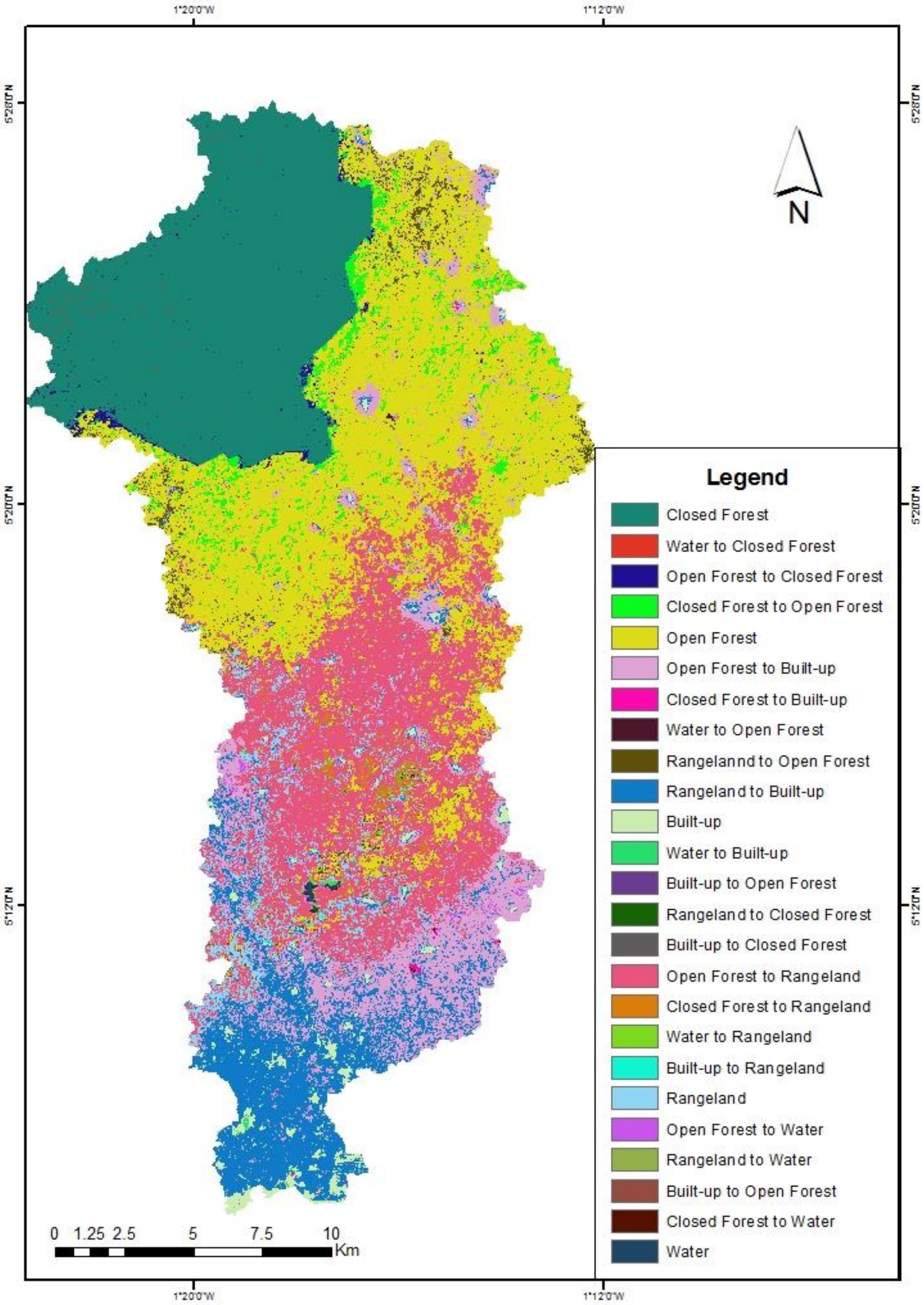


Figure 18: Change detection map.

Source: Data analysis (2017)

Results of Land-Use/Land-Cover on the Kakum River System

As a cascading system, the Kakum river has been identified as consisting of subsystems (upper, middle and lower sections) in a succession dynamically linked by the flow of mass or energy so that one subsystem's output becomes the input of another subsystem. Thus, mass or energy linking the entire Kakum river system include the soils from the adjacent hillslopes/lands, river sediments and the water being transported. As a system, the Kakum also has interconnected pathways for transporting these as well as serving as storages (Strahler, 1980). For this matter, this segment presents results on the analysis performed on the various matter. This has been done on the basis of the identified subsystems so as to correlate the various land use and the observed relationships.

Relationship among Section, Land use and Depth on Soil Nutrients

From Table 18, repeated measurements of ANOVA showed that nutrients were not significantly ($P < 0.05$) affected by Land use at varying depth. However, some nutrients including soil Nitrogen (SN), Soil Potassium (SK), Soil Phosphorus (SP), Soil Zinc (SZn) and Soil Copper (SC_U) were significantly ($P<0.05$) affected by land use and sections. Others including Soil Organic Carbon (SOC) and Soil Iron (SFe) showed no significant relationship. This is presented in the Table 19.

Table 18: Relationship between Section, Land use and Depth on Soil Nutrients

Section	Landuse	Depth	SK	SN	SOC	SP	SZn	Scu	SFe
Lower	Farming	15	0.1516	0.0674	0.732	2.2	0.47	0.549	12.1
		30	0.1049	0.0411	0.464	1.6	0.52	0.399	8.6
		45	0.175	0.0582	0.541	2.3	0.32	0.473	6.2
		60	0.1399	0.0759	0.954	1.4	0.45	0.149	3.1
	Refuse Dump	15	0.4234	0.087	0.836	71.4	5.72	0.982	17.6
		30	0.6993	0.1178	1.642	42.2	6.88	0.945	76.6
		45	0.5664	0.0665	0.8	86.8	4.08	1.076	22.9
		60	0.6062	0.0951	1.937	48.4	5.19	0.763	161.2
	Settlement	15	0.1049	0.0415	0.251	4.3	0.22	0.871	38.2
		30	0.1283	0.0304	0.134	9.4	0.32	0.87	45.8
		45	0.0932	0.0339	0.292	5.8	0.55	1.045	38.5
		60	0.0933	0.0318	0.156	15.9	0.82	0.597	45.4
Middle	Farming	15	0.0903	0.0847	1.098	2.5	0.46	0.398	109.5
		30	0.0787	0.0456	0.641	2	0.27	0.305	105.6
		45	0.0699	0.0309	0.295	2.4	0.35	0.236	57.5
		60	0.0757	0.0335	0.357	2.3	0.54	0.405	79.6
	Woodlots	15	0.0467	0.0269	0.617	2.8	0.3	0.524	27
		30	0.035	0.0409	0.388	3.8	0.4	0.075	45.1
		45	0.0466	0.0455	0.367	1.4	0.1	0.223	35.5
		60	0.0466	0.0408	0.288	3.1	0.1	0.05	28.9
Upper	Farming	15	0.0438	0.0508	1.119	2.5	1.25	0.58	139.6
		30	0.0408	0.04	0.713	2	0.57	0.646	94.4
		45	0.0379	0.0301	0.242	2.4	0.26	0.518	29

Table 18 Continued

	60	0.0321	0.0329	0.463	2.3	0.2	0.528	22.1
Secondary Vegetation	15	0.1808	0.0709	0.425	2.2	0.3	0.87	103.3
	30	0.1634	0.0632	0.328	2	0.27	0.935	67.1
	45	0.0992	0.0823	0.136	3.3	0.2	0.982	77
	60	0.1109	0.0715	0.27	1.9	0.36	1.121	78
p value		0.201	0.16	0.613	0.184	0.595	0.974	0.418
Sed		0.09032	0.02744	0.5844	12.75	1.099	0.3328	51.82
LSD		0.20291	0.05937	1.2972	26.64	4.034	0.6999	154.47

Source: Data analysis (2017)

Table 19: ANOVA Results on Sections, Land use and Soil Nutrients

Section	Landuse	SN	SOC	SK	SP	SZn	SCu	SFe
Lower	Farming	0.0606	0.673	0.1429	1.9	0.44	0.393	7.5
	Refuse damp	0.0916	1.304	0.5738	62.2	5.47	0.942	69.6
	Settlement	0.0344	0.208	0.1049	8.8	0.48	0.846	42
Middle	Farming	0.0487	0.598	0.0787	2.7	0.4	0.336	69.6
	Woodlots	0.0385	0.415	0.0437	2.8	0.22	0.218	34.1
upper	Farming	0.0384	0.634	0.0386	2.3	0.57	0.568	71.3
	Secondary vegetation	0.072	0.29	0.1386	2.4	0.28	0.977	81.4
	P Value	0.037	0.095	<.001	<.001	0.012	0.044	0.704
	Sed	0.021	0.4082	0.071	7.98	1.534	0.224	56.01
	LSD	0.04325	0.8407		16.44	3.159	0.4613	115.35

Source: Data analysis (2017)

In addition to the soil samples from the adjacent lands, river sediments were also sampled from the various sections with their different land use classes. Table 20 presents these results.

Table 20: ANOVA Results on Sections, Land use and River Sediment's Composition

Section	Landuse	Sed N	Sed OC	Sed K	Sed NO_3	Sed P	Sed Cu	Sed Fe	Sed Zn
Lower	Farming	0.09	1.418	0.131	0.637	2.159	9.619	122.2308	78.5705
	Refuse Dump	0.038	0.628	0.127	0.29	20.79	4.8422	32.438	3.6608
	Settlement	0.031	0.048	0.051	0.232	3.735	0.9449	31.5483	0.4226
Middle	Farming	0.089	1.316	0.108	0.414	8.152	6.3297	134.2782	2.0752
	Woodlots	0.219	4.171	0.562	0.646	1.176	21.0577	341.171	7.2028
Upper	Farming	0.013	0.127	0.026	0.479	8.383	3.2753	22.386	0.5824
	Secondary Veg.	0.023	0.226	0.038	0.988	5.04	4.2047	28.894	1.1131
	P value	0.434	0.123	<.001	0.049	0.061	<.001	0.105	0.004
	Sed	0.0712	1.0768	0.0829	0.2362	7.264	3.1733	77.08588	16.84558
5% level	LSD	0.1466	2.2178	0.1706	0.4865	14.9605	6.53554	158.7614	34.69413

Source: Data analysis (2017)

In Table 21, the variation in some nutrients including river K, NO_3, Cu, and Zn were very significant ($P<0.05$) with the land use and sections. However, the remaining chemicals didn't have any significant variation with the land-use in the different sections.

Again, on the relationship among the sections, land-use and water composition some of the chemicals were found to vary with these parameters significantly. These include water Ca, Mg, Fe and Zn. All the others did not have any significant relationship with the section and land-use.

Table 21: ANOVA Results on Sections, Land use and River Water Composition

Section	Landuse	W Ca	WP	WNO_3	WMg	WFe_	WCu	WZn
Lower	Farming	1	0.006	12.96	0.6	0.37	0.055	0.13
	Refuse Dump	8.51	0.023	15.43	5.2	0.98	0.09	0.09
	Settlement	0.75	0.012	14.64	0.5	1.04	0.105	0.65
Middle	Farming	0.94	0.022	28.08	0.6	1.49	0.0825	0.088
	Woodlots	1.5	0.038	14.53	0.9	2.34	0.075	0.055
Upper	Farming	0.63	0.032	14.84	0.4	3.09	0.0762	0.061
	Secondary Veg.	1.25	0.043	15.88	0.8	3.43	0.13	0.098
	P Value	0.009	0.347	0.879	0.009	0.038	0.29	0.001
	Sed	2.277	0.0127	12.759	1.38	0.331	0.03532	0.2309
	LSD	4.69	0.0261	26.278	2.84	0.682	0.07273	0.2309

Source: Data analysis (2017).

