GIS-BASED FLOOD PREDICTION OF THE BLACK VOLTA IN A CLIMATE CHANGE SCENARIO

CASE STUDY: THE DIKPE CATCHMENT IN THE LAWRA DISTRICT OF THE UPPER WEST REGION

By

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DECLARATION

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

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ABSTRACT

Understanding the basic relationships between rainfall and runoff is vital for effective management of flood water. The Lawra District of the Upper West Region (the driest region in Ghana) has experienced periodic and devastating flash flood resulting from high intensity short duration rainfall, a characteristic of semi-arid and arid regions. Many methodologies have been applied such as using Digital Elevation Model (DEM) for hydrological modelling and watershed delineation. In this work delineated catchment area computed in HEC-HMS is used for flood volume computation. Statistical analysis showed the correlation between rainfall and flow rates and their variability and using different statistical approaches for determining which analysis best fit a particular parameter for forecasting. Time Series, Trend Analysis, Moving Average, Weighted Moving Average, Exponential Smoothing, Percentage Growth and Seasonality, were used for analysis on 31 years of data. For 2011 the observed average values were 894.48mm, 1044.26m^3/s and 28.8°C for rainfall, flow rates and temperature respectively. Trend and seasonality analysis best responded to the forecasting of the parameters with 902.52mm, 1056.26m^3/s and 28.70°C for annual average. Annual mean rainfall intensities above 1000mm can cause flood but those above 1100mm are more likely to cause severe damages. There is a significant change in temperature over long periods whereas changes for short periods are quite minimal. Lumped Hydrological modelling with remote sensing data and GIS techniques for flood forecasting is possible using temperature, rainfall and flow rates. Severe flood events are now more probable as a result of increasing temperatures in the Upper West Region of Ghana.

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LIST OF ABBREVIATION

ANN	-	Artificial Neural Network
ARMA	-	Auto-Regressive Moving Average
CN	-	Curve Number
DEM	-	Digital Elevation Model
DSM	-	Digital Surface Model
DTM	-	Digital Terrain Model
EBM	-	Energy Balance Model
EWS	-	Early Warning Service
GCM	-	Global Climate Model/ General Circulation Model
GIS	-	Geographic Information System
GoG	-	Government of Ghana
HEC-HMS	-	Hydrologic Engineering Centre-Hydrologic Modelling System
HEC-RAS	-	Hydrologic Engineering Centre-River Analysis System
HSD	-	Hydrological Services Department
IPCC	-	Intergovernmental Panel on Climate Change
MAD	-	Mean Absolute Deviation
MAPE	-	Mean Absolute Percentage Error
MSE	-	Mean Square Error
NADMO	-	National Disaster Management Organization
NDVI	-	Normalized Difference Vegetation Index
NDWI	-	Normalized Difference Water Index
NIR	-	Near Infra-Red
NRCS	-	Natural Resources Conservation Service
RC	-	Radiative Convective

RCC	-	Regional Co-ordination Council
SCM	-	Single Column Models
SCS	-	Soil Conservation Service
SD	-	Statistical Dynamical
SRTM	-	Shuttle Radar Topography Mission
TIN	-	Triangulated Irregular Network
USAID	-	United State Agency for International Development
USGS	-	United State Geological Service

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DEDICATION

To my family.

CHAPTER ONE: INTRODUCTION

1.0 BACKGROUND

Recent catastrophic floods that occurred after the Black and White Voltas overflowed their banks due to heavy and prolonged rains in October 2010 caused flooding in Upper East, Northern, Upper West, Brong Ahafo, and Volta regions resulting in excessive damage to lives and property. According to the Government of Ghana (GoG) National Disaster Management Organization (NADMO, 2011), floods damaged more than 2,300 houses, destroyed at least one bridge, restricted access to water and sanitation facilities, and submerged farmlands, affecting more than 141,100 individuals. As of November 5, 2010 flood had impacted at least 55 communities, of which 25 were completely submerged, (NADMO-USAID, 2011).

In August and September of 2009, high levels of rainfall had inundated the Upper East, Northern, and Upper West regions of Ghana. According to the U.N. (2009), these floods killed at least 8 people and affected approximately 130,000 others in nearly 660 communities. Government of Ghana (GoG) and U.N. assessment teams reported that, more than 6,350 houses, 13 schools, and 38,000 acres of agricultural lands were destroyed (NADMO-USAID, 2011).

Information such as rainfall intensity, the speed with which the water rises, the strength and height of the houses all affect the extent of damage in situations of flooding. Flood modelling, prediction and its associated empirical results in a computational environment (such as GIS compactible softwares), would give various ideas in the design of Early Warning System (EWS) for flood prevention and disaster management. This is what has necessitated this research into finding ways of predicting flood occurrences and assessing their impacts on societies or communities.

1.1 STATEMENT OF PROBLEM

The semi-arid regions of Northern Ghana are often characterized by infrequent rainfall, drought, poor vegetation cover, and flash floods resulting largely from increased thunderstorm activities. Thunderstorms result from local air circulations that produce 'heat islands' and dust particles caught up in these circulations act as nuclei on which moisture in clouds condenses, forming rain droplets that eventually may develop into the large rain drops of major thunderstorms, (Boubacar et al, 2005).

Increasing high temperatures often result in high intensity short-duration heavy rainfalls which cause flash floods along the Black Volta in the Lawra District of the Upper West region. Climate change is making weather less predictable, rains more uncertain and heavy storm rainfalls more likely, (Opoku-Ankomah, 1998). Extreme flood events have been reported in this region 2007, 2009 and 2010. The key challenge in developing a reliable Early Warning System for disaster mitigation is the development of modelling and simulation tools to accurately make flood predictions, and for simulation of river channel breaching and flood propagation. It is significant to obtain information on flood characteristics for flood hazard mitigation as well as for flood vulnerability assessment.

1.2 OBJECTIVES OF STUDY

The general objective of this study is to use a GIS based model for flood forecasting and to determine the volume of water that cause floods in the Dikpe community of the Lawra district in the Upper West region. A flood model in Hydrological Engineering Centre's Hydrological Modelling System (HEC-HMS) will be used for runoff analysis and to determine the volume of water causing the flood. This would be achieved by the following:

- Develop a model for flood forecasting and prediction of future climate changes.
- Delineate the catchment (watershed) of the Black Volta within the Dikpe community
- Compute volume of runoffs for reservoir analysis and height of inundation

1.2.1 RESEARCH QUESTIONS

- What is the existing climatic trend as against future trend?
- What rainfall amount and height of runoff are necessary for flood?
- When will flood occur and which communities will be affected?
- Does dam spillage and reservoirs cause flood in the Dikpe community?
- Will event rainfall alone does not cause flooding?

The test case in the study is the following statement;

Rainfall amount above 1000mm will cause flooding

$H_o: \mu_1 \geq 1000mm = \mu_2$ $H_A: \mu_1 \geq 1000mm \neq \mu_2$

1.3 JUSTIFICATION OF THE STUDY

It has been estimated that about 2.5 million people were affected in over 14 countries across the African continent during the September 2007 flooding during which 250 people perished in an event which was considered as one of the worst flood recorded in history (Zhang, W., & Montgomery, Wikipedia, 2007b). In Ghana field assessments carried out by the Government through the National Disaster Management Office (NADMO), and partners, estimated that 332,600 people had been affected, and 56 killed.

Aside, torrential rains coupled with the opening of the spillway from the Bagre Dam and other reservoirs in Burkina Faso which have been the cause of major flooding in

Upper East, Upper West and the Northern Regions, land surface changes as desertification and deforestation amongst others have had adverse impact on the climate. Over-grazing and poor agricultural practices has resulted in the removal of vegetation and exposure of bare soil increasing albedo and decreasing soil water storage because of increased runoffs. Such reduction in surface moisture in these semi-arid regions has led to increased surface temperatures resulting in impossible precipitation formation resulting in aridity increase, (Kendale and Ann, 2005). This is a recipe for high intensity short duration rainfalls that could cause flush floods.

The Development of a flood forecasting model for decision support will assist public authorities and citizens in choosing the right flood protection tactics and in managing emergency situations. Although the benefits of being close to water are numerous, so too are potential dangers of flood related disasters created by being so close, hence the need for finding ways for people to live safely reasonably close to water bodies.

Apart from the devastating situations visited on the community of Dikpe and its environs with high records of damages and loss of lives, the Lawra district is hit with the need for good drinking water. Lately there is a "water project" studies being carried out to supply the Upper West region with pipe borne water from the Black Volta River. It is therefore important to know the volume of water the catchment holds and whether or not it can support the domestic and industrial (mainly agricultural) water demands of the region. This influenced the decision to conduct the hydrologic studies of the Black Volta since the information such studies will produce would enure to the effective planning of the flood situation in the district.

1.4 SCOPE OF STUDY

The study combines two major models, a climate model and a hydrological (basin) model. Climate within the Lawra district is modelled at a regional scale, so also are the hydrological processes which lump-up land surface processes. Though some researchers such as Giesen, Liebe and Gerlinde (2010) try to factor in the carbon component and evaporation from the ocean, in distributed models, a lumped model will suffice with only temperature and rainfall values for the whole period under study (Battisti, 2004). Hydrologic models are simplified, with conceptual representations of a part of the hydrologic cycle. They are primarily used for hydrologic prediction and for understanding hydrologic processes. Recent research in hydrologic modelling tries to have a more global approach to the understanding of the behaviour of hydrologic systems to make predictions for water resources management (Rushton, 2003).

Although there are various aspects to flood prediction using various parameters, this research would use rainfall and temperature monthly averages to determine how much water the catchment receives and whether or not the Black Volta at Dikpe will be able to contain the volume of water from precipitation runoffs. If this will cause flood, at what time in future will it happen and to what height will affected areas be inundated. It will evaluate the total rainfall and how much ends as runoffs in a lumped-modelling of land surface processes to calculate runoffs and other parameters. Statistical analysis is made on the trend of the data for future prediction as opposed to typical forecasting model in a GIS environment.

1.5 LIMITATIONS OF THE STUDY

Though climate of an area is only determined after studying the weather patterns for a long period (in some cases 50 years), complete data are available for 30 year period and this will suffice for the study. The research uses average temperature and rainfall values for the past 32 years together with estimated value for albedo (in the case of the climate model) for predictions in climate and hydrologic cycle.

The hydrological processes of the river is modelled accounting for infiltration, evaporation, transpiration, surface runoffs, flows and river discharge (Figure1.1). River measurement will be used to determine its capacity for which modelling will inform whether or not it will contain water coming to it at certain predefined times.

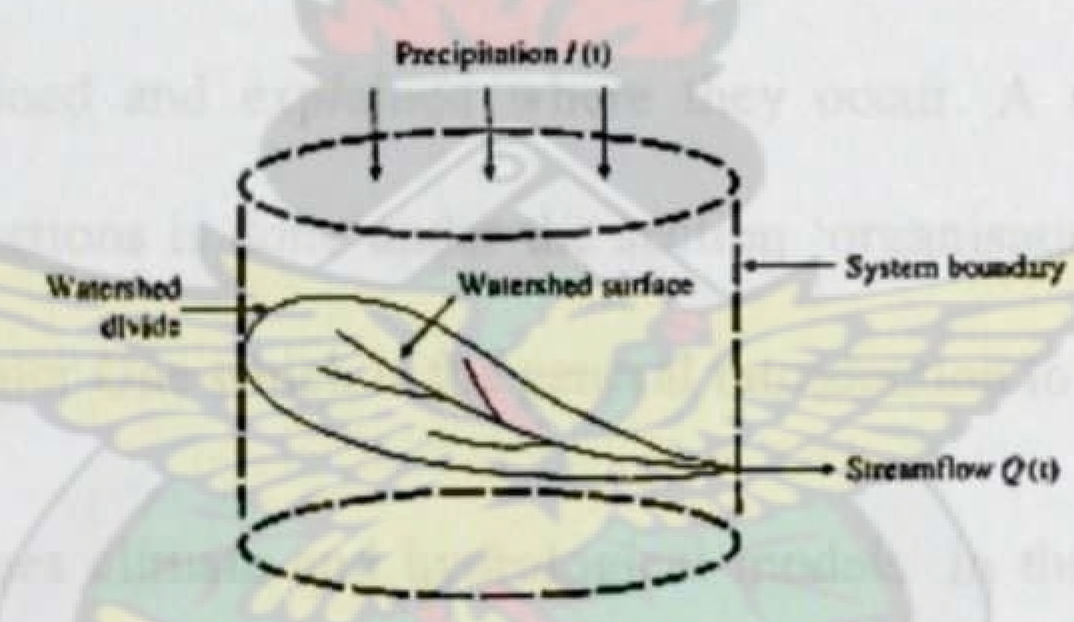

Figure 1. 1 Processes to be modelled in the Hydrological model. Source: Applied Hydrology, Chow et al., 1998.

The research combines precipitation data, DEM for delineating watershed and/or catchment and satellite images to develop a hydrological model of the area in a GIS environment for faster and easy analysis. The study does not seek to simulate flood event but rather calculate the volume of water causing the flood. The concentration is on the hydrologic processes rather than on an analysis of the river itself.

1.6 ORGANIZATION OF THE STUDY

The thesis starts with a little background of flood activities in the region over the last two decades, highlighting on the effects and damages. Inadequacies, inefficiencies and difficulties in the study area will be addressed under the statement of problem. Questions relating to the study that possess unanswered problems will be asked. The objective of the study is set. Research questions are asked in relation to the specific objectives to seek answers in solving them. Contribution and assistance the research will make to knowledge and render to stakeholders respectively are next discussed under justification of the study. The scope of study will summarize the actions to be taken. Model constraint on the research will be tackled when discussing limitations of the study. Under clarification of concepts, terms, acronyms, abbreviations and jargons will be defined and explained where they occur. A narration of various chapters and their sections is done under the section 'organisation of the study'. All these constitute Chapter One which is the general introduction to the thesis.

Chapter Two discusses climate and hydrological models. In this chapter also there was a description or clarification of concepts, terms, acronyms and also a discussion on rainfall-runoff models.

Next is methodology in Chapter Three where the study area (coverage) is stated, variables will be explained and described. Here various derivatives will be tackled and each step in the work will be fully described and the model appropriately specified. Instruments of data collection, methods of analysis, constraints or problems will be thoroughly discussed. Data used will be critically evaluated to ascertain suitability or otherwise for the study.

In Chapter Four analyses of findings of results obtained in the previous chapter will be thoroughly discussed. Empirical results will be analysed as against the expected results and also what was obtained by others who worked on the same study area if there are any. Issues raised under research questions will be tackled.

The last chapter, Chapter Five will summarize the main findings and soundness of methodology and data used. Conclusion and recommendation will be based on the analysis of findings linked to the problem statement. All assumptions made which influenced the method and data will be discussed and concluded upon in its appropriateness or otherwise. There is also an appendix at the end of the thesis.

CHAPTER TWO: CLIMATE AND HYDROLOGICAL MODELS

2.0 INTRODUCTION

Floods are one of the greatest natural hazards that affect humans. After centuries of study and with hundreds of billions of dollars invested in flood control, the seemingly simple process of river flooding continues to inflict damage with floods of unexpected intensity, extent, and duration because flooding is a phenomenon that depends on complex interactions among climate, landscape, and human intervention.