Discussions

Land Use-Land Cover Trends within the Kakum river Basin

Within the Kakum river basin, changes in land use are land cover conversions rather than modifications as some land cover extents have been completely replaced by other. For instance, from the table 17, close to about 48% of the area which used to be covered by open forest has been converted to Built-up and rangeland totally. Whiles the area occupied by built-up alone in 1991 has increased by about 18% in the area. Again, about 60% of the area of water also experienced conversions to both built-up and rangeland. These conversions change the entire classification of the area (Lambin et al., 2003).

From the results presented as shown in Table 17, the conversions can be described as proximate or direct operating at just the local level. The open forest has thus been converted to individual farms and household whiles closed forest have even been encroached on for local reason as building, firewood and even hunting thereby opening up some of these closed forests. This reinforces the assertion of Ojima et al. (1994) and Ayivor and Godon (2012) that proximate causes originate from local livelihood demands and is place-specific being influenced by the nature of the rural economy.

It is however not surprising, that the most drastic and rapid changes were changes in forest covers especially since the surface areas of the various forests (including the Open and closed forests) experienced the greatest degradation of about -25% and -3% as shown in Table 17 This has been the global trend as well as because the United Nations Food and Agriculture Organization (UN FAO) in their Global Forest resources Assesment in the year 2000 estimated that a loss of about 4.2% of natural forests existed in the

1990's but in Africa the loss was about 2.1% and this was mainly as a result of cropland expansion by smallholders (Lambin et al., 2003).

Land-use changes, notwithstanding, has been considered as a complicated scenario having the tendency to influence water availability through the increase in evapotranspiration coupled with a decrease in groundwater recharge as well as a reduction in discharge as well as consequently altering land surface processes including biogeochemistry, hydrology, and biodiversity (Klocking et al., 2002). It is also similar to forest cover changes in Madagascar, Cote D'Ivoire, and the Congo basin.

The major results of the deforestation, as indicated in Table 17, has been the increase in built-up and rangeland which includes agricultural areas as well. In the Kakum river basin, the built-up area experienced the greatest positive change. This basically can be linked to urbanization which though is experienced in the urban areas has an effect on the rural areas through the ecological footprint of cities including the consumption of prime agricultural lands in peri-urban areas for residential, infrastructure and amenities thereby blurring the distinction between cities and countryside (Lambin et al., 2003).

And truly, a very critical look at Figure 18 point out the effect of urbanization. Even though much of the area of the Kakum basin is rural, the southern portion, which is more urban shows the greatest increase in terms of built. Thus, from the Table 17, almost all the areas which used to be rangeland have been replaced totally by the built-up as a result of urbanization.

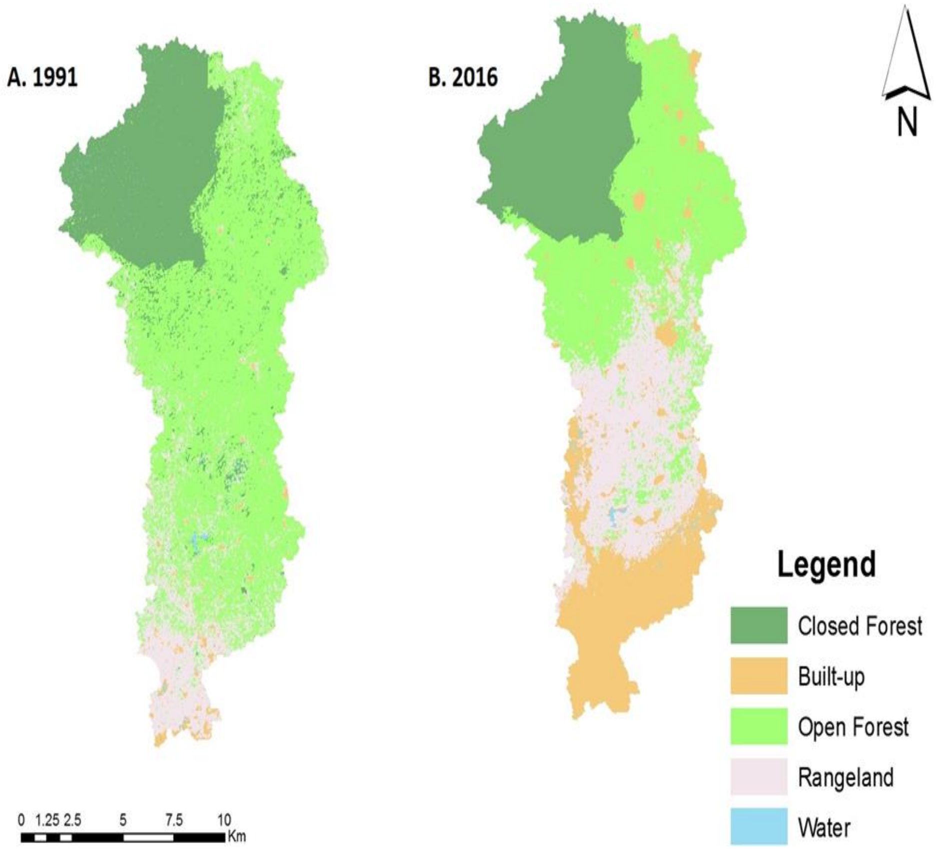


Figure 19: Land use / Land cover map of 1991 to 2016.

Source: Satellite image & orthophoto analysis-DGRP (2017)

Interestingly, the major effect of the deforestation within the Kakum basin has been increased in rangeland. Thus, the growing populace will rather occupy urban areas by degrading other natural areas, thus the effect on the open forest as seen in the map of Figure 19. The urbanization effects have led to the unmeasured and unlooked changes exhibited in the surface area of water. Because the multiplier effect of deforestation and urbanization automatically have always resulted in catchment erosion and subsequent river sedimentation, water shortage, pollution, eutrophication and other physico-chemical impacts just as found in the study on three major basins (Birim, Densu, and Ayensu) in the Okyeman traditional area by Ayivor and Gordon (2012).

These trends exhibited within the Kakum river basin are very similar to the Local trend of land-use in Ghana where agricultural is being intensified, there are conversions to urban land use to meet the growing needs of human settlements as in the Densu basin (Ayivor & Gordon, 2012). Similar also in the Birim Basin, some land use activities impacting the river include mainly farming, indiscriminate waste disposal, water extraction, deforestation for fuelwood and other domestic uses (Ansah-Asare and Asante, 2000). Again, related to what is happening in the Ayensu basin, the Kakum basin is faced with activities as unsanitary conditions such as open defecation along river banks, washing and disposal of sewage, farming close to river banks and inappropriate use of agro-chemicals by farmers within the basin (Appau-Attafuah, 2000).

Impact of Land Use Land Cover (LULC) Changes on the Geochemistry of Soil

Spatial variability/heterogeneity of soil nutrients have been found in several studies to be affected significantly by Landuse types and moderately by vegetation (Lal, Kimble, Levine, & Whitman, 1995; IPPC, 2000; Chen et al., 2005). Soil nutrients found to be very significant within the Kakum river basin include total Nitrogen (N), Potasium (K), and Phosphorus (P). Total Nitrogen was found to be very significant in the Kakum basin across all its sections. However, considering the LSD, there were not much differences or variations in the nitrogen levels in relation to the various land-use. Thus, the differences in the means of the land-use of the upper sections are not very different from those of the middle and lower sections. It, however, would have been expected that the differences in the content levels of N would have been high with respect to the farming land-use since several studies () have found high nitrogen contents to be associated with farmlands. But again, other studies () have associated such low significant differences to the fact that at the surface, these nutrients are susceptible to changes especially in areas which are dominated by soil erosion and intensive cropping which makes them tend to lose a lot of such surface soil nutrients.

Potasium (K) and Phosphorus (P) content levels, even though were found to be significant within the basin, also recorded no much differences in their content levels in relation to the various land-use with the exception of the Refuse dump land-use in the lower section. It was the only land-use whose difference from the other land-use (within and outside its section) was quite significant. K content was as high as 0.5738 cmol/kg while P levels were as high as 62.2 µg/g with LSD for both being 0.142 and 16.44 respectively. These can be explained to be the effects of urbanization and its associated increase in the use of agrochemicals to feed the growing populace. The variation in the nutrients from the computation of means, was such that, P>K>N.

Among the three heavy metals including Fe, Cu and Zn analyzed in this study, the content levels of Cu and Zn were found to be very significant whiles that of Fe was insignificant. The content levels of Cu and Zn, across the various land-use types, were not that significantly different. The sources of these metals were diverse with some being inherited from the parent materials. However, most of them were due to different land use practices such as the excessive applications of agrochemicals (Phosphate fertilizers) which was found to be a very important source of these trace metals (Zheng et al., 2005a;

Chen et al., 2005b; Gaw et al., 2006). All these are linked to the rapid rates of urbanization.

Impact of Land Use Land Cover (LULC) Changes on the Geochemistry of River Sediments

Within the Kakum river basin, the land-use effect on river sediments was found to be significant in relation to river sediment K and Nitrate. All the other nutrients in the river sediment were not so much influenced by land-use. Such variations in the amount and composition of river sediments have been formed to be the consequence of both natural and anthropogenic control factors (Jennerjahn et al., 2008).

The mean content level of river sediment K under the woodlot in the middle section was significantly different from the others and K in fluvial sediments have been related to deforestation (Christie & Fletcher, 1999; Tremblay et al., 2009; Scott et al., 2001). This discovery is somewhat not surprising. This is because, as from figure 19, increase in built up in the lower section of the basin led to the deforestation of open forest in the middle section without sparing forest immediately around the river. It was until quite recently that the forestry commission of Ghana planted acacia trees and gave a buffer within the middle section in which such activities should not take place. Deforestation in this section of the basin have basically been for agriculture and residential purposes since land is now very scarce in the lower sections of the basin. Thus, much of the middle section which used to be rural are now experiencing the ecological footprints of urbanization so have become peri-urban.

River sediment NO_3 also did not show any significant differences across the different land-use with the exception of that related to the Forest which was 0.988 and the LSD was 0.4865. Meanwhile, Nitrate in river sediment have been found in several studies to be relatively lower with densely vegetated areas rather than agriculture dominated regions due to the application of artificial fertilizers and organic manure (Turner & Rabalais 1991; Soman 1999; Filoso et al., 2003; Jennerjahn et al., 2004; Ahearn et al., 2005; Voss et.al., 2006). However, this could be explained that the river as a cascading system is not stagnant with its energy and matter, and so the possibility of the accumulation of such sediments in those reaches of the upper section. Again, the interaction between water and dead plant and animal remains at the bottom of the river as well as firm rock deposits have been added as other sources of nitrates rivers (Aggarwal et al., 2000; Adeyemo, 2003). Thus, with a lot of varying plants and animals, such interaction could as well explain the significant difference observed in the river sediment NO_3 levels. The variation in the nutrients with the Kakum river basin, from the computation of means, however, is such that, $K>NO_3$.

The trace metals found to be very significant in relation to the river sediments were the Cu and Zn. There were some observed significant differences in the content levels with respect to some land use. For instance, the mean value of Cu under the secondary vegetation land-use of the middle section was significantly different (21.0577) from all the others whiles the mean value of Zn under farming in the lower section was also significantly different (78.570) from all the others. The variation in the trace metals in the sediments of the Kakum river basin, from the computation of means, however, is such that Cu>Zn.

Impact of Land Use Land Cover (LULC) Changes on the Geochemistry of River Water

Some studies have established, that once the role of different land use combinations is known in an area, water quality can potentially be improved (Amiri & Nakane, 2006; Woli et al., 2002; Jarvie et al., 2002). Analysis of the relationship between land-use and water quality within the Kakum basin showed that Ca and Mg were very affected by land-use. All the other quality indicators did not show any significant levels including water P and water NO_3. The differences in the content levels over the different land-use did not vary much with respect to the Ca and Mg with the exception of levels found under the Refuse dump (Ca = 8.51 and Mg=5.2) in the lower section of the basin. Calcium and magnesium, however, occur in water naturally because of the earth's crust which gives rivers generally about 1-2 ppm calcium and 4 ppm magnesium content. These, aside from giving the water its taste, are also responsible for water hardness. Thus, higher levels have been sourced from fertilizer application and from cattle feed (WHO, 2006; Eisenberg, 1992).

Three main reasons can, therefore, be assigned to this situation. Firstly, the location of the refuse dump at the very mouth of the river basin acts as a sink which receives all the fertilizers which may have washed these chemicals into the basin aside those from the parent material. Also, because of its confluence with the Surowi river within which cattle are reared, it is possible that as a cascading system, some of these compositions are derived from there. Moreover, strong positive relationships have been observed between agriculture, urbanization and water nutrient concentrations. Forest clearing for farms and pastures leads to an increase of overland flow of several solutes such as phosphates, nitrate, calcium, magnesium (Mendiguchıa et al., 2007; Germer et al., 2009, Michaud & Wieger, 2011).

Under the trace metal analysis, the variation of land-use with Fe and Zn contents with the basin was quite significant. The differences in the content levels were much unique in the upper section under the Forest and Farming land use and in the middle section under the secondary forests land-use systems. The main source of these can be explained as being from the parent materials as most of the rocks here are exposed.

Summary

There has been significant Land cover conversion within the Kakum river basin over the eleven-year period under review. Dominating these conversions is that of open forest being converted to built-up and rangeland. This trend has had profound impact on the surface area of water such that its area has decreased from about 0.54% to about 0.32%. Direct human activities such as building within the floodplains of the river as well as indirect activities such as deforestation around the river channel has reduced the quantity of water by means of sedimentation and increased evapotranspiration. Aside from affecting the quantity of water, deforestation, refuse disposal and other agrochemicals being used have also affected the geochemistry of the river sediment as well as that of the water itself. The Geomorphic context of the Kakum river including its soils and vegetation have been affected by human behavior, hence the consequences on the Kakum river system.

CHAPTER EIGHT

LOWER KAKUM PLANFORM DYNAMICS

Introduction

Baishya and Sahariah (2015) have described river channel networks as being unconfined to a symmetrical track but changing over time and space according to variation in hydrology, sediment load, and uncommonly active tectonics. As such, this objective sort out to assess dynamics in the banklines of the Lower Kakum River. The lower reaches of the Kakum River have been purposively used for this assessment because mostly, it is in alluvial plains of lower reaches that rivers normally develop a single-twisting course, termed meander

To accomplish this, two sets of data (Orthophotos) spanning over eleven years (2005-2016) were analyzed. The former was obtained from the Department of Geography and Regional Planning (DGRP) of the University of Cape Coast. The latter was collected with the help of Phantom 3 professional Unmanned Aerial Vehicle (UAV). Using the mangrove vegetation as the border of the land area, riverbanks were digitized from the two orthophotos using ArcGIS Software 10.3. To analyze the riverbank morphology the study employed the Digital Shoreline Analysis System (DSAS), an extension to ArcMap 10.3 TM developed by the USGS. DSAS calculates rate-of-change statistics from several historic riverbank lines. First, the software generates transects that are cast perpendicular to the baseline at a user-defined interval. The intersections of transects and the riverbank lines along the defined baseline were then used to calculate the rate-of-change statistics. The rate of change statistics included the net shoreline movement (NSM) and endpoint rate (EPR) and these helped to calculate erosion/accretion rates as well as the extent of riverbank migration.

Landscapes can be divided into process domains, in which particular combinations of geomorphic processes operate (Montgomery, 1999). The lower section was sub-divided into three reaches within based on the dominant riparian land-use. Two maps each represent the changes in both the right and left banks of the various reaches.

Riparian Land use

The reaches along which the bank line dynamics were studied baes on the predominant land use namely built-up reach, agricultural reach and the Mangrove forest reach (Fig. 20 and Table 22). From upstream the built-up zone consisted of areas that had some form of construction or building 30 meters from the river. It covered an area from Kwaprow village through to Amamoma village (Fig. 20).

In the agricultural reaches, crops such as cassava, maize, and vegetables (particularly okra, pepper, and tomatoes) have been cultivated on relatively elevated lands. This area consists of the mud flats and the saline marshes towards Abakam village which are not extensively cultivated. Due to the scarcity of arable land, the same plots are cultivated continuously with heavy use of fertilizers.

The Mangrove forest is a natural ecosystem with a high conservation value for its biodiversity and scenic beauty which covers an area of about 28.740 ha and it is composed of the red (Rhizophora) and black (Avicennia) mangroves. Both natural and anthropogenic factors in the mangrove areas have caused several changes along the Kakum river channel (Fig. 20). In Fig.

20 is a map showing the location and extent of the various reaches within the lower section of the Kakum river for bank line dynamics.

From Table 22, the characteristics of the various reaches including the length, average slope and sinuosity have been given. It is observed that the longest reach is that found within the agriculture land-use whiles the shortest is the reach in the built-up area. However, the average slope decreases as one approaches the mangroves or the mouth of the river from 1.4% to about 0.9%.

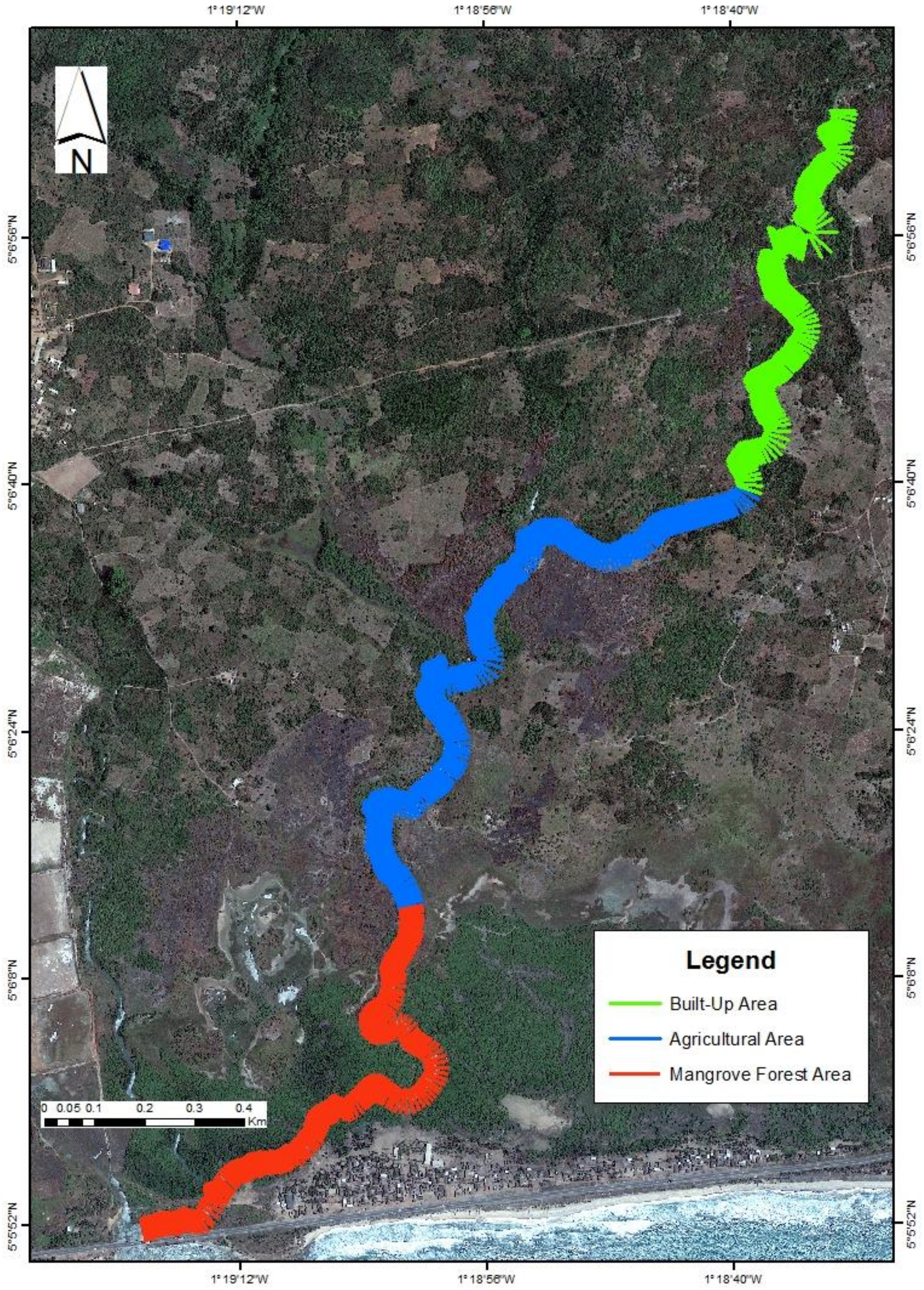


Figure 20: Lower reaches of bankline dynamics.

Source: Orthophoto analysis (2017)

Results

Sinuosity, which is a measure of how a river deviates from a straight line varies from 1.4 in the lower reaches to 1.5 in the upper reaches. This index has been used to categorize alluvial river patterns straight, meandering or braided rivers (Leopold & Wolman 1957). Rivers with the sinuosity of less than 1.1 are described as straight, those between 1.1 and 1.5 are sinuous, and meandering rivers have a sinuosity of greater than 1.5. Therefore, sinuous rivers are the transition between straight and meandering rivers. Based on the results in Table 22, the lower Kakum exhibits sinuous patterns since the calculated sinuosity are around 1.5.

Table 22: Stream Characteristics of the three Land use zone of the lower Kakum River

River Reach	Length (Km)	Average Slope (%)	Sinuosity
Built-up	0.99	1.4	1.5
Agriculture	1.69	1.1	1.4
Mangrove Forest	1.22	0.9	1.4

Source: Data analysis (2017)

Bankline Changes of the Lower Kakum

The erosion rates and deposition events varied among the different riparian land-uses. The analysis summarizes rates of river bank shoreline change as averages of the erosion or accretion values in each zone, along with maximum and minimum values. Positive (+) EPR and NSM values represent areas of accretion whilst negative (-) values represent areas of erosion.