This chapter discusses various climate models as well as the hydrological processes the water go through. The hydrological processes though general cannot fit to every local situation, thus an analysis is made as to which one is appropriate restricted by the data available.

In recent times the use and integration of remote sensing data and GIS has made it relatively effective to predict flood events in a GIS environment. Because development and customization tools within most GIS packages provide relatively simple programming capability and modelling power, applications are developed to connect HEC-HMS and HEC-RAS models in a single ArcView GIS environment allows users to move easily from a DEM to a floodplain map within a single program (Kopp, 1998). The chapter introduces some works of various writers in the field of climate models, hydrology, remote sensing and geographic information systems pertaining to flood forecasting.

2.1 CLARIFICATION OF CONCEPTS

Neelin, (2011), defines Climate as being commonly thought of as the average condition of the atmosphere, ocean, land surfaces and the ecosystems that dwell in them. It also includes the average wind direction and strength, average cloud cover, the atmosphere of the sea surface nearby, which affects the previous quantities, and the ocean currents that affect the sea surface temperature and so on. Climate prediction includes the endeavour to predict not only human induced changes in the global environment but also the natural variations of climate that affect us.

Flood is a natural phenomenon that occurs when the volume of water flowing in a system exceeds its total water holding capacity (Zhang, W. & Montgomery, Wikipedia, 2007b). The United States Geological Survey (2007) defines flood as relatively high water that overflows the natural or artificial banks of a stream or coastal area and submerges land not normally below water. Floods usually are local, short-lived events but can be catastrophic, happening with little or no warning. Floods are most often caused by prolonged rainfall that saturates the ground causing surface runoff into nearby streams to increase their discharge. Though viewed as a "natural hazard" to humans, flooding is a natural, rejuvenating process, (Ritter, 2006).

2.1.1 FLOOD-PLAINS

A floodplain is the normally dry land area adjoining rivers, stream, lakes, bays, or oceans that is inundated during flood events. The channel and floodplain are both integral parts of the natural conveyance of a stream. The floodplain carries flow in excess of the channel capacity. The greater the discharge, the greater is the extent of inundation.

An automated floodplain delineation process determines inundation extent by comparing simulated water levels from a river hydraulic model with ground surface elevations. Cross-sections are required to represent channel geometry in a river hydraulic model (Figure 2.1). The accuracy of simulated water levels, and eventually the accuracy of floodplain delineation, largely depends on the shape as well as extent of these cross-sections. In a flood model it is important to specify a detailed cross-section geometry that not only extends over the floodplain, but also is truly capable of carrying the total flood discharge through it.

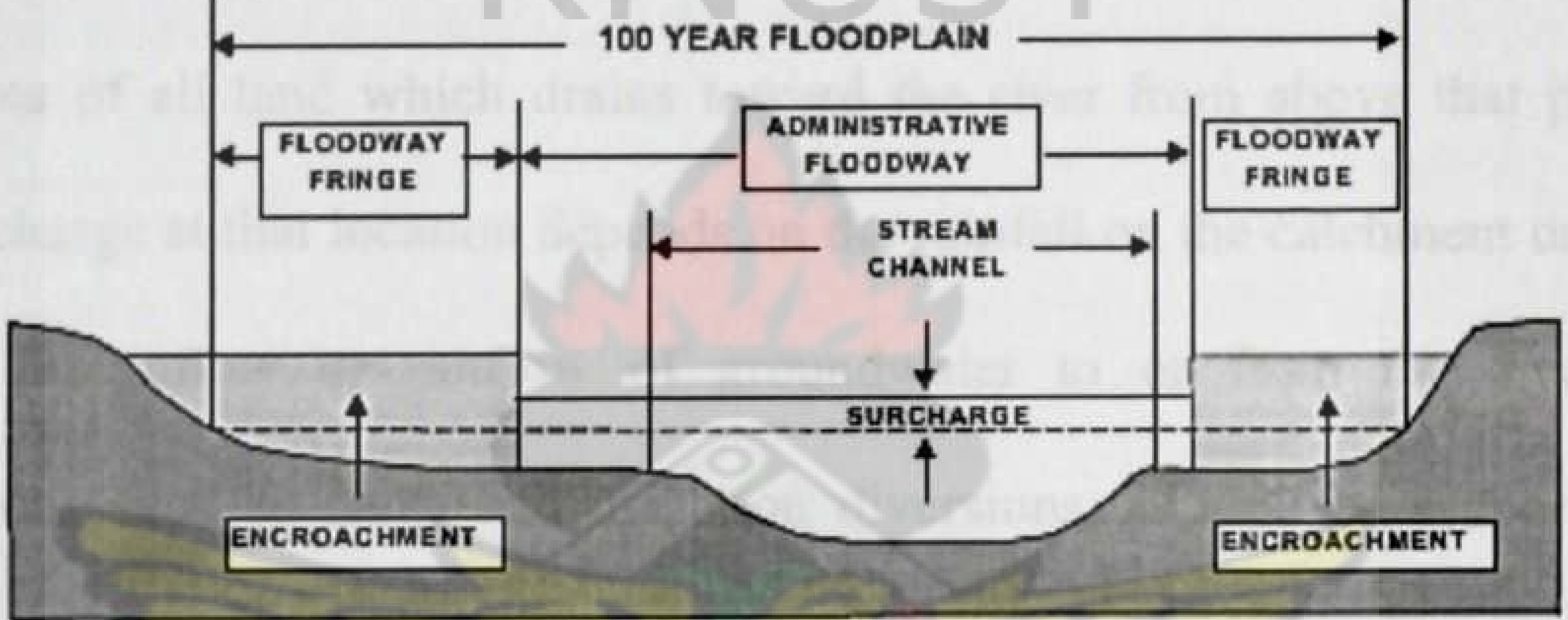

Figure 2. 1 Typical Sections and floodplain in a Reach of Stream valley. Source: State Standard Attachment 2-16

2.1.2 CLIMATE MODELS

Climate models are systems of differential equations based on the basic laws of physics, fluid motion and chemistry. Climate models are numerical representations of various parts of the Earth's climate system. General Circulation Models/ Global Climate Models (GCMs) attempt to represent everything, and often get very complicated. The equations are tweaked, within reasonable boundaries, so that the model does well at producing past and current climates (compared to archived observations). They could then be used to attempt predicting what the climate would be in the future.

2.1.3 CATCHMENT AREA

A catchment area is a hydrological unit representing an area where each drop of precipitation that falls eventually ends up in the river if it doesn't evaporate. Catchment areas are separated from each other by watersheds. A watershed is the region of land draining into a stream, river, pond, lake or other body of water (Nancy, 2004). A watershed is a natural division line along the highest points in an area. Catchments are divided into sub catchments, also along the lines of elevation.

The catchment of a river (Figure 2.2) above a certain location is determined by the surface area of all land which drains toward the river from above that point. The river's discharge at that location depends on the rainfall on the catchment or drainage area and the inflow or outflow of groundwater to or from the area, stream modifications such as dams and irrigation diversions, as well as evaporation and evapotranspiration from the area's land and plant surfaces.

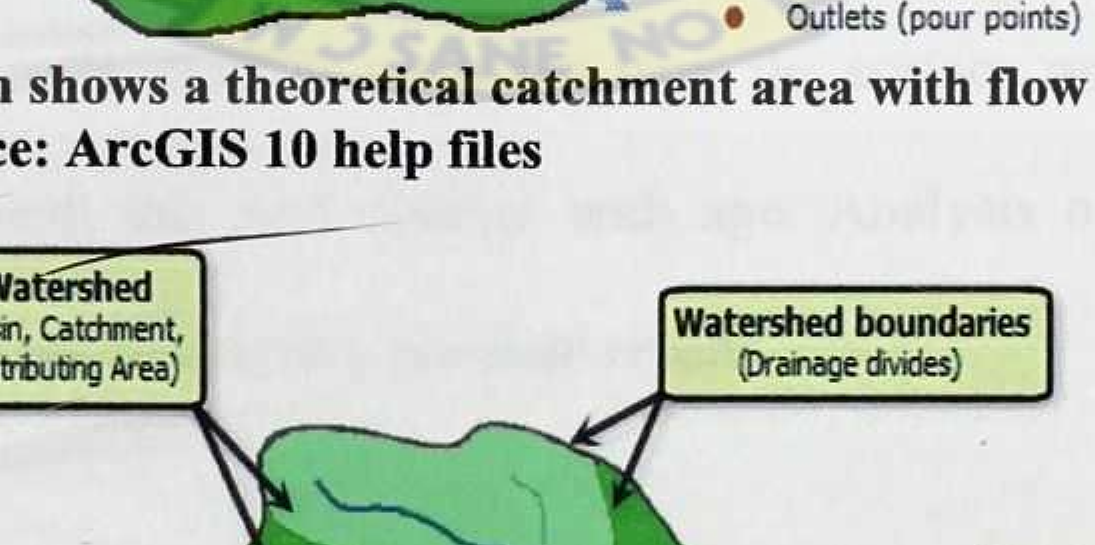

Figure 2. 2 Diagram shows a theoretical catchment area with flow paths of precipitation. Source: ArcGIS 10 help files

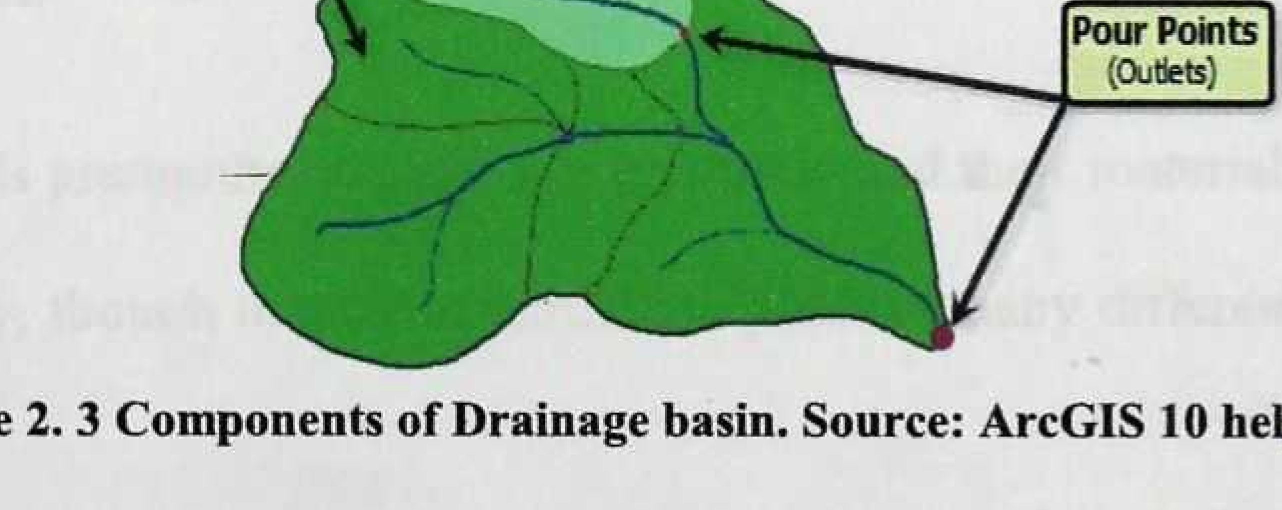

Figure 2. 3 Components of Drainage basin. Source: ArcGIS 10 help files.

A drainage basin (Figure 2.3) is an extent or area of land where surface water from rain (and melting snow or ice in some places) converges to a single point, usually the exit of the basin, where the waters join another water-body, such as a river, lake, reservoir, estuary, wetland, sea, or ocean.

Drainage divides are the boundaries between individual valleys. The area bounded by a drainage divide is called a drainage basin and represents all of the land that is drained by a stream or river. The drainage basin acts as a funnel by collecting all the water within the area covered by the basin and channelling it to a single point. Each drainage basin is separated topographically from adjacent basins by a geographical barrier such as a ridge, hill or mountain, which is known as a water divide. Other terms that are used to describe a drainage basin are catchment, catchment area, catchment basin, drainage area, river basin, water basin and watershed.

2.1.4. WATER CHANNELS

Artificial channels

These are channels made by man. They include irrigation canals, navigation canals, spillways, sewers, culverts and drainage ditches. They are usually constructed in a regular cross-section shape throughout – and are thus prismatic channels commonly constructed of concrete, steel or earth and have the surface roughness's reasonably well defined although this may change with age. Analysis of flow in such well-defined channels gives reasonably accurate results.

Natural channels

Natural channels are neither regular nor prismatic and their materials of construction can vary widely, though mainly of earth, can possess many different properties. The surface roughness will often change with time distance and even elevation. Consequently it becomes more difficult to accurately analyse and obtain satisfactory results for natural channels than is the case for man-made ones. The situation may be further complicated if the boundary is not fixed due to erosion and deposition of sediments, (Ritter, 2006).

Channel Geometry

Channel geometry and characteristics of stream flow are inherently related. Changes in the geometry of the channel can impact stream velocity and discharge. Figure 2.4 depicts a typical cross-sectional view of a river channel.

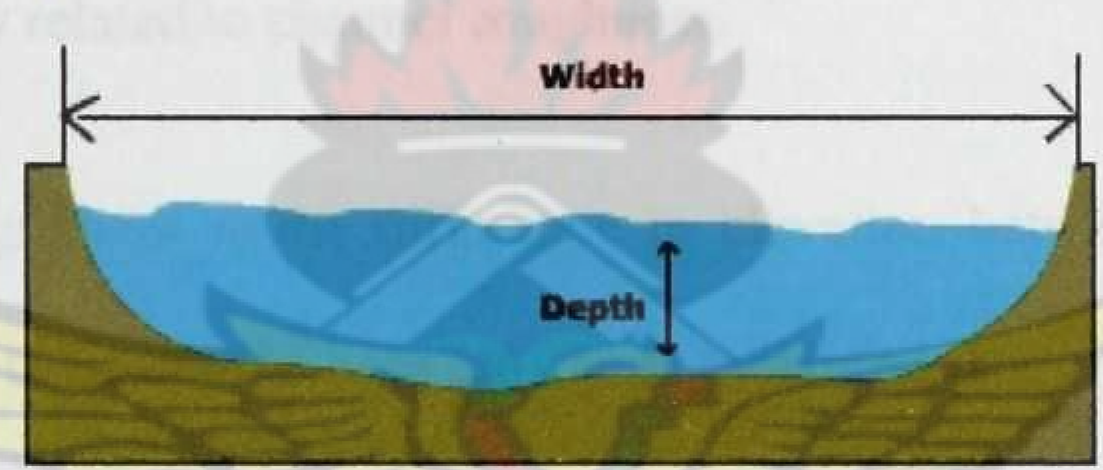

Figure 2. 4 Cross-sectional areas. Source: Ritter Michael

The cross-sectional area of the stream is determined by multiplying channel depth by channel width along a transverse section of the stream. For a hypothetical stream with a rectangular cross-sectional shape, the cross-sectional area (A) is simply the width multiplied by the depth:

$$A = (W * D)$$

The wetted perimeter is the portion of the channel that is "wet". The wetted perimeter (WP) is the width plus twice the depth that the water touches:

$$WP = W + 2D$$

The greater the cross-sectional area in comparison to the wetted perimeter, the more free-flowing the stream will be, because less of the water is in proximity to the frictional bed. Therefore as hydraulic radius increases, so will velocity (all other factors being equal). Studies have shown that width and depth tend to vary regularly with stream discharge. If discharge is held constant and width decreases, then the channel should deepen by scouring as a result of the increased velocity and transportation power which accompanies the narrowing of a channel. Studies have also shown that as mean discharge of a stream increases downstream so do channel width, depth, and average current velocity. The flow velocity is directly related to the hydraulic radius (cross-sectional area divided by the wetted perimeter) and channel slope, and inversely related to channel roughness.

Channel slope or gradient is the difference in elevation between two points on a stream divided by the distance between them measured along the stream channel. The flow velocity, and thus power of the stream to do work is also directly related to the slope of the channel, the steeper the slope, the faster the velocity of flow, (Ritter, 2006).

2.2 TYPES CLIMATE MODELS

Many efforts have been made in the application of using precipitation (rainfall mostly) to predict flood occurrences. (Ekhwan et al, 2009, Jonch-Clausen and Refsgaard, 1984, Konstantin, 2005, Kimmo, Butts et al, 2005, etc) have all modelled flood forecasting using various approaches but fundamental to all is the fact that rain-fed flood forecasting can be incorporated with GIS and satellite images for better comprehension at regional climate zones.

Climate models are derived from fundamental physical laws (such as Newton's laws of motion), which are then subjected to physical approximations appropriate for the large-scale climate system, and then further approximated through mathematical discretization (Randall et al., 2007). Different models have different advantages which may be due to their complexity or the form of their implemented parameterizations. Kendale and Ann, (2005) iterated four components of climate system models as radiation, dynamics, surface processes, chemistry and resolution in both time and space.

The known main climate models include the following; Energy balance models (EBMs) which are zero or one-dimensional models predicting the surface (strictly the sea-level) temperature as a function of the energy balance of the Earth, One-dimensional models such as radiative-convective (RC) models and single column models (SCMs) which focus on processes in the vertical, Dimensionally constrained models which could take a wide variety of forms. The oldest are the statistical dynamical (SD) models, which deal explicitly with surface processes and dynamics in a zonally averaged framework, Global circulation models (GCMs) in which the three-dimensional nature of the atmosphere and ocean is incorporated. According to the IPCC AR4 report of 2012, warming in Africa is very likely to increase, however there is less consistency between GCMs in projections of how precipitation over the south of Sahel-West Africa will pan out. (Christensen et al. 2007).

2.2.1 HYDROLOGIC CYCLES AT CATCHMENT SCALE

At a catchment scale, considerations of hydrological cycles include the processes that precipitation goes through in the atmosphere, land surface and subsurface. Precipitation falls from the atmosphere but before it reaches the ground, part of it is intercepted by vegetation and evaporates back into the atmosphere. The precipitation that reaches the land surface will either infiltrate to the subsurface or will become what is called Horton overland flow or rill flow. As the rill flow accumulates, it becomes a stream flow then channel flow. Channel flow also gets some contribution from the groundwater flow in the form of base flow and becomes the catchment runoff when it flows out from the catchment.

2.2.2 HYDROLOGIC AND HYDRAULIC MODELLING

Hydrologic Modelling

A hydrologic model is a mathematical representation of hydrological processes in a catchment in a simplified form. It can be used to better understand and explain hydrological processes and for hydrologic prediction (Haan et al., 1982). There are two different types of hydrologic models; deterministic and stochastic models. Deterministic models are based on the physical processes in the catchment it is representing. A model can be called as deterministic model if it does not consider randomness, meaning, specific input will always have the same output (Chow et al., 1988). Stochastic models on the other hand refer to models which deal with random variables. These variables have a probability distribution in parameter space (Rientjes, 2007).

The main application of a hydrologic model is to simulate river discharge in a catchment. Hydrologic models are increasingly used in water resources management and applications ranging from simple planning of water resources to more complex issues like assessing effects of climate change on water resources and for studying the interactions between surface water and groundwater.

Hydraulic Modelling

In hydraulic modelling, flow in the channel is simulated by solving the complete set of St.Venant equations, based on continuity (conservation of mass) and momentum (conservation of momentum). These equations are solved numerically by either explicit or implicit methods (Bedient and Huber, 1988). The explicit method solves the velocity and depth in a particular point in the river using previously known data only. The implicit method solves the equations simultaneously at each time step and over all calculation points that cover the entire river.

2.2.3 DIFFERENT TYPES OF RAINFALL-RUNOFF MODELS

A large number of rainfall runoff models have been developed and implemented into software packages since the early 1960s (Wagener, 2004). Todini (1988) gives a historical review of rainfall-runoff modelling. These models use different kinds of approaches and structures. There exist different ways of classifying the variety of model encountered. One of the most common classifications attributed to Wheater et. al, (1993) distinguishes three classes:

- Metric models, also called statistical, stochastic, probabilistic or black box models.
- Parametric models also referred to as conceptual or grey box models.
- Mechanistic models also mentioned as physically based or white box models

METRIC MODELS

Metric or statistical models use time series of data available to derive both model structure and parameters (Wagener, 2004). They are purely based on the information contained in the data and do not require any previous knowledge of the catchment. They therefore only apply to gauged catchments. These models are usually spatially lumped, i.e., they treat the catchment as a single unit. Among the most popular models of this type is Artificial Neural Networks (ANN). ANN simulates biological neural systems and the human way of thinking and learning, (Elshorgaby et al, 2000). Other models of this type are Auto-Regressive Moving Average (ARMA) (Kisi, 2004), Transfer Functions (Young, 1992), or Nonlinear Prediction (Tamea et al, 2005). They are computational tools with the ability to represent non-linear systems.

PARAMETRIC MODELS

Metric or conceptual models use storage elements as the main building component (Wagener et al, 2004). These storages are filled through fluxes such as rainfall, infiltration or emptied through evapotranspiration, drainage or runoff. These models use parametric equations to describe the storage variations or the fluxes and therefore still rely on time series of data to calibrate the various parameters. These parameters mostly have a direct physical interpretation but often cannot be derived from field measurements as a number of processes are often aggregated (in space and time) into a single parameter. Conceptual models usually try to find a trade-off between complexity of the modelling approach and output accuracy. Indeed, more complexity means more parameters, more parameters mean more calibration problems, and more calibration problems mean more uncertainty in predictions (Beven, 2001). One of the most known models of this category is the TOPMODEL (Beven and Kirkby, 1979). TOPMODEL is a conceptual but spatially distributed model which implements an index of hydrological similarity known as the topographic index (Kirkby, 1975). It has been originally developed to simulate small catchments in the UK (Beven et al, 1979), but has been applied to several different basins throughout the world (Beven, 2001).

MECHANISTIC MODELS

The physical realism sought by these models makes it possible to relate their parameters to measurable characteristics of the catchment, thus, in theory, eliminating the need for calibration. Therefore the potential for physically based distributed models to be used in locations where no stream gauge exists is a major motivation for this approach (Vieux et al, 2004). The Systeme Hydrologique European (SHE) (Abbott et al, 1986) model, originally developed as a joint collaboration between the Institute of Hydrology in the UK, the Danish Institute of Hydraulics and SOGREAH in France was one of the first models of this kind to be developed. It is a grid based model coupling hydrological process involved in rainfall-runoff process and subsurface and groundwater flows.

2.2.4 CLASSIFICATION OF HYDROLOGICAL MODELS

The modelling of the physical phenomena which govern the response of a river basin to meteorological forcing can only be achieved with great difficulty, due to the complexity and variability in time and in space of the processes and elements involved in the transformation of rainfall into runoff, (Barbara, 2008). Hydrological models are based on a set of interrelated equations that try to convert the physical laws, which govern extremely complex natural phenomena, to abstract mathematical forms, (Barbara, 2008). Any hydrological model (Figure 2.5) emphasizes some aspects which are considered relevant instead of others considered of secondary importance, and should be sufficiently comprehensible and easy to be used and in the same way sufficiently to represent the physical studied problem. Moreover different varieties of models can be used, depending upon the conceived output, the existing database, input variables and required analysis.

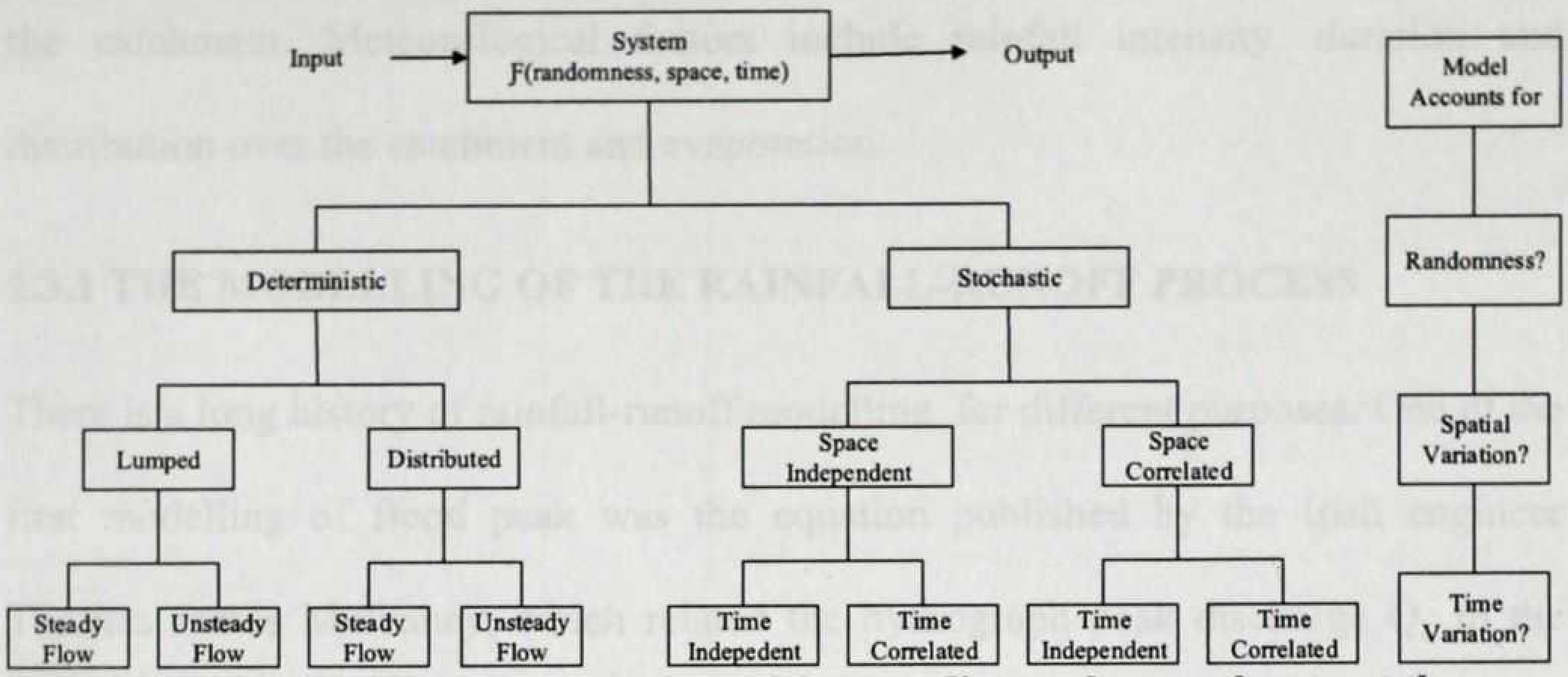

Figure 2. 5 Classification of hydrologic models according to the way they treat the randomness and space and time variability of hydrologic phenomena. Source: Applied Hydrology – Civil Engineering Series, 1998

Singh (1995) suggests the rainfall-runoff models can be classified according to their degree of representation of the physical processes and to the spatial and temporal description (Melone et al., 2005). All hydrologic models are approximations of reality, so the output of the actual system can never be forecast with certainty; likewise, hydrologic phenomena vary in all three space dimensions, and in time, but the simultaneous consideration of all five sources of variation (randomness, three space dimensions, and time) has been accomplished for only a few idealized cases. A practical model usually considers only one or two sources of variation as shown in Figure 2.5.

2.3 RUNOFF PROCESSES

Runoff from a catchment is often expressed by a river flow hydrograph. The shape of the hydrograph in a particular catchment is a combined function of physiographic characteristics of the catchment and the meteorological variables (Bedient and Huber, 1988). Physiographic factors that affect the flow in a catchment includes; size and shape of the catchment, slope of the river system and the storage capacity of the catchment. Meteorological factors include rainfall intensity, duration and distribution over the catchment and evaporation.

2.3.1 THE MODELLING OF THE RAINFALL-RUNOFF PROCESS

There is a long history of rainfall-runoff modelling, for different purposes. One of the first modelling of flood peak was the equation published by the Irish engineer Thomas James Mulvaney, which related the hydrograph peak discharge Q_p to the catchment area A, a maximum rainfall areal average R and an empirical parameter C in $Q_P = CAR$. This kind of estimation for Q_p is often all that is needed for engineering hydrologists to design a bridge or a culvert. This model has become known as the "rational method", and many variations have been published since and are still in use today. Although Rainfall-runoff modelling has developed since then as hydrologic knowledge spread alongside with computational tools, Hydrological processes involved are not yet perfectly known, and as Shertzer et al, (2002) puts it, the understanding of the dynamics of the rainfall runoff process constitutes one of the most important and challenging problems in hydrology.

The main reason for modelling hydrological processes is the limitation of hydrological measurements (Beven, 2001). Modelling is carried out for pure research to develop scientific knowledge about hydrological systems but the ultimate aim of prediction using models must be to improve decision-making about hydrological problems. Flood forecasting is one of these applications of rainfall-runoff modelling in predicting stream flows at the outlet of the catchment from rainfall input.

2.3.2 RUNOFF: INFILTRATION EXCESS AND SATURATION EXCESS

The classical theory of Horton is based on the idea that it is possible to separate total stream flow into a quick-flow and a base-flow. Quick-flow is the portion of runoff that is "prompt" or rapid after the rain and it consists of overland flow, (Barbara, 2008). Base-flow is the contribution of groundwater. Horton refined this "capacity" concept by referring it to an infiltration rate that declines exponentially during a storm (Horton, 1936a, b). He defined the maximum rate at which rain can be absorbed by the soil in a given condition as the infiltration capacity, hence overland flow is generated when the rainfall intensity falling on the ground exceeds the infiltration capacity of the soil (infiltration excess), which in turn decreases with time during a rainfall event in proportion to the volume of infiltrated water. When the precipitation rate exceeds the infiltration rate of the soil, there is excess precipitation available for runoff and depression storage: depressions on the soil surface begin to fill until their storage is emptied and water flows out moving down-slope as overland flow or in defined channels.

Other models, assuming a different variability law of infiltration capacity with time, use empirical equations, like the non-linear function proposed by Kostiakov (1932) and Horton (1933) or physically based equations like the Green-Ampt (1911) or Philip (1954) equations whose parameters are estimated by means of soil properties (porosity and hydraulic conductivity) measured in the field or in laboratory and tabulated for different type of soils.

2.3.3. FLOODS, FLOODPLAINS, AND FLOOD-PRONE AREAS

Flooding is a natural and recurring event for a river or stream. Flooding is a result of heavy or continuous rainfall exceeding the absorptive capacity of soil and the flow capacity of rivers and streams which overflow the banks onto adjacent lands. Floodplains are, in general, those lands most subject to recurring floods, situated adjacent to rivers and streams. Floodplains are therefore "flood-prone" and are hazardous to development activities if the vulnerability of those activities exceeds an acceptable level.