Changes in the river bank lines along the built-up reaches throughout the 11year period for both the right and left banks were measured using 229 transects along the river and the results have been presented in Fig.21 Erosion and accretion rate varied throughout the study period along the built-up reach in both the right and left banks

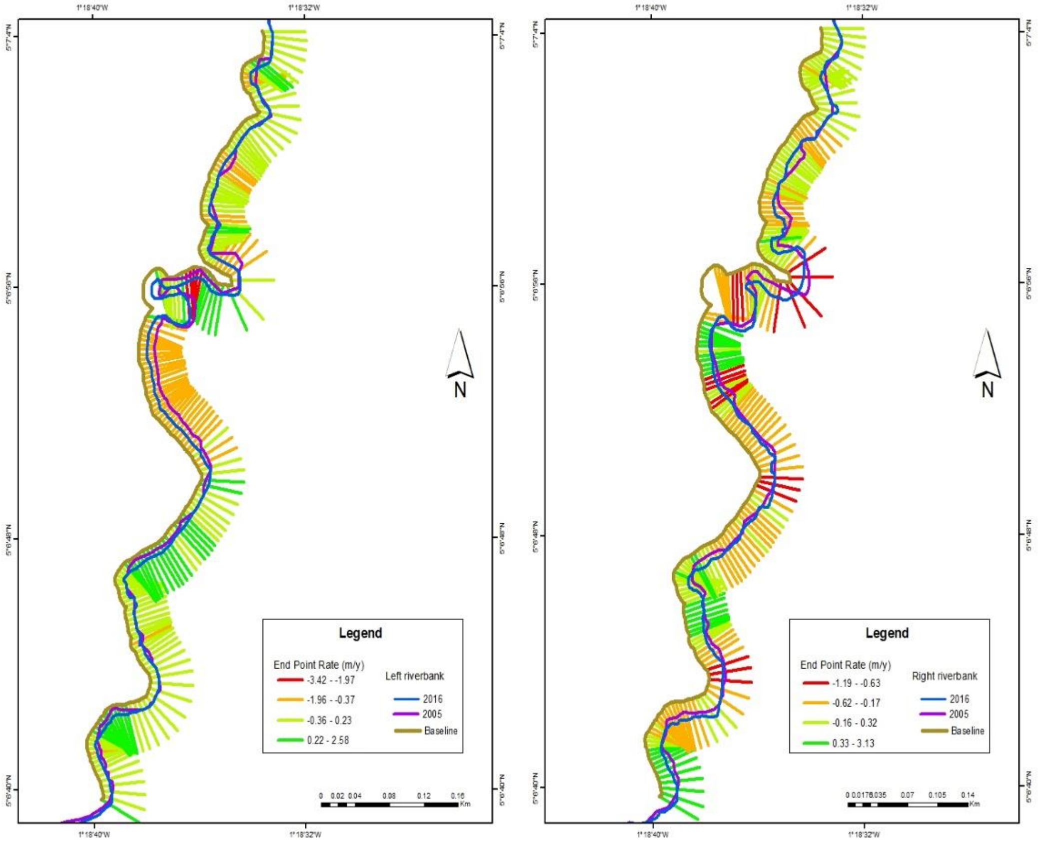


Figure 21: Rate of Bankline change along the built-up riparian reach of lower Kakum river.

Source: Data analysis (2017)

Erosion rate peaked at -3.42 m/y in the left bank whilst in the right bank erosion went only as high as -1.19m/y. However, the right bank experienced a relatively higher rate of accretion (3.13m/y) than the left bank whose accretion rate was 2.58m/y. Thus in the built-up reaches of the lower Kakum over the eleven (11) year period, the left bank experienced a relatively higher rate of erosion whiles the right bank, on the contrary, acknowledged a higher rate of deposition.

Net Shoreline Movement (NSM) reports the distance between the oldest and youngest shoreline features for each transect (DSAS v 3.1). Fig. 22 presents the results of the migration or shifts in the entire bank line of the built-up reach with positive shifts indicating movement of the bank to the right side and negative shifts indicating movement to the left side. From the NSM graph in Fig. 22, both right and left bank experienced a shift towards the leftward direction confirming a greater rate of bank erosion. Again, the linear equation of both the right and left bank lines i.e. ($y=-0.0102x+0.3655$ and $y=-0.0189x+0.4855$) respectively were observed to be having a negative slope indicating the direction of bankline shift as buildings increase within this reach.

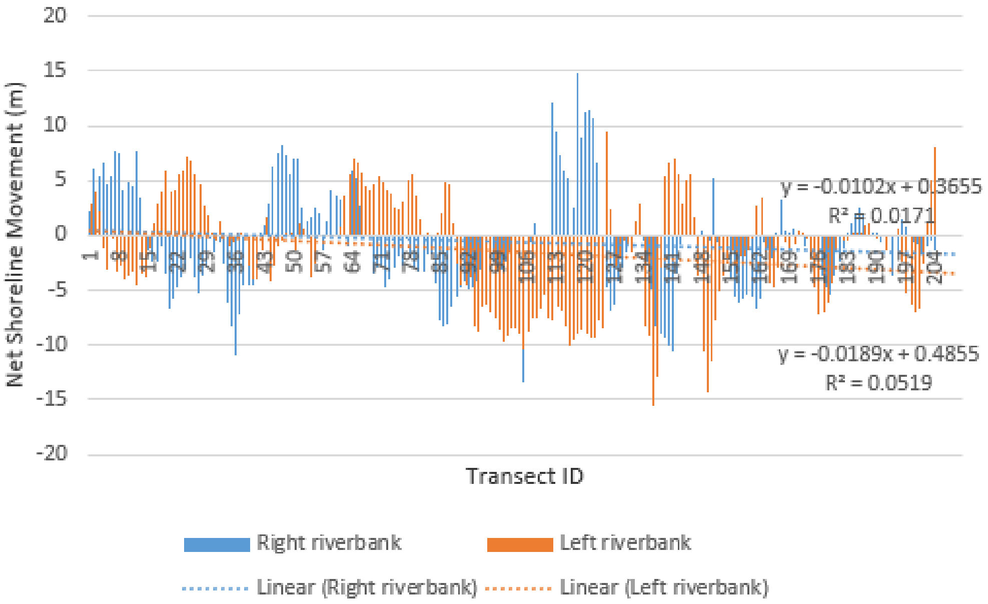


Figure 22: River bank shifting assessment for built up riparian reach.

Source: Data analysis (2017)

In the farming riparian reach, 327 transects were generated. From Fig 23, over the 11 year period, the rate of erosion in the left bank varied from as low as -0.14 to as high as -2.25m/y whiles along the right bank erosion varied from -0.31m/y to -1.00m/y. With respect to accretion in the left bank, the rate varied from 0.25m/y to 3.20m/y whiles that of the right bank varied from 0.04m/y to 0.70. Thus in comparison, the left bank experienced a relatively higher rate of both erosion and accretion than the right bank.

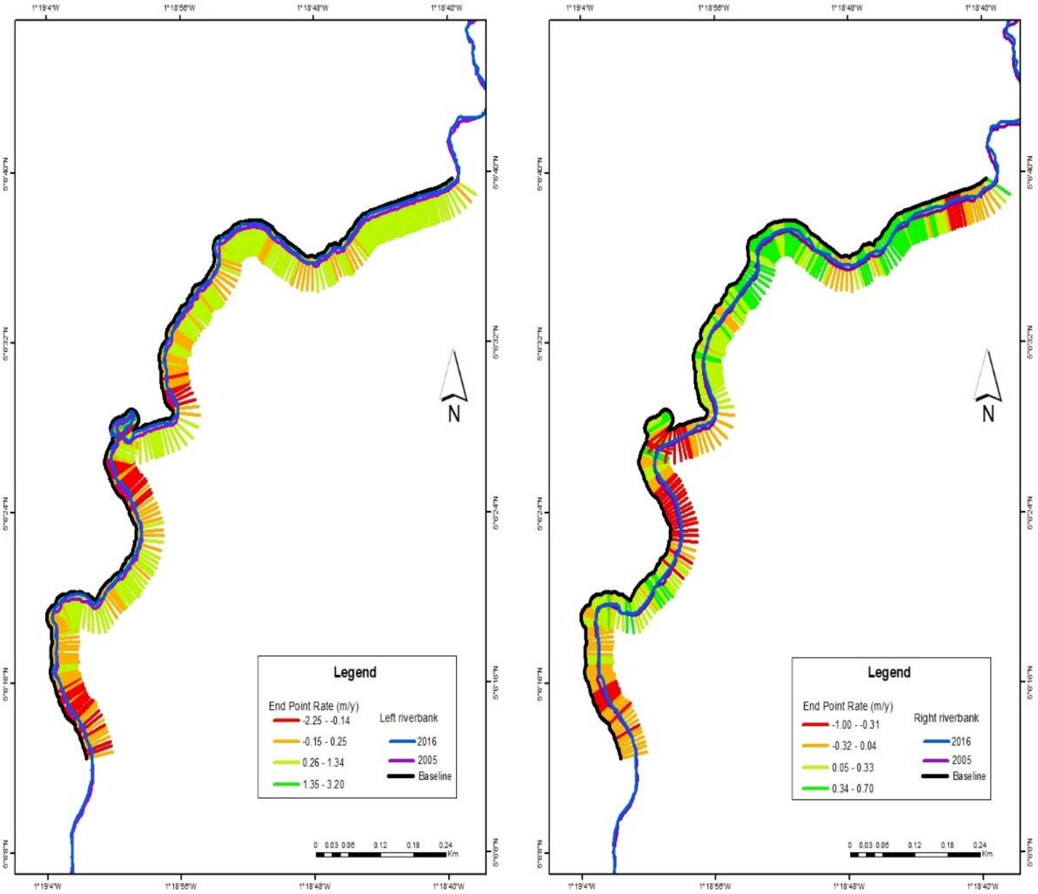


Figure 23: Rate of Bankline change along the farming riparian reach of lower Kakum river.

Source: Data analysis (2017)

From Fig. 24, it can be observed that the movement of both the right and left banks towards the left or as a result of erosion was almost insignificant. However, the process of accretion was quite of great impact on both left and right banks. This is further confirmed by the equation of the linear trend line of both right and left banks having a positive slope i.e. (y = 0.017x+1.5632 and y= 0.014x+0.3335) respectively.

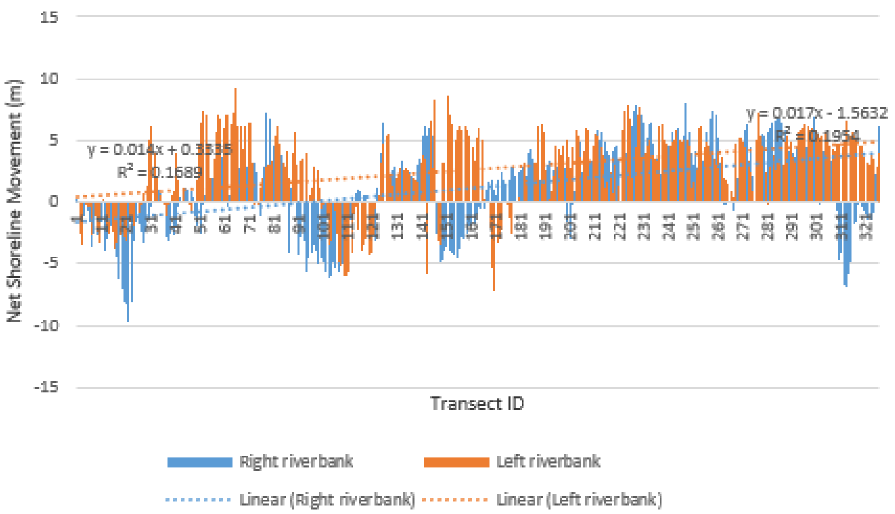


Figure 24: River bank shifting assessment for agriculture riparian reach.
Source: Data analysis (2017)

At the mangrove reach, 247 transects were cast. Examining the erosion rate along the left bank, it was found that it varied from -0.17m/year to -1.00my and along the right bank, -0.31m/y to -0.99m/y. In terms of accretion along the left bank, the rate varied from 0.16m/y to 0.94m/y whiles in the case of the right bank, accretion rate varied from 0.10m/y to 1.21m/y. Thus, the rate of erosion and accretion in the left and right banks of the mangrove reach were almost similar.