Floodplains can be looked at from several different perspectives: 'To define a floodplain depends somewhat on the goals in mind. As a topographic category it is quite flat and lies adjacent to a stream; geomorphologically, it is a landform composed primarily of unconsolidated depositional material derived from sediments being transported by the related stream; hydrologically, it is best defined as a landform subject to periodic flooding by a parent stream. A combination of these characteristics perhaps comprises the essential criteria for defining the floodplain" (Schmudde, 1968). Most simply, technically, a flood-plain is defined as "a strip of relatively smooth land bordering a stream and overflowed at a time of high water" (Leopold et al, 1964).

2.4 REMOTE SENSING AND GEOGRAPHIC INFORMATION SYSTEM IN FLOOD MODELLING

Remote Sensing processes include gathering catchment information and hydrologic state variables through the use of measured electromagnetic spectrum (Maidment, 1993). Sensors used in remote sensing are carried by platforms with altitude ranging from few centimetres (e.g. handheld field equipment) up to orbits in space of thousands of kilometres (e.g. geostationary satellites) and beyond (Janssen et al., 2001). The sensors that are used for hydrological applications can either be passive or active and covers a broad range of the electromagnetic spectrum. Data acquired through remote sensing tremendously trigger advancements in flood modelling. During the early days of flood modelling, data acquisition was the major limitation for its advancement. Data acquisition activity is often considered the most time consuming and costly component in flood modelling.

2.4.1 HYDROLOGY AND GIS

The goal of flood forecasting is to provide a reliable prevention mechanism to eliminate disasters and reduce the negative consequences of a hazard. However, this requirement is not often met by hydrological models only, (Karimi and Blais, 1997; Karimi and Chapman, 1997; Al-Sabhan et al.). The application of watershed models require the efficient management of large spatial and temporal datasets, which involves data acquisition, storage, and processing of modelling inputs, as well as the manipulation, reporting, and display of results. These management requirements are usually met by integrating watershed simulation models and GISs, thereby generating the capacity to manage large volumes of data in a common spatial structure.

2.4.2 TERRAIN MODELS

The term Digital Elevation Model is often used as a generic term for Digital Surface Models DSMs and Digital Terrain Models DTMs, when only representing height information without any further definition about the surface, (Peckham et al, 2007). In the most cases the term digital surface model represents the earth's surface and includes all objects on it. In contrast to a DSM, the digital terrain model represents the bare ground surface without any objects like plants and buildings, (Li et al, 2005).

The term Digital Elevation Model (DEM) has several meanings and is not always understood correctly or misinterpreted due to the surface it represents or geographic location the DEM data is being used. DEM can be created by collecting elevations and referencing them to the corresponding points in the mapped area. Digital contour lines digitised from the topographic map is the main source of the DEM generation.

The DEM provides automatic layers for perspective viewing, slope analysis, terrain analysis, hydrography analysis and flood simulation.

The quality of a DEM is a measure of how accurate elevation is at each pixel (absolute accuracy) and how accurately is the morphology presented (relative accuracy). A DEM can be represented as a raster (a grid of squares, also known as a height map when representing elevation) or as a vector-based triangulated irregular network (TIN). The TIN DEM dataset is also referred as a primary (measured) DEM, whereas the Raster DEM is referred as a secondary (computed) DEM, (Ronald Toppe, 1987).

2.5 THEORETICAL FRAMEWORK

When waterways or channels are no longer able to hold the amount of water running through, it will overflow the banks of the stream or river. Technically, all water in and on the ground within the catchment end up in the river or stream. All water from rainfall within the catchment will also end there. If the volume of water coming into the river channel within a period of time is greater than the capacity (volume) of the river channel, then the excess will overflow into areas known as floodplains. If human settlement is within the floodplain then "flooding" will occur in this community. In coming up with flood prediction models, primarily the hydrological processes need to be understood, separating the elements and lumping where necessary. When rain falls on the surface of the Earth, some of the water is evaporated and returns to the atmosphere, some of it infiltrates the soil and moves downward into the groundwater system, and some is intercepted by depressions and vegetation. What remains on the surface of the Earth and eventually flows into streams is called ***runoff***. In general, (Nelson, 2007) then:

Runoff = Precipitation - Infiltration - Interception – Evaporation

2.5.1 RUNOFF PROCESSES

Figure 2.6 is a system diagram of the watershed runoff process. The processes illustrated begin with precipitation. (Currently precipitation is limited to analysis of runoff from rainfall). In the simple conceptualization shown, the precipitation can fall on the watershed's vegetation, land surface, and water bodies (streams and lakes). In the natural hydrologic system, much of the water that falls as precipitation returns to the atmosphere through evaporation from vegetation, land surfaces, and water bodies and through transpiration from vegetation. During a storm event, this evaporation and transpiration is limited. Some precipitation on vegetation falls through the leaves or runs down stems, branches and trunks to the land surface, where it joins the precipitation that fell directly onto the surface. There, the water may pond, and depending upon the soil type, ground cover, antecedent moisture and other watershed properties, a portion may infiltrate.

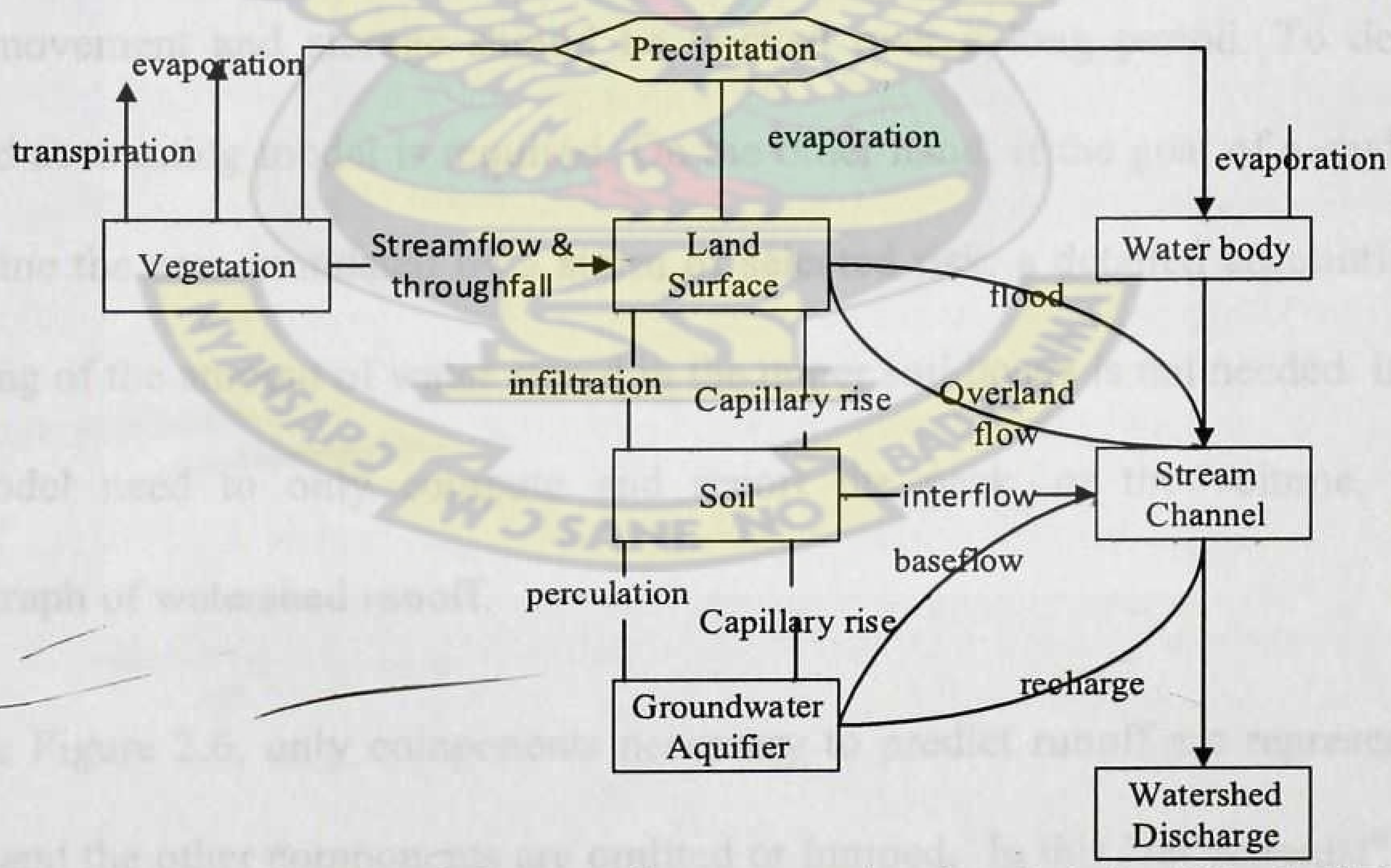

Figure 2. 6 Systems diagram of the runoff process at local scale (after Ward, 1975).

This infiltrated water is stored temporarily in the upper, partially saturated layers of soil. From there, it rises to the surface again by capillary action, moves horizontally as interflow just beneath the surface, or percolates vertically to the groundwater aquifer beneath the watershed. The interflow eventually moves into the stream channel. Water in the aquifer moves slowly, but eventually, some returns to the channels as baseflow. All that do not pond or infiltrate move by overland flow to a stream channel. The stream channel is the combination point for the overland flow, the precipitation that falls directly on water bodies in the watershed, and the interflow and baseflow. Thus, resultant streamflow is the total watershed outflow.

2.5.2 REPRESENTATION OF THE RUNOFF PROCESS

For some analyses, a detailed accounting of the movement and storage of water through all components of the system is required. For example, to estimate changes due to watershed land use changes, it may be appropriated to use a long record of precipitation to construct a corresponding long record of runoff, which can be statistically analysed. In that case, evapotranspiration, infiltration, percolation, and other movement and storage should be tracked over a long period. To do so, a detailed accounting model is required. On the other hand, if the goal of a study is to determine the area inundated by a storm of selected risk, a detailed accounting and reporting of the amount of water stored in the upper soil layers is not needed. Instead, the model need to only compute and report the peak, or the volume, or the hydrograph of watershed runoff.

Despite Figure 2.6, only components necessary to predict runoff are represented in detail, and the other components are omitted or lumped. In this "reductionist" mode, the program is configured to include models of infiltration from the land surface, but it does not model storage and movement of water vertically within the soil layer. It implicitly combines the near surface flow and overland flow and models this as direct runoff.

2.6 SUMMARY AND CONCLUSION

Floods continue to be an increasing problem, catching individuals and communities by surprise in a repetitively exasperating way, and causing disruption, damage and even death (Keith and Roy, 1998).

A flash flood can be defined as a flood that threatens damage at a critical location in the catchment, where the time for the development of the flood from the upstream catchment is less than the time needed to activate warning, flood defence or mitigation measures downstream at the critical location. With current technology even when the event is forecast, the achievable lead-time is not sufficient to implement preventative measures (e.g. evacuation, erecting of flood barriers).

The Black Volta basin is characterised by mainly Birrimain which consists of metamorphosed lavas and pyroclastic rocks and hypabyssal basic intrusives, phyllites and greywackes (Erdelyi, 1999) which makes infiltration difficult and percolation very slow for ponding areas. Many efforts have been made in the application of using precipitation (rainfall mostly) to predict flood occurrences. Ekhwan et al, 2009; Jonch-Clausen and Refsgaard, 1984; Konstantin, 2005; Kimmo, Butts et al, 2005, etc. have all modelled flood forecasting using various approaches but fundamental to all is the fact that rain-fed flood forecasting can be incorporated with GIS and satellite images for better comprehension of the various models to regional climate zones.

Modern geographic information systems (GIS) offer new opportunities for the collection, storage, analysis, and display of spatially distributed meteorological and geophysical data (Goodchild et al., 1992). Forkuo, (2010) suggests the ease and usefulness in combining GIS and satellite image and DEM for delineating flood hazard extents. However, little work has been done in the Black Volta Basin (a sub-basin of the Volta Basin), in this regard. This research therefore seeks to combine precipitation data and satellite images to develop a hydrological model of the area in a GIS environment for flood water volume computation and hydrologic analysis.

CHAPTER THREE: MATERIALS AND METHODS.

3.0 INTRODUCTION

Capacities of river channels determine how much volume of water they can hold. When these capacities are overrun in periods of high intensity rainfall duration flooding occurs because the river channels fail to hold the overwhelming flow of water. The use of Geographic Information Systems (GIS) softwares like ArcHydro (an extension of ArcGIS) and HEC-HMS in modelling hydrologic processes in recent times has become excellent tools in analysing and management of water resources. Whereas Archydro depend greatly on digital elevation models or "bare earth" models for various processing of the terrain, HEC-HMS depend very much on physical descriptive parameters of the watershed.

3.1 STUDY AREA

The Upper West Region, with Wa as the regional capital, was formerly part of the then Upper Region which was itself carved out of the Northern Region in July 1960. In pursuance of the decentralisation policy, the Government, in 1983, divided the Upper Region into Upper East and Upper West. The Upper West region covers a geographical area of approximately 18,626.6 km^2. This constitutes about 7.81% of the total land area of Ghana. The region is bordered on the North by the Republic of Burkina Faso, on the East by Upper East Region, on the South by Northern Region and on the West by Cote d'Ivoire.

3.1.1 POLITICAL AND ADMINISTRATIVE STRUCTURE

The region is administered politically from Wa. The main administrative structure at the regional level is the Regional Co-ordination Council (RCC), headed by the Regional Minister. Other members of the RCC include representatives from each

District Assembly, regional heads of decentralized ministries, and representatives of the Regional House of Chiefs. The region has nine administrative districts as shown in Figure 3.1b. A Municipal/District Assembly, headed by a Chief Executive nominated by the President and approved by the Assembly Members, administers each district. Two-thirds of the members of the Assembly are directly elected. The other one-third is appointed by the Central Government in consultation with local leaders. The districts are autonomous with regards to the planning, budgeting and implementation of projects. In addition, Area/Town Councils/Unit Committees assist in the performance of key roles. The region currently has eight political parliamentary constituencies namely, Wa Central, Wa East, Nadawli North, Nadawli South, Jirapa, Lambussie, Sissala and Lawra-Nandom. Figure 3.1 represents the study area showing communities and the major water bodies within the Lawra district.

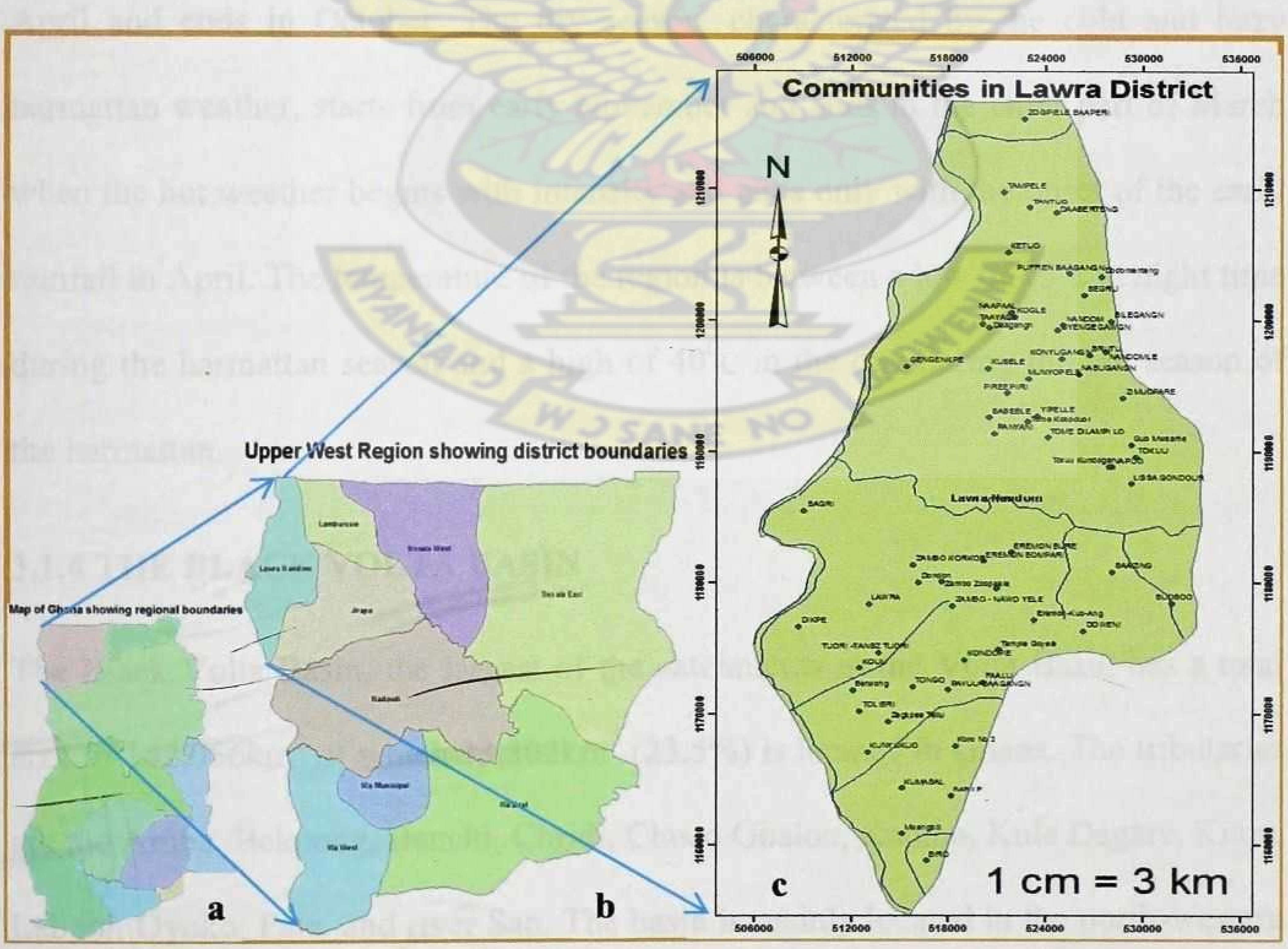

Figure 3. 1 Shows: a-map of Ghana, b-map of upper west region and districts, c-map of lawra District and its communities and the Black Volta

3.1.2 TOPOGRAPHY

The region is located in the guinea savannah vegetation belt. The vegetation consists of grass with scattered drought resistant trees such as the shea, the baobab, dawadawa, and neem trees. The heterogeneous collection of trees provides all domestic requirements for fuel wood and charcoal, construction of houses, cattle kraals and fencing of gardens. The shorter shrubs and grass provide fodder for livestock. Although terrain on the average is fairly flat, there are some high lands to the south and east of the region and occasional mountains lined up close to the boundary between Ghana and Burkina Faso.

3.1.3 CLIMATE

The climate of the region is one that is common to the three northern regions. There are two seasons, the dry and the wet seasons. The wet season commences from early April and ends in October. The dry season, characterized by the cold and hazy harmattan weather, starts from early November and ends in the latter part of March when the hot weather begins with intensity and ends only with the onset of the early rainfall in April. The temperature of the region is between a low of 15^{0}c at night time during the harmattan season and a high of 40^{0}c in the day during the hot season of the harmattan.

3.1.4 THE BLACK VOLTA BASIN

The Black Volta Basin, the largest of the catchments in the Volta Basin has a total area of $142{,}056km^2$ of which $33{,}302km^2$ (23.5%) is located in Ghana. The tributaries are the Aruba, Bekpong, Benchi, Chridi, Chuco Gbalon, Kamba, Kule Dagare, Kuon, Laboni, Oyoko, Pale, and river San. The basin is mainly located in the north-western part of Ghana and the south-western part of Burkina Faso. The basin includes northern and central parts of Ghana, southern Burkina Faso and northern Cote D'Ivoire (Boubacar Barry et. al, 2005). Figure 3.3 shows the Black Volta of the Black Volta basin.

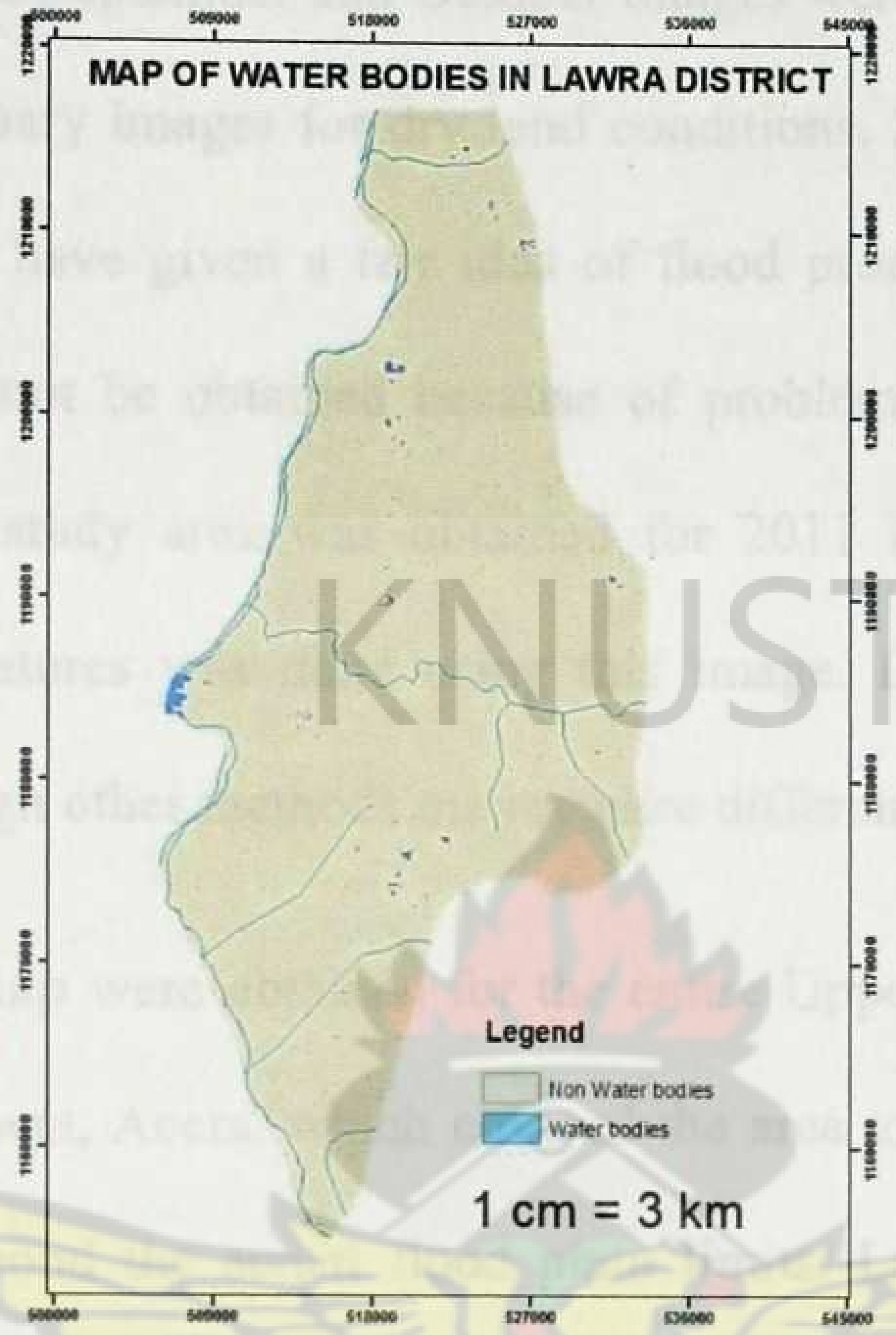

Figure 3. 2 Black Volta River in Lawra District

3.2 DATA SOURCES AND SELECTION CRITERIA

Rainfall values from 1980-2011 were obtained for Wa, Babile, Tumu and Lawra as these are the four weather stations in the region. It was important for a regional distribution because precipitation formation is quiet localized. It would have been much better to obtain temperature values for the other stations as well but they were not available. However because the Wa station is a synoptic weather station it suffice for the whole of upper west region thus it gives a good representation of temperature for the entire study area. For a good climate model long periods need to be studied and thirty-two years is a good period for such work as recommended by the World Meteorological Organization (states at least 30 years).

This study used Landsat 7 ETM scenes as the source image. Landsat ETM imagery was selected because the 30 by 30 meter pixel size appeared to satisfy medium-scale graphic mapping requirements. Images of 2007, 2009 September, October and February were obtained. September and October images were for extraction of flood water extent, and February images for dry land conditions. Subtraction of February from the others would have given a fair idea of flood prone communities (areas). However, these could not be obtained because of problems with Landsat sensors since 2003. Image of study area was obtained for 2011 though it was stripped. Extraction of water features was done using this image. Data for the hydrologic modelling were (although other methods may require differently);

- **Topographic map** were obtained for the entire Upper West region from the Survey Department, Accra, which covered the area to be studied with plenty of coverage beyond the actual flood plain limits. Land-use and land-cover maps were also obtained.
- **Flow discharges**: Ideally values for the same period of study determined at places with tributaries or with storm sewer discharges or where the drainage area increases significantly would have been appropriate for this work. Although values were obtained for the period from Ghana Hydrological Services, they were not for those designated places and years. Some experiment was performed to verify the values at important places to compensate for the others. It is worth noting that for hydrologic process modelling if the flow discharges are highly questionable, then detailed modelling will still provide highly questionable results. Discharges measured at bends or areas with a lot of debris do not represent the flow discharges of the river since these cause impediments in river flow. Therefore considerable

judgement was applied in selecting cross-sections for the experiments, like bends and areas with sharp change in slope.

- **Cross-sections**: Careful selection for good location for these measurements was necessary as analysis are important for flood depth, river width, velocity, change in shape of the river, slope changes, bends in river and changes in flood-plain different from upstream and downstream conditions.
- **Manning's 'n' value**: These were determined for each reach of river as they are necessary for roughness of stream channel and overbanks. Values were looked up in the National Engineering Handbook.
- **Digital Elevation Model (DEM)**: This was necessary for the determination of terrain processes such as flow direction, flow accumulation, stream segmentation, watershed delineation, etc., extracted from shuttle radar topography mission (SRTM) files.
- **Meteorological Data**: This study deals with a climatic model and a hydrological model. Temperature values will suffice for the climatic model with rainfall values as input (major factor) for the hydrological model. These were obtained from the Meteorological Department.
- **Software application**: There are many GIS platforms for flood prediction and modelling but the data available was suitable for HEC-HMS and ArcHydro environments.

The Hydrologic Modelling System (HEC-HMS) is designed to simulate the precipitation-runoff processes of dendritic watershed systems. It is designed to be applicable in a wide range of geographic areas for solving the widest possible range of problems. This includes large river basin water supply and flood hydrology, and small urban or natural watershed runoff.

A model of the watershed is constructed by separating the hydrologic cycle into manageable pieces and constructing boundaries around the watershed of interest. Any mass or energy flux in the cycle can then be represented with a mathematical model. In most cases, several model choices are available for representing each flux. Each mathematical model included in the program is suitable in different environments and under different conditions. Making the correct choice requires knowledge of the watershed, the goals of the hydrologic study, and engineering judgment. The program features a completely integrated work environment including a database, data entry utilities, computation engine, and results reporting tools. A graphical user interface allows the seamless movement between the different parts of the program. Program functionality and appearance are the same across all supported platforms.

ArcHydro is not a complete data model or application specific but provides a starting point for model design and components for developments. ArcHydro is a model developed for building hydrologic information systems to synthesize geospatial and temporal water resources data that support hydrologic modelling and analysis. The model is developed as an Add-on to ArcGIS software. It is used to extract topologic variables from a digital elevation model raster (DEM) for building geometric networks for hydrologic analysis. ArcHydro describes the hydrologic features that are available in a watershed on a spatial scale and also provides a link between these features by establishing a relationship between different features. Thus Arc Hydro and hydrologic model represent two different aspects namely description and prediction respectively and it is difficult to have these two functionalities in one environment.

A river flow rate measuring experiment was conducted to validate the flow rate values obtained from the Hydrological Services Department. Although the experiment values was not exact, it was close signifying the degree of accuracy of the values. See appendix 1 for a detailed description of the experiment procedure.

3.3 DESIGN OF STUDY

3.3.1 METHODOLOGY

The design has been broadly grouped into 'data preparation' and 'modelling procedures'. In data preparation, further groupings are made into the various type of data acquired so as to give a detailed description of the various procedures. Under modelling procedures, descriptions of the prediction in GIS environments are discussed.

3.3.2 DATA PREPARATION

Satellite Image and Digital Elevation Model (DEM)

Per the geographic location of my study area, the satellite image cells that adequately cover it are Path 195, Row 53 and Path 195, Row 52. These can be found within latitude 10.1 (10° 06′ 00″), longitude -2.2 (-02° 12′ 00″) and latitude 11.6 (11° 36′ 00″), longitude -1.9 (-01° 54′ 00″) respectively. The Landsat 7 ETM was downloaded from USGS's website glovis.com. The zip files unzipped gives the tiff format of the six (used for the purpose) bands contained therein. These were then stacked in the ERDAS IMAGINE 2010 environment to obtain an image for that cell. Fourier editing can be used to remove regular errors in data such as those caused by sensor anomalies (e.g., striping). The Fourier algorithm expressed below adopted from Oppenheim and Schafer, 1975; Press et al, 1988.

$$F(u,v) \leftarrow \sum_{x=0}^{M-1} 1 \sum_{y=0}^{N-1} [f(x,y)\, e^{-j2\pi ux/M - j2\pi vy/N}]$$

Where:

M = the number of pixels horizontally

N = the number of pixels vertically

u, v = spatial frequency variables

e = 2.71828, the natural logarithm base

j = the imaginary component of a complex number

Next an overlay of the area of interest (Lawra Nandom district) was done on the de-stripped image to clip them out, one at a time. The image file as well as the shapefile was all in the same coordinate system (UTM zone 30/ WGS 84) so there was no need to do any transformation.