The net shoreline movement of this reach portrayed in figure 25 and 26 reveals quite an insignificant rate of erosion in both banks except the 153-193 transect. Otherwise, the banks of this reach could be described as relatively stable even though the slope of the trend line equation both right and left banks depict a negative direction of movement i.e. (y=-0.0192x+4.166 and y=-0.0148x+4.3516) respectively.

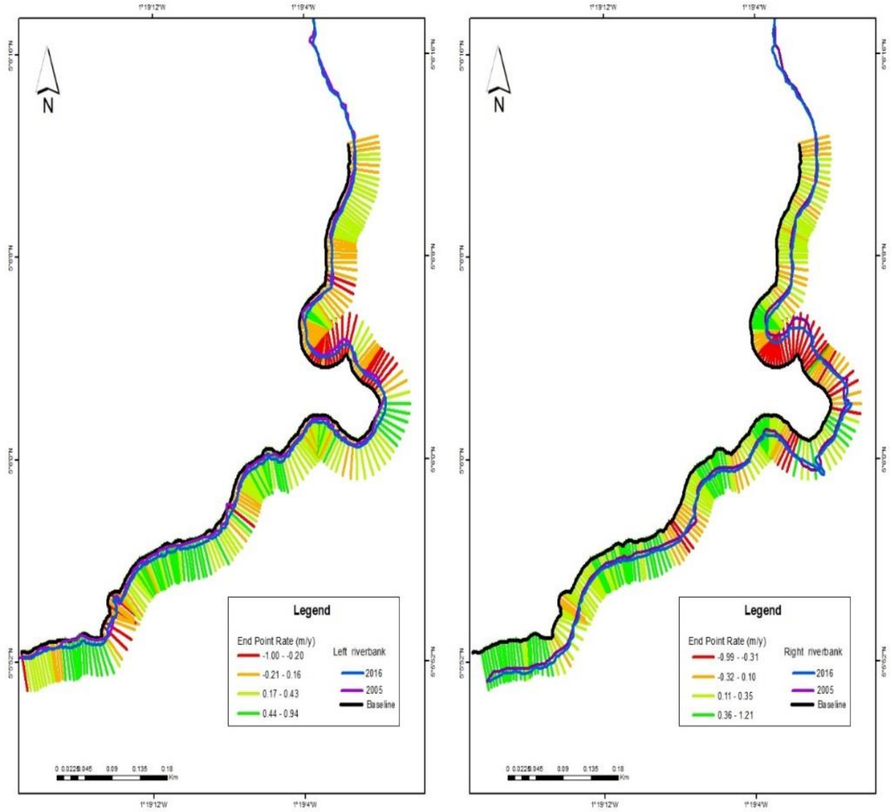
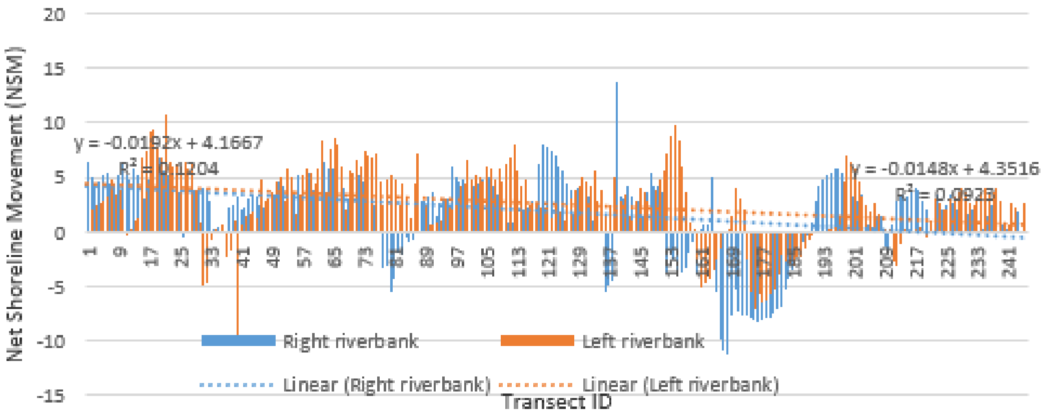


Figure 25: Bankline changes along the mangrove riparian reach.



Source: Data analysis (2017)

Figure 26: River bank shifting assessment for mangrove riparian reach.

Source: Data analysis (2017)

Table 23: A summary of End Point Rate (EPR) and Direction of Net Shoreline Movement (NSM)

Riparian landuse	LEFT BANK EPR (m/y)	Trend-line equation	RIGHT BANK EPR (m/y)	Trend-line equation
Built-up (E)	-0.36 to -3.42	Y=-0.0189x+0.4855	-0.16 to -1.19	Y=-0.0102x+0.365
(A)	0.22 to 2.58	R^2 = 0.0519	0.32 to 3.13	R^2=0.3655
Agriculture (E)	-0.14 to -2.25	Y=0.014x+0.3335	-0.31 to -1.00	Y=0.017x-1.5652
(A)	0.25 to 3.20	R^2= 0.1689	0.04 to 0.70	R^2=0.1954
Mangrove (E)	-0.20 to -1.00	Y=0.0148x+4.3516	-0.31 to -0.99	Y=-0.0192x+4.166
(A)	0.16 to 0.94	R^2= 0.1204	0.11 to 1.21	R^2=0.0923

Source: Data analysis (2017)

Therefore from the basal endpoint control concept, Input < output resulting in excess basal capacity with an excess basal capacity to transport sediment than that supplied. This results in basal lowering and under-cutting, increasing bank height and angle whiles consequently decreasing bank stability. Thus, the relatively higher slope of 1.4%

Within the agriculture riparian reaches, deposition is relatively higher than erosion. The reason being that there is the supply of sediments from both the built-up reaches and the adjacent farmlands leads to Input > output leading to impeded removal especially as slope decreases relatively. Increase in such basal accumulation decreases bank angle and height, whiles buttressing the bank. Bank stability is therefore increased and the rates of sediment input and bank retreat is decreased. Again, as one moves along these reaches, one observes a soil type relatively rich in silt and clay (shown in plate 39). This gives some form of real cohesion from the chemical bonds associated with clay and silt particles (Thorne, 1990; Langendoen et al., 2009).

Plate 39: Silt/Clay- rich soil types

Source: Field survey (2017)

In the mangrove forest riparian reaches, accretion was almost predominant but for a major meander loop in the river's course where erosion was very pronounced. Stability within this reach was derived from both cohesion from chemical bonds associated with clay particles and mechanical from plant roots or riparian vegetation (Thorne, 1990; Langendoen et al., 2009). Mangroves along this reach, are very developed and new ones are always sprouting on both left and right banks, thus the binding effect of vegetation roots and rhizomes decreasing erosion as shown in Plate 40.

Plate 40: Chemical and mechanical bonds by clay particles and mangrove rhyzomes
Source: Field survey (2017)

This form of stability offered by the mangroves and their rhizomes are not prevalent on the outer neck of the meander loop where the erosion along this reach was relatively intense as portrayed in plate 41.

Plate 41: Channel undercutting of grassy banks

Source: Field survey (2017)

This situation is due to the fact that on the banks on the outer neck of the meander loop, vegetation is purely grass though some pockets of mangroves exist but a bit farther from the banks. The relative stability offered by the grass in the upper part of the banks, has resulted in the undercutting of the lower portions thereby producing an overhanging cantilevered block as shown in Plate 41 (Goswami,2002).

Again, erosion in channel bends is a very common phenomenon where streamflow detach material from the outside bank and deposits sediment along the other (Leopold & Wolman, 1960 Nanson & Croke, 1992). Thus, lateral outside erosion and accretion of material on the inside of channel bends often occur simultaneously (Nanson & Hickin, 1986). And so, it can be observed from the figure on the mangroves forest reaches that, almost the areas inside the bend has a green color, indicating more accretion than erosion.

Summary

As a dynamic system, the lower reaches were evaluated to measure how it has evolved in the phase of the changing land-use/land-cover patterns within the Kakum river basin. This was done to ascertain how the Kakum as a non-linear system differs. With the various limiting factors, only the lower reaches could be evaluated for this and was based on Campbell (1989). In terms of the behavior of the Kakum overtime, the left bank of the Kakum River in the lower section have been found to be relatively unstable than the right bank. This stability again varies across the different riparian land-uses with the bank-lines in the built up area being relative unstable than that in the others in the Agricultural and Mangrove land-use areas. In terms of its response to stimulus, the main stimulus causing changes in this section of the river was human induced. Whiles the roots of the mangroves as well as the clayey and silty nature of the soils at the mangrove reaches was found to offer some mechanical cohesion thereby increasing stability in this area.

CHAPTER NINE

PROPOSED MANAGEMENT APPROACHES

Introduction

Basin-specific management approaches within watersheds is vital for the protection and maximum utilization of every nation's waterways. After adopting a holistic approach to understanding the characteristics, processes and impact factors on the Kakum river basin from its headwater areas to the lower river reaches, it is essential to propose effective management strategies to regulate human actions.

Management Approaches

River basin morphometry is a very important means of analyzing the hydro-geomorphic behavior including flooding, soil erosion and ground water recharge. The most important of these behaviors in the Kakum river basin relates to the issue with flooding in some parts of the basin especially during the rainy season and that of ground water recharge due to some studies forecasting future water scarcity of the basin. In view of this, the flooding status of the basin can be inferred from some parameters including the bifurcation ration and the areal parameters such as length of overland flow, drainage density as well as the shape parameters. Based on these parameters, the basin is expected to produce minimum storm response as there is a longer flow duration before run-off gets concentrated in channels. Again, the basin possesses permeable subsurface materials, good vegetation cover and low relief which results in more infiltration capacity of the basin. Flooding in some parts of the basin especially around Kwaprow is therefore an induced phenomenon due to human activity and should be tackled by re-examining human influences especially in that part of the basin.

With the characteristic of permeable subsurface materials, good vegetation cover and low relief which results in more infiltration capacity and can therefore be good sites for ground water recharge, explorations could be made in this regard. As this can be explored to help reduce the water quantity issues which have come about mainly as a result of human actions through the reduction in the surface area of the Kakum River by means of encroachment, siltation and exposure to high evapotranspiration rates. This is inferred from the infiltration capacity, basin configuration, drainage density, drainage texture and length of overland flow. The basin is likely to possess ample ground water resources.

Even though relief parameters including basin relief and ruggedness number suggest the basin’s susceptibility to soil erosion which can be aggravated in times of rainfall, this susceptibility could be minimized by the dense vegetation cover especially in the upper section. Therefore, sources of sediments supplied and leading to siltation is basically from the increased rate of deforestation and so should be keenly monitored.

A basin-wide holistic approach indicated that past management of the Kakum river basin lacked integration. From this study, was realized that the upper section of the Kakum is much more stable than the lower section and this is largely due to the interruption of sediments continuum by the Brimsu dam and engineering works including meander cutting and sediment dredging in the middle and immediate upper parts of the lower section. The remaining lower parts are experiencing river bed degradation due to the increase in transport capacity, increase in slope and further removal of vegetation on the river banks. This, should be controlled as it has implications of lowering the groundwater table, destabilizing instream structures as well as deteriorating habitat quality within the basin. Hence, the inter-linkages between the hydrological, ecological and socio-economic components of the Kakum river basin must be adequately considered by decision-makers such as politicians, land-use planners and water engineers. This is essential to sustain fresh water resources and maintain such dynamic living systems in the long term.