Normalized Difference Vegetation Index (NDVI) which principle is the comparison of differences of two bands, red and near-infra-red (NIR), where the presence of terrestrial vegetation and soil features is enhanced while the presence of open water features is suppressed because of the different ways in which these features reflect these wavelengths (McFeeters, 1996). $\left[\frac{(NIR-Red)}{(NIR+Red)}\right]$ is the equation for NDVI. If the equation is reversed and the green band used instead of the red, then the outcome would also be reversed, the vegetation suppressed and the open water features enhanced (McFeeters, 1996). The equation for a Normalized Difference Water Index (NDWI) is $\left[\frac{(Green-NIR)}{(Green+NIR)}\right]$. The selection of these wavelengths maximises the reflectance properties of water. That is:

- Maximise the typical reflectance of water features by using green wavelengths;
- Minimise the low reflectance of NIR by water features; and

- Maximise the high reflectance of NIR by terrestrial vegetation and soil features

Kauth and Thomas (1976), Crist and Cicone (1984), Crist (1985), and Crist and Kauth (1986) have done extensive work in Tasselled Cap Transformation in this aspect. DEM were created in the ENVI environment. The regional and district maps were then clipped out in ArcGIS after the necessary re-projection and transformation. This was used as the DEM layer for all processes that involved DEM.

Meteorological Data

The following data were acquired from the Upper West regional branch of Ghana Meteorological Services; Rainfall and Temperature monthly values (1980-2011) for Babile, Tumu, Lawra and Wa stations. These were tabulated for monthly averages, yearly averages and yearly totals. With the rainfall values the regional average from the four stations were found but since temperature values were available for only Wa (and since it is a synoptic station) it was used to represent the entire region by finding the mean. It was important to find the correlation between temperature and rains thus using a moving average of three and five year periods, an interpretable correlation diagram was obtained. Other analyses such as trend analysis were also conducted to determine growth patterns between the variables. The models are based on data from 1980-2010 with 2011 data serving as a test year for the models.

Topographic Data

For such an investigation it is always necessary to acquire very reliable data as this can affect the results. These were acquired from the Survey and Mapping Division. Regional maps of the following were obtained – landuse and landcover (and compared with classified map), basin and hydrology, soil and geology. After classification the district maps were clipped out in ArcGIS environment where necessary. Those that were in different coordinate systems were all transformed into the UTM zone 30/ WGS 84 system to be consistent with the image data acquired.

River Morphology

Cross-sections, river discharges for the study period, river depths, river width and watershed or catchment map were the data needed for this investigation. From the Hydrological Services Department flow rates were obtained for some years within the study period. But for verification it was important to perform experiments since these data needed to be highly reliable as the hydrological modelling process depended on their accuracy. The simple experiment is described in appendix 1 and obtained values were consistent with what HSD produced.

3.4 MODELLING PROCEDURES

3.4.1 CLIMATE MODELLING PROCEDURE

Due to non-availability of relevant data such as atmospheric vapour content and carbon content it was unnecessary to have attempted doing any rigorous mathematical computations. The Energy Balance Model was used because this model best suits the semi-arid and arid areas of upper west region.

Energy balance models (EBMs) are zero- or one-dimensional models predicting the surface (strictly the sea-level) temperature as a function of the energy balance of the Earth. Simplified relationships are used to calculate the terms contributing to the energy balance in each latitude zone in the one-dimensional case (Kendal and Ann, 2005). The total energy received from the Sun per unit time is $\pi R^2 S$ where R is the radius of the Earth. The total area of the Earth is, however, $4\pi R.^2$ Therefore the time-averaged energy input rate is $S/4$ over the whole Earth. Hence, $(1-\alpha)S/4 = \sigma T_e^4$

where α is the planetary or system albedo, S is the solar constant (1370 Wm^{-2}) and σ is the Stefan–Boltzmann constant ($5.67051 \times 10^{-8} Wm^{-2}K^{-4}$). If the atmosphere of the planet contains gases which absorb thermal radiation then the surface temperature, T_s, will be greater than the effective temperature, T_e. The increment ΔT is known as the *greenhouse increment* and depends upon the efficiency of the infrared absorption. Thus the surface temperature can be calculated if ΔT is known since $\boldsymbol{T_s = T_e + \Delta T}$. For the Earth, the greenhouse increment due to the present atmosphere is about ΔT = 33K (-240.15°c), (Kendal and Ann, 2005) and hence combining both equations give, for $\alpha = 0.3$, T_s= 288K. (Note that the only prognostic variable in an EBM is the temperature, characterized as a surface temperature). The moving average and regression analyses were used to develop patterns and predictions in temperature cycle which is the major factor in the energy balance model.

3.4.2 FLOOD MODELLING PROCEDURE

ArcGIS – ArcHYDRO

Add the DEM file and streams layers to a new project. Save the project. The complete processes is in Figure 3.4.

After completing pre-processing a user is able to use the new data to further analyse the data set with the other Arc Hydro menus as applicable; Watershed Processing, Attribute Tools, Network Tools. Watershed Processing tools operate on top of the spatial data produced in the pre-processing stage to create watersheds and sub-watersheds. The Attribute Tools provide a means for creation of some of the key fields in the Arc Hydro data model. The Network Tools create or change properties of the geometric (hydro) network.

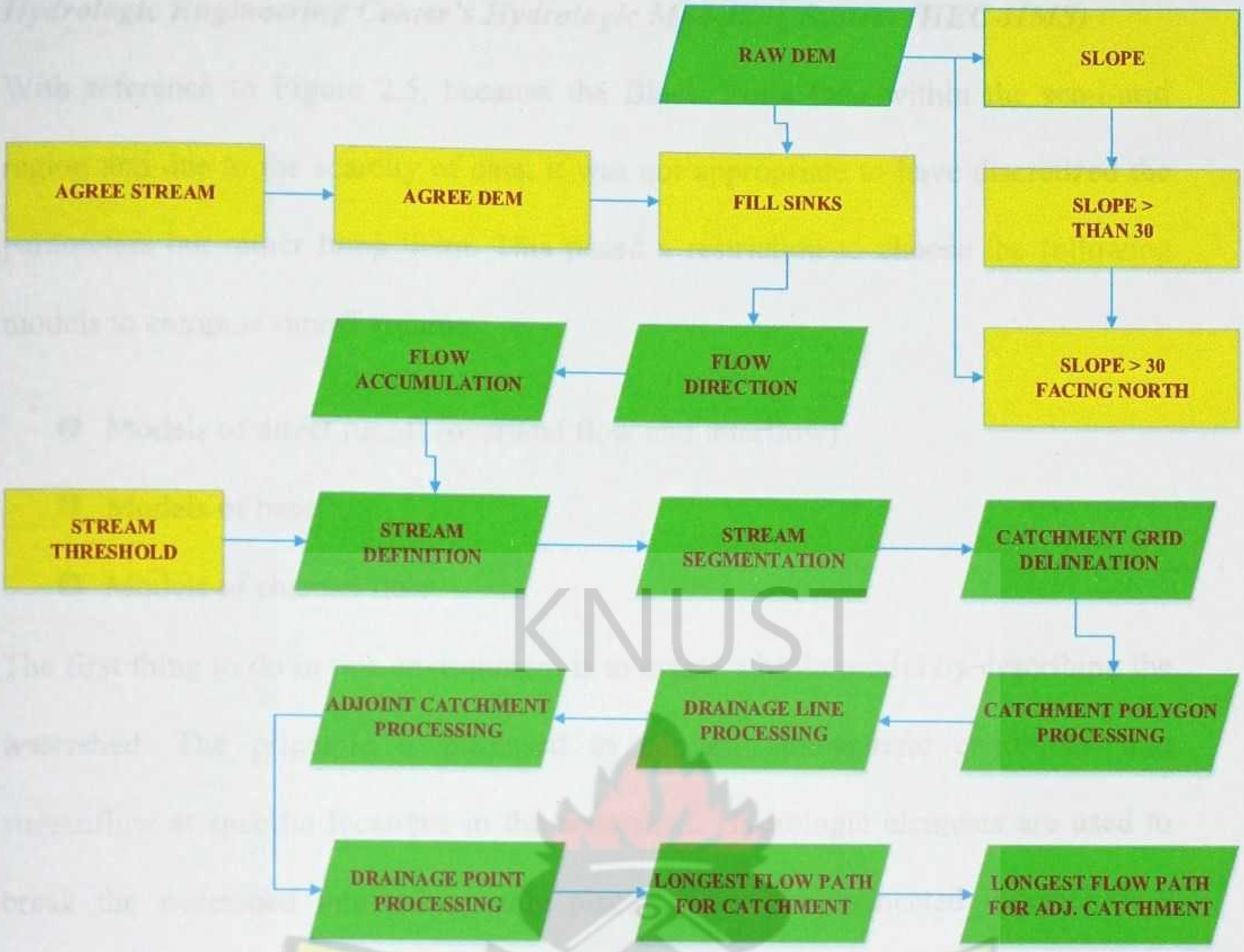

Figure 3. 3 Flowchart of Terrain Processes

A Selection of Watershed Processing Tools is as follows:

- **Batch Watershed Delineation**

  Creates a watershed from a point (or a point feature class) you create using the Batch Point Generation tool.

Click on the batch point generation tool on the Arc Hydro Toolbar and create a batch point feature class.

- *Watershed Processing → Batch Watershed delineation*

  The default inputs can be accepted in the window that appear or you can change the watershed names. Run it.

Hydrologic Engineering Center's Hydrologic Modelling System (HEC-HMS)

With reference to Figure 2.5, because the Black Volta falls within the semi-arid region and due to the scarcity of data, it was not appropriate to have discretized the parameters but rather lump them. This posed a restriction to choose the following models to compute runoff volume;

- Models of direct runoff (overland flow and interflow)
- Models of baseflow
- Models of channel flow

The first thing to do in this environment is to create a basin model by describing the watershed. The principle is purposed to convert atmospheric conditions into streamflow at specific locations in the watershed. Hydrologic elements are used to break the watershed into manageable pieces. They are connected together in a dendritic network to form a representation of the stream system as shown in Figure 3.4.

In the HMS environment, Flow ratios were chosen as this is used to increase or decrease the computed flow by a fixed ratio; they can only be applied to sub-basin and source elements. Once the flow ratios are turned on, each sub-basin and source can have a separate ratio, or no ratio. An alternative is to use Missing inflow where data for an element can be set to zero. Downstream routing elements generally cannot process missing data. When missing flow data is not replaced, any element that encounters missing inflow data will halt a simulation with an error message. When missing flow data is replaced, the missing inflow data is set to zero and a message is generated that indicates how many values were missing.

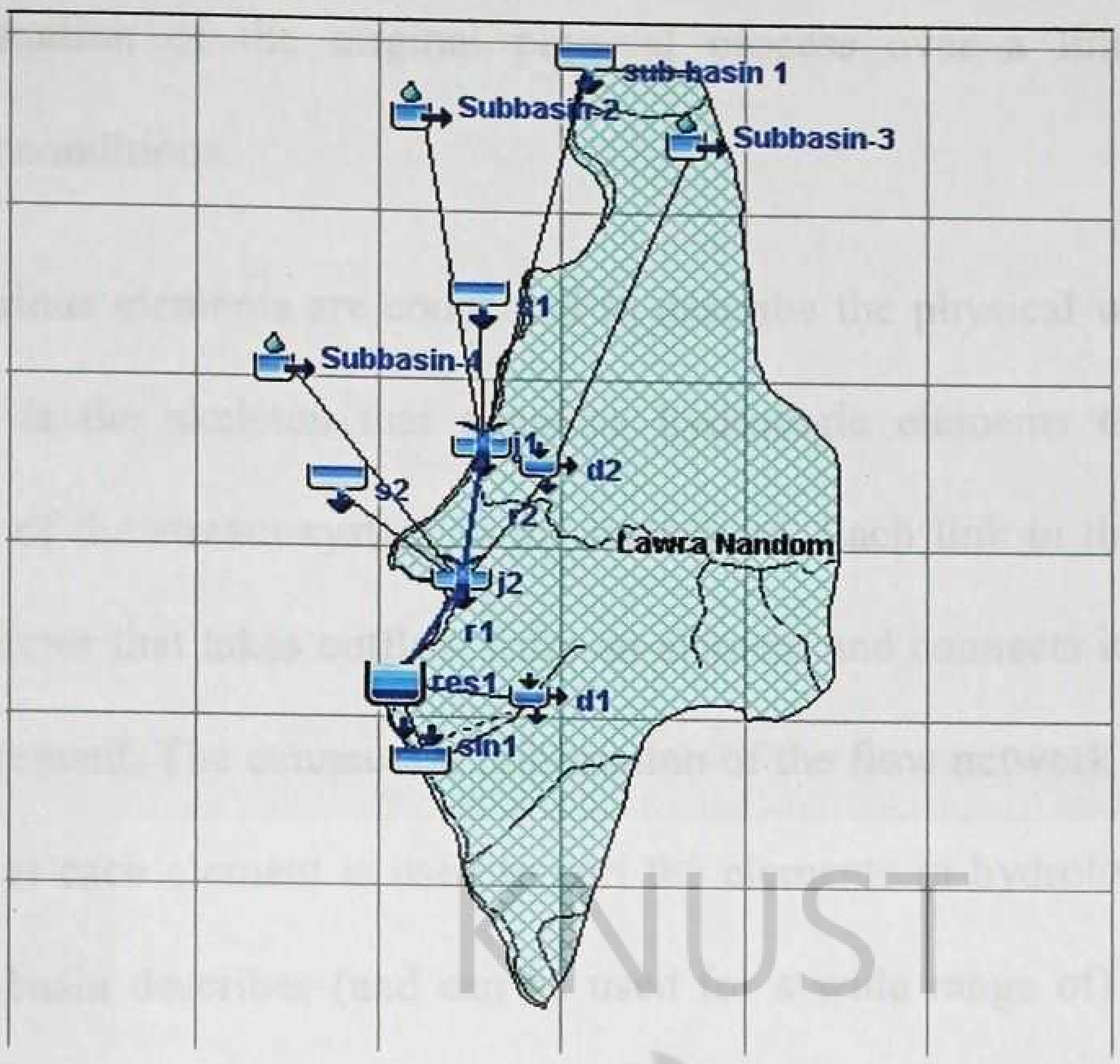

Figure 3. 4 HEC-HMS Basin Model of Hydrologic Elements

The next step is to model the basin. The Lawra district map was used as the background map and the river shapefile created in ArcGIS for this purpose. The basin model map is the primary method for visualizing the hydrologic elements that are added to the basin model to represent the watershed. Background maps provide a spatial context for the hydrologic elements composing a basin model. The maps are not actually used in the computation process, but they can be very helpful in showing the spatial relationship between elements.

Next the model is designed by placing onto the user interface, hydrologic elements. Hydrologic elements are the basic building blocks of a basin model. An element represents a physical process such as a watershed catchment, stream reach, or confluence. Each element represents part of the total response of the watershed to atmospheric forcing. Seven different element types have been included in the HMS: sub-basin, reach, reservoir, junction, diversion, source, and sink. An element uses a mathematical model to describe the physical process. Sometimes the model is only a good approximation of the original physical process over a limited range of environmental conditions.

Finally the various elements are connected to describe the physical watershed. This flow network is the skeleton that connects hydrologic elements together into a representation of the stream system in the watershed. Each link in the network is a one-way connector that takes outflow from an element and connects it as inflow to a downstream element. The connection information of the flow network along with the drainage area at each element is used to sort the elements in hydrologic order. The modelled sub-basin describes (and can be used for a wide range of) the catchment sizes. Here canopy, surface, loss, transform as well as unit baseflow methods are defined. The following were chosen because they best describe the physical attributes of the Black Volta watershed.