Focusing only on specific-sites and lacking a regional watershed perspective may be the causes of invalid river management practices. Findings from this study indicates that urban and agricultural land use primarily affects river water and sediment quality. Therefore, the urban and peri-urban areas within the basin should be critical areas of river restoration or management. Among the several techniques which could be adopted include preserving and conserving the near tropical forest, secondary vegetation as well as the mangrove forest in the upper, middle and lower catchments respectively as they may have profound effects on water quality by filtering sediment and sediment-borne pollutants carried in surface runoff. The expansion of urban areas, especially impervious areas as well as their disposal of refuse, agro-farming and management of livestock close to the river should be restricted.

Human actions especially in the middle and lower catchment of the basin must be keenly monitored as it has profound implications on the stability of the river bankline. It therefore necessitates the establishment of plans to minimize human intervention to natural flow of the river as well as ensure the growth of the riparian mangrove forest so that the ecological and biological diversity of the floodplain area will be more prosperous and healthier.

Summary

Most of the issues being faced in the Kakum river basin is human-induced in nature. As such specific plans must be adapted to ensure that this small but important system is restored and conserved due to it socio-economic as well as hydro-ecological importance. This can help reduce the current global fresh water crises.

CHAPTER TEN

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

Summary

Upon the dynamics and complexities of river systems, they are the most common and preferred units for water-related issues as far as humans are concerned (Klocking & Haberlandt, 2002). In order to better understand such systems and derive the utmost benefits, whiles ensuring their sustainability, the holistic approach has been proposed by Gregory et al. (1992) as offering a comprehensive analysis and such approach has been adopted in several international water-related studies. This situation is somewhat different in Ghana as far as drainage basin studies are concerned. This study therefore set out to use this approach to study the Kakum river basin in the Central region of Ghana which seemed to be undergoing a lot of challenges in terms of its form, water supply and water quality. The main objective was to understand the controls on the morphology of the Kakum river system and to accomplish this, the study was guided by the folling questions:

- What are the hydro-geomorphic characteristics of the Kakum river basin?
- How distinct are the channel reach substrates within the Kakum river basin?
- What is the nature of land-use / land- cover and vegetation influences on the Kakum river system?
- How has the planform of the lower reaches been affected?
- What management approaches can be adapted to reverse the effect of headwater and downstream processes on the Kakum river?

The case study design was adopted for this study and data types included both field (soil samples, water samples, and river sediment samples) and secondary data (Toposheets, DEM, and Satellite images). Among analyses applied on the data were morphometric analysis, morphologic analysis (bedform and particle size distribution), chemical analysis (soils, river sediment and river water), land-use/land-cover analysis and river bankline analysis. Data analysis was done by the use of Observation, Arc map 10.3, DSAS, Genstat and Excel.

Major Findings

The Kakum river basin is a fairly elongated third order basin characterized by steep to moderate slope, not affected by geological structures but local topography, dense vegetation, and permeable subsurface materials. Its hydro-geomorphic attribute include longer hydrograph peak (no flash floods), relatively low soil erosion rates, better hydraulic conductivity, and good ground water potential.

The upper reaches dominated by both bedrock and alluvial channels, largely unconfined with steep slopes, large clasts and characterized with dense near- tropical vegetation which affect supply of sediments, color of water and patterns on bedrock.

Particles found in the upper reach were mainly coarse sand and were well sorted whereas those found in the middle and lower reaches were predominantly alluvial channels with a lot of human interventions such as dams, farms, bridges, sediment dredging and deforestation. Vegetation is mainly secondary in the middle section and mangroves in the lower section. Particles found were also coarse sand which were poorly sorted.

Land-use/Land-cover mainly in the built-up and rangeland, have had profound influence on the morphology (form), cascades (water and sediment) as well as the processes and responses of the river system. It greatly reduced the surface area of the water land-use from 0.52% to 0.32% from 1991 to 2016. There is also the presence of some chemicals such as Potassium (K) Nitrate (NO_{3}), Copper (Cu), Iron (Fe) and Zinc (Zn) in both river water and river sediments. The processes of deforestation, agriculture and refuse disposal were responded to by the levels of these chemicals in the water even though not all these chemicals were derived from the various land-use.

The planform of the middle lower reaches has been affected by such human interventions namely dams, sediment dredging and meander cutting in the middle and upper parts of the lower catchment. The river has responded to these through the processes of erosion and accretion. Bank width changes have also been observed in areas where the mangrove has been degraded to grass indicating the variations in the cohesion offered by both mangroves and grass.

Even though the Kakum basin is small, it is of great socio-economic and hydro-ecological importance. As such, a major board should be set to overlook the various riparian activities that go on within the basin since this basin-wide holistic approach has indicated that past management lacked integration.

Conclusion

- In studying the hydrogeomorphic attributes of river systems, morphometric analysis of drainage basins is a vital starting point for undertaking drainage basin studies. By this, the hydrogomorphc characteristics of the Kakum basin has been brought to bear through the evaluation of the main morphometric parameters including the linear, relief and the areal. Thus, local topography and lithological structures have carved the pattern of the Kakum and not geological structures like lineaments and faults. And by possessing characteristics susch as good vegetation, resistant soils and a comparatively plain terrain which gives the basin good of permeability and an increased flow length, the basin under normal circumstances should not be flood-prone.

- As a dynamic system, the various sections of the Kakum River have been found to be variable through the River styles approach which views the river landscape at four scales including the catchment, landscape units, river styles and geomorphic units. By this, the study has characterized the Kakum River as a mixed Channel, possessing both characteristics of and alluvial channel and a bedrock channel. The bedrock characteristics were very predominant in the upper reaches whiles the alluvial channel characteristics were very pronounced in the middle and lower reaches. One very unique characteristic of the basin is, flowing through both tropical and mangrove forests in the extreme sections. However, the presence of large woody debris in the upper reaches does not affect the morphology of the upper reaches in any way. But the middle and immediate upstream of the lower sections have been very much affected by athropogenic influences such as dams and bridges at both Esuekyir and Kwaprow.
- The quantity and quality of water as well as the sediments in the Kakum river ha mainly been affected by anthropogenic landuse and

land cover conversions. These mainly include direct human activities such as building within the floodplains of the river as well as indirect activities such as deforestation around the river channel which has resulted in the decreament in the surface area of water from 0.54% to about 0.32%.and also affecting the presence of some chemicals such as Fe, Cu, Zn and others in the river water and sediments.

- Geomorphic phenomenon such as bankline shifts are better appreciated over relatively longer periods of time. This is because, geomorphic processes are gradual and imperceptible. Thus, the time concept in the systems theory is very essential though rarely emphasized. However, anthropogenic factors are the main stimuli causing changes in the lower section of the Kakum River. But stability of the river at certain portions have been as a result of the roots of the mangroves as well as the clayey and silty nature of the soils at the mangrove reaches which offer some mechanical cohesion thereby increasing stability in this area.

Recommendations

- The Ghana Water Company Limited should incorporate the hydro-geomorphic analysis of basins in their quest to supply quality and sufficient water. This will help reduce cost of pumping water from very distant basins and the cost of treatment of the pumped water as most of the surface water bodies in Ghana are under serious quality threats.
- In an attempt to establish river basin boards by the Water Resources Commission (WRC), smaller basins like the Kakum and it likes should

not be subdued under the relatively bigger ones but rather boards of their own should also be set. Again, such boards should be the starting point of this holistic approach with members having diverse backgrounds, from land-use planners, ecologist, structural engineers, hydrologists, geomorphologists as well as economist to the authorities of riparian communities. This will better bring to bear the "naked" facts and unsurpassed methodologies to solving the issues without compromising any of the basin's functions.

- Water related issues are global challenges which are very primary in causing poverty, hunger and unsustainability in our environments, thus, MDGs goal One (1) and Eight (8). Again, about seven (7) of the SDG's are all dependent on water;

  GOAL 1: No Poverty

  GOAL 2: Zero Hunger

  GOAL 3: Good Health and Well-being

  GOAL 6: Clean Water and Sanitation

  GOAL 7: Affordable and Clean Energy

  GOAL 11: Sustainable Cities and Communities

  GOAL 14: Life below Water

  GOAL 15: Life on Land

  These, therefore, place the burden and responsibility on each individual in every corner of the basin and the world to re-examine the way we treat our water-bodies since our own lives and that of all other living things depend on us (human beings). We as individuals, academics, patriots and citizens should also, by means of all the media forms available (Wassup, Internet, community radios), publicize such a daunting need to those less privy to such emergency change in attitude.

- The numerous benefits of mangrove ecosystems, just like those of the tropical forest cannot be under looked. However, the forestry commission of Ghana has more often than not focused all their attention to only the Tropical forests of the country to the neglect of the other kinds of forests such as the mangrove forest. The Natural resources ministry must therefore, clearly handover the management of these forest types as well to the forestry commission so as to conserve the little left in our part of the world.

Suggestions for Further Research

- Geochemistry of river water and sediments: A Seasonal Analysis on the Brimsu Lake in the Kakum river Basin of Central region, Ghana.
- Groundwater Quality in the Kakum river Basin, Central region, Ghana.
- Geochemistry of exposed Bedrocks and its effects on Water Quality: The Case of the Upper Kakum river basin.

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APPENDICES

APPENDIX A

IMAGES FROM THE FIELD

Image1: Researcher clearing site for soil sample collection at first location

Source: Field survey (2017)

Image 2: Soil sample collection and bagging

Source: Field survey (2017)

Image 3: Clearing of site for soil sample collection

Source: Field survey (2017)

Image 4: Soil sample collection at a forested area near the Kakum River

Source: Field survey (2017)

Image 5: Researcher and her assistants on their way for sample collection

Source: Field survey (2017)

Image 6: Observation of river sediments collected at a location closer to bamboo vegetation

Source: Field survey (2017)

Image 7: A pegmatite rock layer laying across the channel of the Kakum River at Obosando (Upper Section)

Source: Field survey (2017)

Image 8: Researcher and assistants on exposed bedrock channel (behind is a picture of rapid) (Upper Section)

Source: Field survey (2017)

Image 9: Brimsu Dam on the middle section of the Kakum river

Source: Field survey (2017)