- Canopy Method – Simple Canopy
- Surface Method – Simple Surface
- Loss Method – Initial and Constant
- Transform Method – Kinetic Wave
- Baseflow Method – Constant Monthly

The Natural Resources Conservation Service (NRCS) method of estimating direct runoff from storm rainfall is used. The NRCS method of estimating direct runoff from storm rainfall was the end product of a major field investigation and the work of numerous early investigators (Mockus, 1949; Sherman, 1942; Andrews, 1954; and Ogrosky, 1956). Climate is one indicator of the probability of the types of runoffs that will occur in a given watershed. In arid regions the flow on smaller watersheds is nearly always surface runoff. Surface runoff or overland flow occurs when the rainfall rate is greater than the infiltration rate. The runoff equation developed for this condition ensures that runoff flows on the surface of the watershed and through channels to the point of reference.

Basically it starts with a runoff-volume model where the Kinetic Wave is chosen because it fits the natural behaviour of river flows. Alternatively the Soil Conservation Service (SCS) Curve Number (CN) models estimates precipitation excess as a function of cumulative precipitation, soil cover, landuse, and antecedent moisture, using the following equation:

$$P_e = \frac{(P - I_a)^2}{P - I_a + S}$$

where P_e = accumulated precipitation excess at time t; P = accumulated rainfall depth at time t; I_a = the initial abstraction (initial loss); and S = potential maximum retention, a measure of the ability of a watershed to abstract and retain storm precipitation. Until the accumulated rainfall exceeds the initial abstraction, and the precipitation excess, the runoff will be zero. Analysis of results from many small experimental watersheds, the SCS has developed an empirical relationship of I_a and S:

$I_a = 0.2S$, thus substituting gives;

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}$$

Incremental excess for a time interval is computed as the difference between the accumulated excess at the end of and beginning of the period. The maximum retention, S, and watershed characteristics are related through an intermediate parameter, the curve number (commonly abbreviated CN) as:

$$S = \begin{cases} \dfrac{1000 - 10CN}{CN} \\ \dfrac{25400 - 254CN}{CN} \end{cases}$$

The bottom equation is evaluated in SI units. CN values range from 100 (for water bodies) to approximately 30 for permeable soils with high infiltration rates. Table 3.1 gives the CN values for arid and semi-arid rangelands.

Secondly the direct runoff is modelled were the kinematic wave form because for kinematic wave routing, the watershed and its channels are conceptualized to represent the watershed as two plane surfaces over which water runs until it reaches the channel. The water then flows down the channel to the outlet. At a cross section, the system would resemble an open book, with the water running parallel to the text on the page (down the shaded planes) and then into the channel that follows the book's centre binding. The kinematic wave overland flow model represents behaviour of overland flow on the plane surfaces. It combines overland-flow and channel-flow models considering the shape of the channel and applying the appropriate equation. The Black Volta channel discharge is represented as follows, having a trapezoidal section as shown in Figure 3.5.

$$Q = \frac{1.49}{n} S^{\frac{1}{2}} A^{\frac{5}{3}} \left[\frac{1}{W - 2Y\sqrt{1 + Z^2}} \right]^{\frac{2}{3}}$$

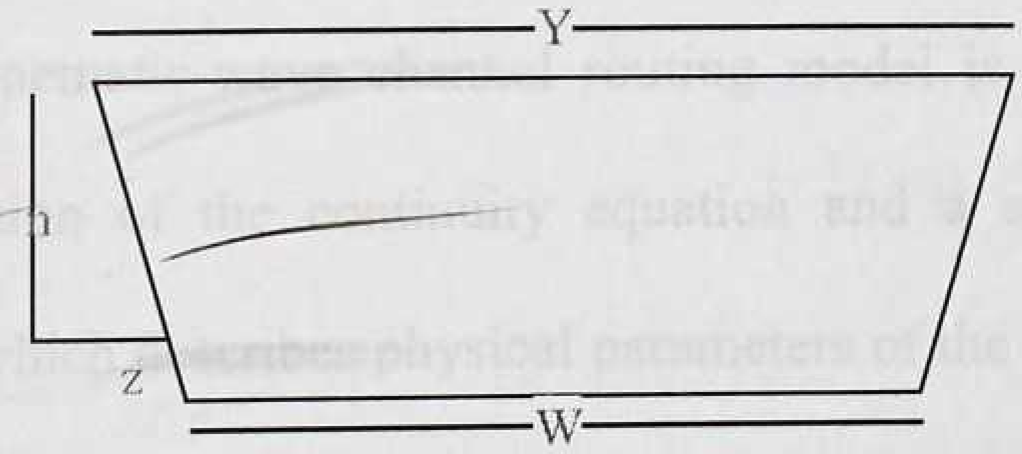

Figure 3. 5 Trapezoidal section representation of river channel

Table 3. 1 Runoff curve numbers for arid and semi-arid rangelands

Cover description: cover type	hydrologic condition 2/	Hydrologic soil group: A 3/	B	C	D
Herbaceous—mixture of grass, weeds and low-growing brush, with brush the minor element	Poor		80	87	93
	Fair		71	81	89
	Good		62	74	85
Oak-aspen—mountain brush mixture of oak brush, aspen, mountain mahogany, bitter brush, maple, and other brush	Poor		66	74	79
	Fair		48	57	63
	Good		30	41	48
Pinyon-juniper—pinyon, juniper, or both; grass understory	Poor		75	85	89
	Fair		58	73	80
	Good		41	61	71
Sage-grass—sage with an understory of grass	Poor		67	80	85
	Fair		51	63	70
	Good		35	47	55
Desert shrub—major plants include saltbush, greasewood, creosotebush, blackbrush, bursage, paloverde, mesquite, and cactus	Poor	63	77	85	88
	Fair	55	72	81	86
	Good	49	68	79	81

1/ Average runoff condition, and Ia= 0.2s. 2/ Poor: <30% ground cover (litter, grass, and brush over story). Fair: 30 to 70% ground cover. Good: >70% ground cover.
3/ Curve numbers for group A have been developed only for desert shrub. Source: National Engineering Handbook, HMS reference manual; Soil Conservation Service (1971, 1986)

In modelling the baseflow in the next step, the constant option was chosen with monthly varying baseflow model since it is the simplest baseflow model which adequately represents baseflow as a constant flow which may vary monthly. A user-specified flow is added to the direct runoff computed from rainfall for each time step of the simulation.

The final modelling step is the channel routing model which is the fundamental equations of open channel flow: the momentum equation and the continuity equation known as St. Venant equations accounts for forces that act on a body of water in an open channel. The kinematic-wave channel routing model is based upon a finite difference approximation of the continuity equation and a simplification of the momentum equation which describes physical parameters of the channel and include, shape of the cross section-which is trapezoidal, principle dimension- bottom width of the channel, and diameter of the conduit. Side slope of trapezoidal shape, length of the reach, slope of the energy grade line, Manning n, roughness coefficient for channel flow were described accordingly.

3.5 METHODS OF ANALYSIS

The following statistical methods of analysis are used to draw conclusions and attempt answering the questions raised as part of the objectives the research set out to investigate.

- Correlation against linear regression
- Empirical approaches
- Mean and Median
- Moving Averages
- Probability Analysis

3.5.1 CORRELATION AGAINST LINEAR REGRESSION

Correlation quantifies the degree to which two variables are related. Correlation does not find a best-fit line. It simply computes a correlation coefficient that tells how much one variable tends to change when the other one does. Here, it doesn't matter which of the two variables is called "X" and which is called "Y", the same correlation coefficient is obtained if variables are swapped. It applies almost always when both variables are measured quantities like temperature and rainfall from weather stations.

With regression, it is important to think about cause and effect as the regression line is determined as the best way to predict Y from X. It uses magnitude in analysis with time as the independent variable and rainfall/temperature (in this research) as the dependent variables with the model. The line that best predicts Y from X is not the same as the line that predicts X from Y. For linear regression, the X variable is often something experimentally manipulated (time, concentration...) and the Y variable is something measured (rainfall, temperature, discharges or flows…).

3.5.2 EMPIRICAL APPROACH

As an empirical approach the most extreme event among past observations is often selected as the design value. The probability that the most extreme event of the past N years will be equalled or exceeded once during the next n years can be estimated as;

$$P(N,n) = \frac{n}{N+n}$$

For this analysis the data for, 1995 and 2009 was used as these are flood years or years with very high records of rainfall, based on the assumption that rainfall excesses caused these floods.

Thus, for example, the probability that the largest flood observed in N years will be equalled or exceeded in N future years is 0.50. If a flood lasting m years is the critical event of record over an N-year period, what is the probability P (N, m, n) that a worse flood will occur within the next n years? The number of sequences of length mm N years of record is N-m+1, and in n years of record n-m+1. Thus the chance that the worst event over the past and future spans combined will be contained in the n future years is given approximately by,

$$P(N,m,n) = \frac{(n-m+1)}{(N-m+1)+(n-m+1)}$$

$$= \frac{n-m+1}{N+n-2m+2} \qquad (n \geq m)$$

Which reduces to the above equation when m=1.

3.5.3 MEAN AND MEDIAN

The sum of all the items in a set divided by the number of items gives the mean value,

$$\overline{X} = \frac{\sum x}{n}$$

$\overline{X}$ = the mean value, Σx = sum of all the items, n = total number of items.

The magnitude of the item in a set such that half of the total number of items is larger and half are smaller is called the median. The apparent median is the ordinate corresponding to 50% of the years. The mean may be unduly influenced by a few large or small values, which are not truly representative of the samples (items), whereas the median is influenced mainly by the magnitude of the main part of intermediate values. To find the median, the items are arranged in the ascending order; if the number of items is odd, the middle item gives the median; if the number of items is even, the average of the central two items gives the median.

3.5.4 MOVING AVERAGES CURVE

If the rainfall at a place over a number of years is plotted as a bar graph it will not show any trends or cyclic patterns in the rainfall due to wide variations in the consecutive years. In order to depict a general trend in the rainfall pattern, the averages of three or five consecutive years are found out progressively by moving the group averaged, one year at a time. The first two (or three or five, which ever suits the study) years of record are averaged and this average is plotted at the mid-point of the group. The next point is obtained by omitting the first and averaging the 3 to 5years of record, again plotting the average at the mid-point of the group and so on. Thus, a 3-year moving mean curve is obtained in which the wide variations in the consecutive years are smoothed out.

3.5.5 PROBABILITY ANALYSIS

This is a rather simple, graphical method adopted to determine the probability or frequency of occurrence of yearly or seasonal rainfall. For the design of water harvesting schemes (for irrigation and runoff volume calculation), this method is as valid as any analytical method described in statistical textbooks. The first step is to obtain annual rainfall totals for the upper west region from the four weather stations. It is important to obtain long-term records. An analysis of only 5 or 6 years of observations is inadequate as these 5 or 6 values may belong to a particularly dry or wet period and hence may not be representative for the long term rainfall pattern. The case of thirty-one years is therefore adequate for this kind of analysis. The next step is to rank the annual mean totals with m == 1 for the largest and m == 31 for the lowest value and to rearrange the data accordingly. The probability of occurrence P (%) for each of the ranked observations can be calculated from the equation:

$$P(\%) = \left[\frac{m - 0.375}{N + 0.25}\right] \times 100$$

Where

P = probability in % of the observation of the rank m

m = the rank of the observation

N = total number of observations used, ie. 31

The above equation is recommended for N = 10 to 100 (Reining et al. 1989).

The next step is to plot the ranked observations against the corresponding probabilities. Finally a curve is fitted to the plotted observations in such a way that the distance of observations above or below the curve should be as close as possible to the curve. From this curve it is now possible to obtain the probability of occurrence or exceedance of a rainfall value of a specific magnitude. Inversely, it is possible to obtain the magnitude of the rain corresponding to a given probability. The statistical elements described below gives a degree of the appropriateness of a method to a set of data.

BIAS - The arithmetic mean of the errors n is the number of forecast errors

$$BIAS = \frac{\sum(Actual - Forecast)}{n} = \frac{\sum Error}{n}$$

Mean Absolute Deviation - MAD

$$MAD = \frac{\sum|Actual - Forecast|}{n} = \frac{\sum|Error|}{n}$$

Mean Square Error – MSE. Standard error is square root of MSE

$$MSE = \frac{\sum(Actual - Forecast)^2}{n} = \frac{\sum(Error)^2}{n}$$

Mean Absolute Percentage Error - MAPE

$$MAPE = \frac{\sum \frac{|Actual - Forecast|}{Actual} \times 100\%}{n}$$

3.6 CONSTRAINTS / PROBLEMS

Hydrologic modelling depends on flow rates and discharges at specific segments of the river under investigation. The data from HSD could not tell the location of these measurements. This can affect the actual volume of runoff collected at the pour point. Also lack of proper equipment for conducting the flow measure experiment could affect the outcome of discharges for that reach. It would have been better to have known the exact discharge entering the Ghana section of the Black Volta to be able to use it as the source outflow from Burkina Faso, but it was necessary to estimate and this can affect the runoff volume at Dikpe.

CHAPTER FOUR: RESULTS AND ANALYSIS OF FINDINGS

4.0 INTRODUCTION

Statistical approaches used fall under either of these; deterministic, parametric, probabilistic and stochastic maintaining their usual definitions and meanings. Diagrams supporting arguments and deductions can be found under appendix 2. Only a few are left here for emphases.

Correlation and Linear Regression

There is clear direct correlation between high rainfall and high flow rates but in an inverse relationship with temperature giving an indication of less evaporation. The monthly plot gives the 'linear' correlation between rainfall and flow rates where increase rainfall depicts high flow rates. The temperature plot is stable with slight variations conforming to the dry and wet seasons of the region. These plots establish the foundation of the argument this research seek to put out that climate change with high temperatures creates high intensity short duration rainfall, which excesses cause flood. The graphical representation is in Figure 4.1.