APPENDIX B

RAW DATA FROM LABORATORY ANALYSIS ON RIVER SEDIMENTS

LAND-USE TYPES AND CORRESPONDING RIVER SEDIMENTS AT DIFFERENT SECTIONS WITHIN THE KAKUM RIVER BASIN

				River Sediment						
Sections	Community	Rep	Land use	NO_3 (mg/100g)	%OC	%OM	R%N	P(µg/g)	K (cmol/kg)	Fe(mg/L)
Lower	Brimsu	1	Farming	0.580	1.569	2.704	0.090	2.181	0.133	240.484
	Brimsu	2	Farming	0.695	1.267	2.184	0.090	2.137	0.1281	3.9779
	Esuakyir	1	Refuse damp	0.423	0.441	0.760	0.030	54.215	0.174	2.2438
	Esuakyir	2	Refuse damp	0.278	0.484	0.834	0.020	26.714	0.123	1.9319
	Kwaprow	1	Settlement	0.222	0.048	0.082	0.013	3.730	0.053	29.6179
	Kwaprow	2	Settlement	0.242	0.048	0.082	0.049	3.739	0.049	33.4787
	Ahiaboboe	1	Refuse damp	0.166	0.112	0.194	0.006	13.975	0.052	8.3191
	Ahiaboboe	2	Refuse damp	0.180	0.136	0.234	0.011	20.446	0.042	5.0965
	Ahia. Mang	1	Refuse damp	0.394	1.862	3.210	0.075	5.563	0.183	72.6548
	Ahia. Mang	2	Refuse damp	0.297	0.730	1.259	0.084	3.823	0.186	104.382
Middle	Aboenu	1	Farming	0.656	0.106	0.184	0.013	8.040	0.247	20.2317
	Aboenu	2	Farming	0.354	0.068	0.118	0.013	6.452	0.137	18.2287
	Abaasa	1	Farming	0.604	7.069	12.186	0.492	1.900	0.256	440.785
	Abaasa	2	Farming	0.238	0.147	0.253	0.013	2.495	0.032	25.3099
	Abaasa Bun	1	Farming	0.276	1.140	1.966	0.064	14.113	0.081	226.678
	Abaasa Bun	2	Farming	0.305	1.802	3.106	0.106	20.060	0.067	307.469
	Sorodoful	1	Woodlots	0.647	5.469	9.429	0.196	0.797	0.867	350.614
	Sorodoful	2	Woodlots	0.645	2.873	4.953	0.243	1.555	0.256	331.728
	Kwanotum	1	Farming	0.552	0.081	0.140	0.006	5.936	0.021	17.7766
	Kwanotum	2	Farming	0.325	0.111	0.191	0.008	6.222	0.025	17.7466

Upper	Nsain	1	Farming	0.439	0.076	0.131	0.013	8.931	0.028	19.7171
	Nsain	2	Farming	0.217	0.111	0.191	0.012	9.524	0.025	24.7080
	Yebi	1	Farming	1.101	0.134	0.232	0.010	4.046	0.028	15.4079
	Yebi	2	Farming	0.328	0.095	0.163	0.014	6.616	0.028	19.7547
	Obosando	1	Secondary veg.	1.506	0.130	0.224	0.016	7.457	0.021	19.0483
	Obosando	2	Secondary veg.	1.667	0.178	0.307	0.021	7.603	0.0212	20.4509
	Bun Kofi	1	Farming	0.489	0.347	0.598	0.023	5.601	0.024	34.9443
	Bun Kofi	2	Farming	0.326	0.134	0.232	0.016	10.846	0.028	35.7153
	Kokode	1	Farming	0.357	0.066	0.114	0.009	15.583	0.021	15.1728
	Kokode	2	Farming	0.577	0.050	0.086	0.010	5.915	0.025	13.6680

RCu(mg/L)	RZn(mg/L)
12.7845664	3.46411
6.4535	153.677
1.5222	8.4985
1.1643	2.1552
1.0467	0.4979
0.8431	0.3472
3.4995	1.4913
1.4989	1.6239
9.6877	4.2695
11.6808	3.9266
1.2447	0.4984
3.1256	0.6200
14.6082	5.3942
5.3488	1.6924
11.6947	3.3592
11.7527	4.0913
16.5136	8.6776
25.6019	5.7281
0.7217	0.5726
2.1412	0.3731
2.7424	0.5831
2.0216	0.9734
2.4851	0.2731
2.1175	0.1241
4.7907	0.7693
3.8145	0.6225
5.8528	1.5376
5.0663	0.8197
3.2532	0.1738
2.6635	0.1741
5.8806	2.0683
2.3331	0.9924

APPENDIX C

RAW DATA FROM LABORATORY ANALYSIS ON SOIL PARAMETERS

LAND USE TYPE AND CORRESPONDING SOIL NUTRIENTS AT VARIOUS DEPTH WITHIN DIFFERENT SECTIONS OF THE KAKUM RIVER BASIN

At depth of 15 cm

				Soil Parameters							
Sections	Community	Rep	Land use	N	P	K	OC	OM	fe	Cu	Zn
Lower	Brimsu	1	Farming	0.067	1.159	0.047	0.460	0.794	7.494	0.30	0.348
	Brimsu	2	Farming	0.068	2.020	0.163	0.468	0.806	9.652	0.80	0.599
	Esuakyir	1	Refuse damp	0.100	56.132	0.630	0.843	1.453	34.49	1.548	3.197
	Esuakyir	2	Refuse damp	0.121	52.276	0.628	0.812	1.401	26.294	0.649	1.898
	Kwaprow	1	Settlement	0.042	8.606	0.117	0.230	0.396	49.957	1.044	0.199
	Kwaprow	2	Settlement	0.041	10.201	0.140	0.039	0.067	41.656	0.698	0.249
	Ahiaboboe	1	Refuse damp	0.064	39.562	0.349	0.772	1.331	18.6879	0.05	0.50
	Ahiaboboe	2	Refuse damp	0.088	43.087	0.466	0.505	0.871	14.6746	0.25	0.40
	Ahia. Mang	1	Refuse damp	0.069	61.039	1.122	3.074	5.300	201.11	2.05	12.94
	Ahia. Mang	2	Refuse damp	0.079	1.196	1.000	3.846	6.631	164.45	1.35	15.38
Middle	Aboenu	1	Farming	0.075	1.777	0.093	0.579	0.997	38.38	0.55	0.20
	Aboenu	2	Farming	0.087	0.338	0.093	0.653	1.126	53.20	0.64	0.45
	Abaasa	1	Farming	0.017	1.150	0.047	0.421	0.726	57.83	0.05	0.55
	Abaasa	2	Farming	0.017	1.648	0.047	0.231	0.398	50.66	0.35	0.60
	Abaasa Bun	1	Farming	0.178	2.839	0.093	1.083	1.867	281.97	0.35	0.69
	Abaasa Bun	2	Farming	0.176	5.079	0.117	1.046	1.803	234.65	0.45	0.55

	Sorodoful	1	Woodlots	0.028	2.527	0.023	0.505	0.871	40.54	0.40	0.35
	Sorodoful	2	Woodlots	0.025	5.168	0.047	0.271	0.466	49.72	0.65	0.25
	Kwanotum	1	Farming	0.062	1.226	0.070	0.579	0.999	76.14	0.10	0.55
	Kwanotum	2	Farming	0.065	4.076	0.070	0.536	0.925	51.69	0.70	0.10
Upper	Nsain	1	Farming	0.064	1.292	0.047	0.728	1.256	369.63	0.30	0.65
	Nsain	2	Farming	0.115	1.560	0.023	0.775	1.336	194.36	0.55	0.40
	Yebi	1	Farming	0.033	2.014	0.047	0.698	1.203	45.47	0.45	0.35
	Yebi	2	Farming	0.036	1.722	0.047	0.271	0.468	15.64	0.45	0.50
	Obosando	1	Secondary veg.	0.023	1.408	0.234	0.270	0.466	26.46	0.94	0.50
	Obosando	2	Secondary veg.	0.035	1.867	0.303	0.193	0.333	48.57	0.40	0.35
	Bun Kofi	1	Farming	0.017	0.602	0.023	1.461	2.518	28.85	0.50	3.08
	Bun Kofi	2	Farming	0.020	6.443	0.023	0.846	1.458	27.97	0.30	3.05
	Kokode	1	Farming	0.059	1.244	0.070	0.464	0.800	79.36	1.10	1.05
	Kokode	2	Farming	0.062	0.798	0.047	0.465	0.801	91.46	1.00	0.95
	Kokoado	1	Secondary veg.	0.104	1.661	0.047	0.539	0.928	162.08	1.19	0.25
	Kokoado	2	Secondary veg.	0.122	3.240	0.070	0.312	0.537	107.43	0.95	0.10

At depth of 30 cm

				Soil Parameters							
Sections	Community	Rep	Land use	N	P	K	OC	OM	fe	Cu	Zn
Lower	Brimsu	1	Farming	0.039	2.327	0.163	0.810	1.397	7.494	0.55	0.550
	Brimsu	2	Farming	0.043	1.990	0.140	0.653	1.126	9.652	0.25	0.498
	Esuakyir	1	Refuse damp	0.109	92.894	0.513	1.051	1.812	34.49	1.346	2.093
	Esuakyir	2	Refuse damp	0.079	91.649	0.511	1.148	1.980	26.294	1.488	1.836
	Kwaprow	1	Settlement	0.029	5.167	0.093	0.232	0.400	49.957	0.897	0.299
	Kwaprow	2	Settlement	0.032	3.346	0.117	0.270	0.465	41.656	0.843	0.347
	Ahiaboboe	1	Refuse damp	0.086	41.376	0.140	0.698	1.203	18.6879	1.04	5.12
	Ahiaboboe	2	Refuse damp	0.109	124.348	0.163	0.578	0.997	14.6746	0.75	4.70
	Ahia. Mang	1	Refuse damp	0.153	35.066	0.653	0.615	1.060	201.11	0.80	14.22
	Ahia. Mang	2	Refuse damp	0.171	43.159	0.561	0.925	1.594	164.45	0.25	13.29
Middle	Aboenu	1	Farming	0.046	3.383	0.070	0.770	1.328	38.38	0.50	0.25
	Aboenu	2	Farming	0.040	0.813	0.093	0.810	1.396	53.20	0.65	0.15
	Abaasa	1	Farming	0.016	1.814	0.047	0.270	0.465	57.83	0.20	0.35
	Abaasa	2	Farming	0.014	4.393	0.023	0.193	0.333	50.66	0.15	0.50
	Abaasa Bun	1	Farming	0.077	4.717	0.187	2.740	4.724	281.97	0.10	0.45
	Abaasa Bun	2	Farming	0.071	3.786	0.186	2.541	4.381	234.65	0.20	0.15
	Sorodoful	1	Woodlots	0.040	3.213	0.047	0.731	1.260	40.54	0.10	0.45
	Sorodoful	2	Woodlots	0.041	2.371	0.047	0.503	0.867	49.72	0.05	0.35
	Kwanotum	1	Farming	0.048	1.664	0.047	0.767	1.323	76.14	0.25	0.20
	Kwanotum	2	Farming	0.053	4.095	0.070	0.694	1.197	51.69	0.40	0.10
Upper	Nsain	1	Farming	0.099	1.398	0.047	0.778	1.341	369.63	0.30	0.45
	Nsain	2	Farming	0.062	3.261	0.047	0.729	1.256	194.36	0.25	0.20

	Yebi	1	Farming	0.030	1.657	0.047	0.387	0.667	45.47	0.25	0.20
	Yebi	2	Farming	0.024	1.662	0.047	0.540	0.931	15.64	0.79	0.40
	Obosando	1	Secondary veg.	0.021	1.402	0.326	0.460	0.793	26.46	1.10	0.40
	Obosando	2	Secondary veg.	0.013	1.785	0.304	0.273	0.470	48.57	0.60	0.25
	Bun Kofi	1	Farming	0.013	3.992	0.047	2.763	4.763	9.95	0.40	1.00
	Bun Kofi	2	Farming	0.008	4.795	0.023	2.558	4.409	7.55	0.70	0.65
	Kokode	1	Farming	0.035	1.224	0.047	0.697	1.202	66.92	1.10	1.05
	Kokode	2	Farming	0.049	1.725	0.047	0.502	0.866	45.80	1.39	0.64
	Kokoado	1	Secondary veg.	0.088	3.722	0.047	0.348	0.600	85.49	0.90	0.20
	Kokoado	2	Secondary veg.	0.131	2.083	0.047	0.620	1.068	108.03	1.15	0.25

At depth of 45 cm

				Soil Parameters							
Sections	Community	Rep	Land use	N	P	K	OC	OM	fe	Cu	Zn
Lower	Brimsu	1	Farming	0.058	2.395	0.186	0.465	0.802	7.739	0.20	0.347
	Brimsu	2	Farming	0.059	2.205	0.164	0.617	1.064	4.587	0.75	0.299
	Esuakyir	1	Refuse damp	0.035	126.385	0.326	0.272	0.469	19.5419	0.746	0.696
	Esuakyir	2	Refuse damp	0.039	111.743	0.374	0.193	0.332	23.0768	0.249	0.696
	Kwaprow	1	Settlement	0.032	5.718	0.093	0.428	0.738	33.908	0.799	0.449
	Kwaprow	2	Settlement	0.036	5.935	0.093	0.155	0.267	43.097	1.291	0.645
	Ahiaboboe	1	Refuse damp	0.080	35.563	0.744	1.046	1.803	7.73326	0.80	4.17
	Ahiaboboe	2	Refuse damp	0.092	36.637	0.560	1.084	1.868	11.2292	0.40	4.74
	Ahia. Mang	1	Refuse damp	0.077	89.615	0.743	0.934	1.610	34.37	2.28	7.13
	Ahia. Mang	2	Refuse damp	0.077	121.088	0.651	1.271	2.191	41.62	1.99	7.06
Middle	Aboenu	1	Farming	0.039	0.065	0.070	0.385	0.663	32.89	0.15	0.40
	Aboenu	2	Farming	0.030	2.594	0.093	0.269	0.464	25.63	0.65	0.40
	Abaasa	1	Farming	0.009	11.176	0.023	0.078	0.134	27.55	0.15	0.50
	Abaasa	2	Farming	0.004	4.214	0.023	0.116	0.201	19.57	0.10	0.40
	Abaasa Bun	1	Farming	0.029	5.145	0.070	0.429	0.739	86.67	0.05	0.05
	Abaasa Bun	2	Farming	0.026	1.841	0.140	0.351	0.605	168.92	0.05	0.60
	Sorodoful	1	Woodlots	0.038	1.191	0.047	0.348	0.601	32.47	0.20	0.10
	Sorodoful	2	Woodlots	0.053	1.703	0.047	0.385	0.663	38.46	0.25	0.10
	Kwanotum	1	Farming	0.054	1.626	0.070	0.117	0.201	54.97	0.45	0.25
	Kwanotum	2	Farming	0.056	1.037	0.070	0.614	1.058	43.91	0.30	0.25
Upper	Nsain	1	Farming	0.055	1.565	0.023	0.308	0.531	56.25	0.10	0.35
	Nsain	2	Farming	0.050	1.598	0.047	0.542	0.935	38.18	0.05	0.05

	Yebi	1	Farming	0.015	2.068	0.047	-0.273	-0.470	30.44	0.45	0.30
	Yebi	2	Farming	0.017	1.205	0.047	0.155	0.267	17.87	0.45	0.15
	Obosando	1	Secondary veg.	0.040	2.920	0.140	-0.231	-0.398	25.03	0.95	0.15
	Obosando	2	Secondary veg.	0.056	1.446	0.163	0.349	0.602	108.91	0.60	0.50
	Bun Kofi	1	Farming	0.007	4.851	0.023	0.154	0.266	1.84	0.40	0.30
	Bun Kofi	2	Farming	0.008	4.909	0.023	0.506	0.873	2.49	0.30	0.10
	Kokode	1	Farming	0.048	1.057	0.047	0.116	0.200	46.78	0.95	0.50
	Kokode	2	Farming	0.041	1.671	0.047	0.423	0.730	38.33	1.45	0.35
	Kokoado	1	Secondary veg.	0.095	2.346	0.047	0.116	0.201	80.26	1.15	0.05
	Kokoado	2	Secondary veg.	0.138	6.313	0.047	0.308	0.532	93.99	1.24	0.10

At depth of 60cm

				Soil Parameters							
Sections	Community	Rep	Land use	N	P	K	OC	OM	fe	Cu	Zn
Lower	Brimsu	1	Farming	0.076	1.633	0.140	0.973	1.677	5.582	0.05	0.498
	Brimsu	2	Farming	0.076	1.141	0.140	0.934	1.611	0.598	0.25	0.398
	Esuakyir	1	Refuse damp	0.035	122.776	0.327	0.386	0.666	40.441	0.596	1.043
	Esuakyir	2	Refuse damp	0.034	41.579	0.396	0.345	0.595	47.561	0.899	1.099
	Kwaprow	1	Settlement	0.034	13.567	0.140	0.155	0.268	39.632	0.695	0.795
	Kwaprow	2	Settlement	0.030	18.173	0.047	0.156	0.268	51.165	0.500	0.849
	Ahiaboboe	1	Refuse damp	0.067	42.491	0.630	0.464	0.799	1.64781	1.29	6.44
	Ahiaboboe	2	Refuse damp	0.048	57.316	0.607	0.619	1.066	12.5087	0.80	5.69
	Ahia. Mang	1	Refuse damp	0.218	11.186	0.887	5.241	9.036	444.76	0.40	7.94
	Ahia. Mang	2	Refuse damp	0.170	14.796	0.791	4.565	7.869	420.17	0.60	8.91
Middle	Aboenu	1	Farming	0.043	0.134	0.116	0.424	0.731	27.72	0.25	0.50
	Aboenu	2	Farming	0.038	0.771	0.093	0.270	0.465	23.18	0.40	0.40
	Abaasa	1	Farming	0.004	4.185	0.023	0.117	0.202	17.59	0.30	0.50
	Abaasa	2	Farming	0.008	3.011	0.047	0.153	0.264	11.05	0.05	0.30
	Abaasa Bun	1	Farming	0.042	2.237	0.093	0.542	0.934	304.15	0.60	0.55
	Abaasa Bun	2	Farming	0.044	2.706	0.093	0.307	0.530	181.21	0.20	0.70
	Sorodoful	1	Woodlots	0.039	1.242	0.047	0.230	0.396	25.69	0.05	0.15
	Sorodoful	2	Woodlots	0.043	5.031	0.047	0.346	0.597	32.02	0.05	0.05
	Kwanotum	1	Farming	0.044	1.227	0.070	0.501	0.865	35.95	0.95	0.95
	Kwanotum	2	Farming	0.043	1.099	0.070	0.541	0.933	35.63	0.50	0.40
Upper	Nsain	1	Farming	0.056	1.119	0.023	0.612	1.055	26.14	0.40	0.05
	Nsain	2	Farming	0.062	0.854	0.047	0.656	1.131	44.64	0.20	0.30

	Yebi	1	Farming	0.023	3.653	0.047	0.307	0.530	13.73	0.35	0.25
	Yebi	2	Farming	0.024	1.252	0.047	0.192	0.332	18.35	0.15	0.45
	Obosando	1	Secondary veg.	0.057	1.387	0.163	0.234	0.403	41.44	0.35	0.40
	Obosando	2	Secondary veg.	0.065	1.620	0.187	0.233	0.401	31.81	0.45	0.15
	Bun Kofi	1	Farming	0.007	4.497	0.023	0.701	1.209	9.10	0.55	0.15
	Bun Kofi	2	Farming	0.007	5.298	0.023	0.501	0.864	2.83	0.30	0.20
	Kokode	1	Farming	0.036	0.846	0.047	0.307	0.529	22.01	1.14	0.05
	Kokode	2	Farming	0.048	0.794	0.000	0.429	0.739	40.19	1.14	0.15
	Kokoado	1	Secondary veg.	0.081	3.169	0.047	0.308	0.531	89.08	1.95	0.50
	Kokoado	2	Secondary veg.	0.084	1.449	0.047	0.308	0.530	149.65	1.74	0.40

APPENDIX D

RAW DATA FROM LABORATORY ANALYSIS ON WATER NUTRIENTS

LAND USE TYPES AND CORRESPONDING WATER NUTRIENTS AT DIFFERENT SECTION OF THE KAKUM RIVER BASIN

				Water Nutrients						
Sections	Community	Rep	Land use	NO_3(mg/L)	Ca(mg/L)	Mg(mg/L)	P(mg/L)	Fe(mg/L)	Cu(mg/L)	Zn(mg/L)
Lower	Brimsu	1	Farming	13.35	0.00	0.0	0.007	0.38	0.05	0.13
	Brimsu	2	Farming	12.57	2.00	1.2	0.005	0.36	0.06	0.13
	Esuakyir	1	Refuse damp	14.92	1.00	0.6	0.005	0.84	0.06	0.11
	Esuakyir	2	Refuse damp	19.75	0.00	0.0	0.007	0.85	0.08	0.1
	Kwaprow	1	Settlement	14.47	0.00	0.0	0.012	1.05	0.1	0.16
	Kwaprow	2	Settlement	14.81	1.50	0.9	0.012	1.03	0.11	1.14
	Ahiaboboe	1	Refuse damp	17.39	11.01	6.7	0.043	1.30	0.1	0.11
	Ahiaboboe	2	Refuse damp	13.80	13.01	7.9	0.043	1.40	0.11	0.1
	Ahia. Mang	1	Refuse damp	12.23	12.01	7.3	0.020	0.73	0.09	0.06
Lower	Brimsu	1	Farming	13.35	0.00	0.0	0.007	0.38	0.05	0.13
	Brimsu	2	Farming	12.57	2.00	1.2	0.005	0.36	0.06	0.13
	Esuakyir	1	Refuse damp	14.92	1.00	0.6	0.005	0.84	0.06	0.11
	Esuakyir	2	Refuse damp	19.75	0.00	0.0	0.007	0.85	0.08	0.1
	Kwaprow	1	Settlement	14.47	0.00	0.0	0.012	1.05	0.1	0.16
	Kwaprow	2	Settlement	14.81	1.50	0.9	0.012	1.03	0.11	1.14
	Ahiaboboe	1	Refuse damp	17.39	11.01	6.7	0.043	1.30	0.1	0.11
	Ahiaboboe	2	Refuse damp	13.80	13.01	7.9	0.043	1.40	0.11	0.1
	Ahia. Mang	1	Refuse damp	12.23	12.01	7.3	0.020	0.73	0.09	0.06
	Ahia. Mang	2	Refuse damp	14.47	14.01	8.5	0.019	0.75	0.1	0.06
Middle	Aboenu	1	Farming	15.15	1.00	0.6	0.041	2.38	0.01	0.04
	Aboenu	2	Farming	14.25	0.00	0.0	0.043	2.40	0.02	0.03

	Abaasa	1	Farming	76.30	1.00	0.6	0.007	1.03	0.12	0.07
	Abaasa	2	Farming	77.42	2.00	1.2	0.005	1.05	0.11	0.05
	Abaasa Bun	1	Farming	8.98	1.00	0.6	0.005	1.49	0.1	0.11
	Abaasa Bun	2	Farming	3.25	1.00	0.6	0.007	1.51	0.1	0.1
	Sorodoful	1	Woodlots	14.47	1.00	0.6	0.036	1.82	0.05	0.04
	Sorodoful	2	Woodlots	14.59	2.00	1.2	0.039	2.86	0.1	0.07
	Kwanotum	1	Farming	14.47	0.00	0.0	0.032	1.05	0.1	0.16
	Kwanotum	2	Farming	14.81	1.50	0.9	0.036	1.03	0.1	0.14