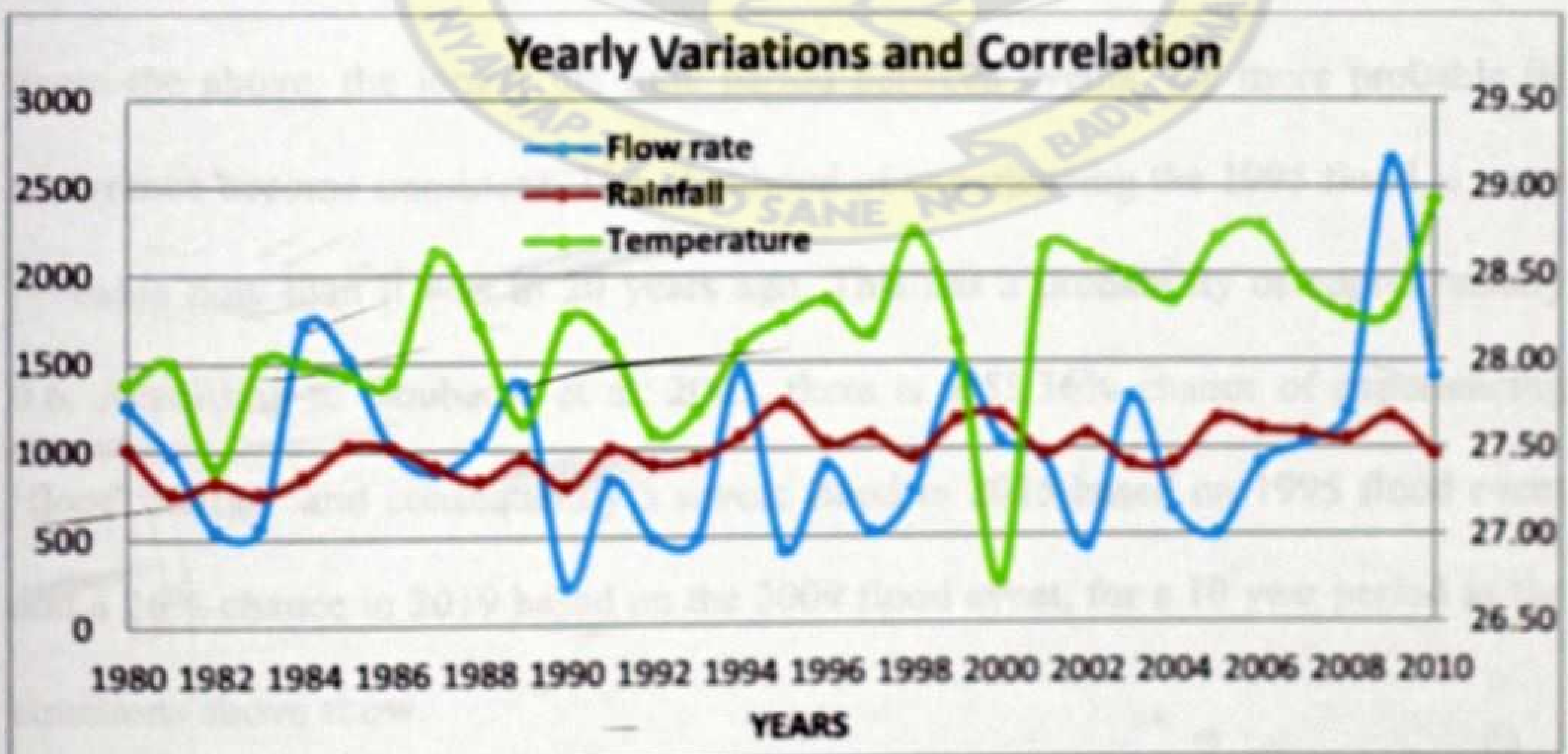

Figure 4. 1 Correlation between Model parameters

Empirical Approach

Reported flood years with extreme events are used for this analysis giving an indication of similar event happening in the near future. For 1995: m = 1/3 years (4 months – periods of high rainfall), N = 16 years (1980-1995). What is the chance that a more severe flood will occur during the next n years of 5, 10 and 20? Then using the appropriate equation;

$$P(16,1/3,5) = \frac{5-(1/3)+1}{16+5-2\times(1/3)+2} = 0.2537 = 25.37\%$$

$$P(16,1/3,10) = \frac{10-(1/3)+1}{16+10-2\times(1/3)+2} = 0.3902 = 39.02\%$$

$$P(16,1/3,20) = \frac{20-(1/3)+1}{16+20-2\times(1/3)+2} = 0.5536 = 55.36\%$$

Similarly for 2009 flood event, m = 1/3 years, N = 30 years (1980-2009)

$$P(30,1/3,5) = \frac{5-(1/3)+1}{30+5-2\times(1/3)+2} = 0.1559 = 15.59\%$$

$$P(30,1/3,10) = \frac{10-(1/3)+1}{30+10-2\times(1/3)+2} = 0.2581 = 25.81\%$$

$$P(30,1/3,20) = \frac{20-(1/3)+1}{30+20-2\times(1/3)+2} = 0.4026 = 40.26\%$$

From the above, the longer the time period between events, the more probable its recurrence become imminent. The likelihood of experiencing the 1995 flood is more probable now than it was in 20 years ago. This has a probability of approximately 0.6. According to Boubacar et al, 2005, there is a 55.36% chance of experiencing 'flood rainfall' and consequently a severe flood in 2015 based on 1995 flood event and a 26% chance in 2019 based on the 2009 flood event, for a 10 year period as the equations above show.

Moving Averages Curve with mean and median

A 3-year moving mean curve is useful in identifying the long term trends or patterns in the rainfall at a place. Accordingly

$$\overline{X} = \frac{\sum x}{n} = \frac{30654.228}{31}$$

$$= 988.85$$

as the mean value with a standard deviation of 131.41. The 3yr moving average has smoothed out the spikes giving a general trend of 3-4yrs of low rainfall to 2-3yrs of very high rainfall. Consult appendix 2 for a pictorial explanation.

Probability Analysis

Table 4. 1 Annual Rainfall Means for 4 stations in Upper West Region

YR/TWN	LAWRA	TUMU	WA	BABILE	ANN. AVE TOTAL	RANK	PROB (%)	PERIOD (T)
1980	628.600	1201.000	1104.000	1113.700	1011.825	15	45.35	2.21
1981	558.900	815.200	755.700	902.800	758.150	30	91.86	1.05
1982	459.440	798.000	981.700	1056.500	823.910	28	85.66	1.13
1983	830.600	957.900	670.300	563.500	755.575	31	94.96	1.02
1984	750.000	956.600	936.700	764.100	851.850	26	79.46	1.21
1985	1160.600	917.000	1059.800	973.800	1027.800	13	39.15	2.55
1986	1451.500	933.300	516.900	1175.600	**1019.325**	14	42.25	2.37
1987	890.400	949.200	776.800	1005.000	905.350	25	76.36	1.31
1988	515.500	936.100	930.500	914.100	824.050	27	82.56	1.17
1989	668.400	1006.000	1042.300	1081.100	949.450	19	57.75	1.73
1990	645.600	779.900	906.300	820.600	788.100	29	88.76	1.09
1991	689.300	1364.900	1007.800	953.700	1003.925	16	48.45	2.06
1992	913.600	903.700	862.600	970.500	912.600	23	70.16	1.43
1993	552.340	1012.500	1130.200	1089.500	946.135	21	63.95	1.56
1994	1137.300	1082.100	1000.400	1069.100	1072.225	10	29.84	3.35
1995	1243.900	1096.000	1037.400	1665.200	**1260.625**	1	1.94	51.60
1996	1006.700	1241.600	954.600	911.500	1028.600	12	36.05	2.77
1997	883.000	941.900	1357.800	1140.600	1080.825	9	26.74	3.74
1998	1095.400	1016.500	767.300	912.300	947.875	20	60.85	1.64
1999	1193.300	984.100	1290.400	1218.800	**1171.650**	4	11.24	8.90
2000	1069.600	1282.400	1141.800	1274.100	1191.975	2	5.04	19.85
2001	927.400	999.900	1005.300	945.600	969.550	17	51.55	1.94
2002	1102.550	1241.500	939.300	1047.200	1082.638	8	23.64	4.23
2003	474.500	890.600	1199.400	1078.600	910.775	24	73.26	1.37
2004	415.200	872.400	1080.200	1300.500	**917.075**	22	67.05	1.49
2005	1446.200	1095.700	1069.800	1071.200	**1170.725**	5	14.34	6.97
2006	816.700	1193.700	1010.800	1416.500	**1109.425**	6	17.44	5.73
2007	1012.700	1416.500	996.700	931.000	**1089.225**	7	20.54	4.87
2008	955.400	931.000	1273.100	1047.000	**1051.625**	11	32.95	3.04
2009	1261.800	1221.000	1142.400	1088.300	**1178.375**	3	8.14	12.29
2010	594.300	1068.700	1022.283	1156.100	**960.346**	18	54.65	1.83

As shown in Table 4.1 the probability and period columns give the likelihood of a rainfall event occurring and its time of occurrence respectively. Extreme rainfall events generate high runoffs which act as catalyst for flood event. The annual rainfall with a probability level of 67 percent of exceedance is 917.075mm, i.e. on average in

67 percent of time (2 out of 3 years) annual rain of 917.075mm would be equalled or exceeded. For a probability of exceedance of 33 percent, the corresponding value of the yearly rainfall is 1051.625mm.

$$T = \frac{100}{P\%} years$$

From Table 4.1, an annual rainfall of 917.075mm at 67 percent has a return period of 1.49 years thus from 2004, in the return period it implies that similar records will show in 2005-2006. Similarly 2002 of 4.23 years results in 2007 whereas 1999 having a return period of 8.9 (approximately 9 years) results in 2008, significantly showing an effective model analysis tabulated in Table 4.1.

4.1 FORECASTING METHODS

4.1.1 PERCENTAGE GROWTH METHOD

The assumption underlying this method is that data in hand follow either an increasing or decreasing trend. The records of rainfall and temperature show such increasing and decreasing trends seasonally. That's why this very method is applicable, to forecasting.

- The Total Percentage Change in annual rainfall total is

$$P\Delta = \left[\frac{1980\ annual\ mean - 2010\ annual\ mean}{2010\ annual\ mean}\right] \times 100$$

$$= \left(\frac{1011.825 - 960.35}{960.35}\right) \times 100 = 5.36\%$$

- The Yearly Percentage Change is

$$\frac{P\Delta}{N} = \frac{5.36\%}{31} = 0.173\%$$

where N is the number of observations

- The Forecasted rainfall for year 2011 is

$$960.35 \times (1 + 0.0536) = \mathbf{1011.5}\boldsymbol{mm}$$ for Upper West region

4.1.2 NAÏVE METHOD

This is based on the assumptions that whatever happened recently will happen again this time same time period. The model is simple and flexible and provides a baseline to measure other models. This approach attempts to capture seasonal factors at the expense of ignoring trend. These were applied to rainfall, temperature, and flow rates as shown in appendix 2.

4.1.3 TIME SERIES METHOD

The Time Series Method tries through regression analysis to come up with a line that minimizes the distance between any Actual Point on the Curve and its Corresponding Point on the Line (Least Square Method). The consideration assumes item forecasted will stay steady over time. This technique will smooth out short-term irregularities in the time series.

$$k - period\ moving\ average = \sum_{k-1}^{k} (Actual\ value\ in\ previous\ k\ periods)/k$$

This Technique is also referred to as the Regression Analysis. After finding the Equation of the Line (i.e. f (x) = y = a * x + b; y = 8.2312*x - 15429), as can be seen from figure 4.5, I have tried to forecast for 2012 annual mean rainfall. This gives

$$y = 8.2312x - 15429 = (8.2312 \times 2011) - 15429 \cong \mathbf{1123.94}\boldsymbol{mm}$$

4.1.4 MOVING AVERAGE METHOD

Similar to the "Percentage Growth Method", the Moving Average Method assumes an increasing or decreasing trend. This very forecasting technique aims at smoothing data and adjusts it as to minimize volatility reflected in a high standard deviation between different records in the same data range. The most commonly used moving average is the Double year moving average, which calculates a third column by taking averages of couples of any three successive years. Later, the percentage growth method would be applied to the smoothed data. Then, come up with the forecasted value. Table 4.3 is the tabulated double moving average.

- The Total Moving Average Percentage Change

$$P\Delta = \frac{1069.36 - 884.99}{884.99} \times 100 = 20.83\%$$

- The Period Moving Average Percentage Change

$$Period\ MA = \frac{20.83}{31} = 0.672\%$$

- The Forecasted 2010 - 2011 Moving Average

$$1069.36 \times (1 + 0.00672) = 1076.5mm$$

- The Forecasted 2011 annual rainfall value

$$(1076.5 \times 2) - 960.35 \cong \mathbf{1192.7mm}$$

Table 4. 2 Double Moving Averages

YR	ANN.R AVE	DOUBLE MA	YR	ANN.R AVE	DOUBLE MA	YR	ANN.R AVE	DOUBLE MA
1980	1011.83		**1991**	1003.93	896.013	**2002**	1082.64	1026.09
1981	758.15	884.99	**1992**	912.60	958.263	**2003**	910.78	996.71
1982	823.91	791.03	**1993**	946.14	929.368	**2004**	917.08	913.93
1983	755.58	789.74	**1994**	1072.23	1009.18	**2005**	1170.73	1043.90
1984	851.85	803.71	**1995**	1260.63	1166.43	**2006**	1109.43	1140.08
1985	1027.80	939.83	**1996**	1028.60	1144.61	**2007**	1089.23	1099.33
1986	1019.33	1023.56	**1997**	1080.83	1054.71	**2008**	1051.63	1070.43
1987	905.35	962.38	**1998**	947.88	1014.35	**2009**	1178.38	1115.00
1988	824.05	864.70	**1999**	1171.65	1059.76	**2010**	960.35	1069.36
1989	949.45	886.75	**2000**	1191.98	1181.81			
1990	788.10	868.78	**2001**	969.55	1080.76			

4.1.5 EXPONENTIAL SMOOTHING METHOD

The prediction of the future depends mostly on the most recent observation, and on the error for the latest forecast. With this method a comprehensive record keeping of past data is not a requirement. A smoothing constant α with a value between 0 and 1 usually 0.1 to 0.3 is used. When α is low there is little reaction to differences however if α is high there is a lot of reaction to differences.

$$Forecast\ for\ period\ t = forecast\ for\ period\ t-1 + \alpha(actual\ value\ in\ period\ t-1 - forecast\ for\ period\ t-1)$$

$$F_t = F_{t-1} + \alpha(A_{t-1} - F_{t-1})$$

Assume that we are currently in period *t* forecast for the last period (F_{t-1}) can be calculated since the actual demand for last period (A_{t-1}) is known. Both moving averages and weighted moving averages are effective in smoothing out sudden fluctuations in the demand pattern in order to provide stable estimates. Increasing the size of k (number of periods averaged) smoothes out fluctuations even better. These are expressed in appendix 2.

4.1.6 WEIGHTED MOVING AVERAGES METHOD

The Weighted Average Method assigns Certain Importance Factor or Coefficient to each historical value. Later, the forecasted value is computed by dividing the weighted data to its coefficients by the sum of coefficients. Assigning weights or coefficients is an art that depends on experience, thorough analysis of past figures, and performances. Yet, whatsoever coefficients are chosen, there is always a certain subjectivity factor that might affect eventually the forecasted figure. One of the most common types of the weighted average method is the simplest method, which assigns the lowest weight to the oldest data in a sequential order. Though the simplest weighted average method is straight forward, assigning least weight to oldest data assumes that:

- The factors that affect the oldest demand diminish through time and hence are not important as far as the future period to be forecasted is concerned.
- The factors and hence the conditions that created the last period's demand are assumed to continue heavily playing an important role in the next period to be forecasted.

Since the above mentioned assumptions might not be valid, in most of the cases, records could be adjusted and coefficients attributed in the simplest weighted average method in a way that mostly puts more weight on factors thought to affect next period's demand and less weight to those which would be considered relatively unimportant. Appendix 2 has the results.

The 2011 Forecasted annual rainfall

$$\frac{Sum\ of\ product}{Sum\ of\ weights} = \frac{512758.60}{496}$$

$$= \mathbf{1033.8mm}$$

4.1.7 TREND ANALYSIS METHOD

This approach uses technique that fits a trend equation (or curve) to a series of historical data points which projects the curve into the future for medium and long term forecasts. Figure 4.2 to 4.4 represent the annual pattern of rainfall, temperature and flow rates respectively whilst appendix 2 gives the statistical table.

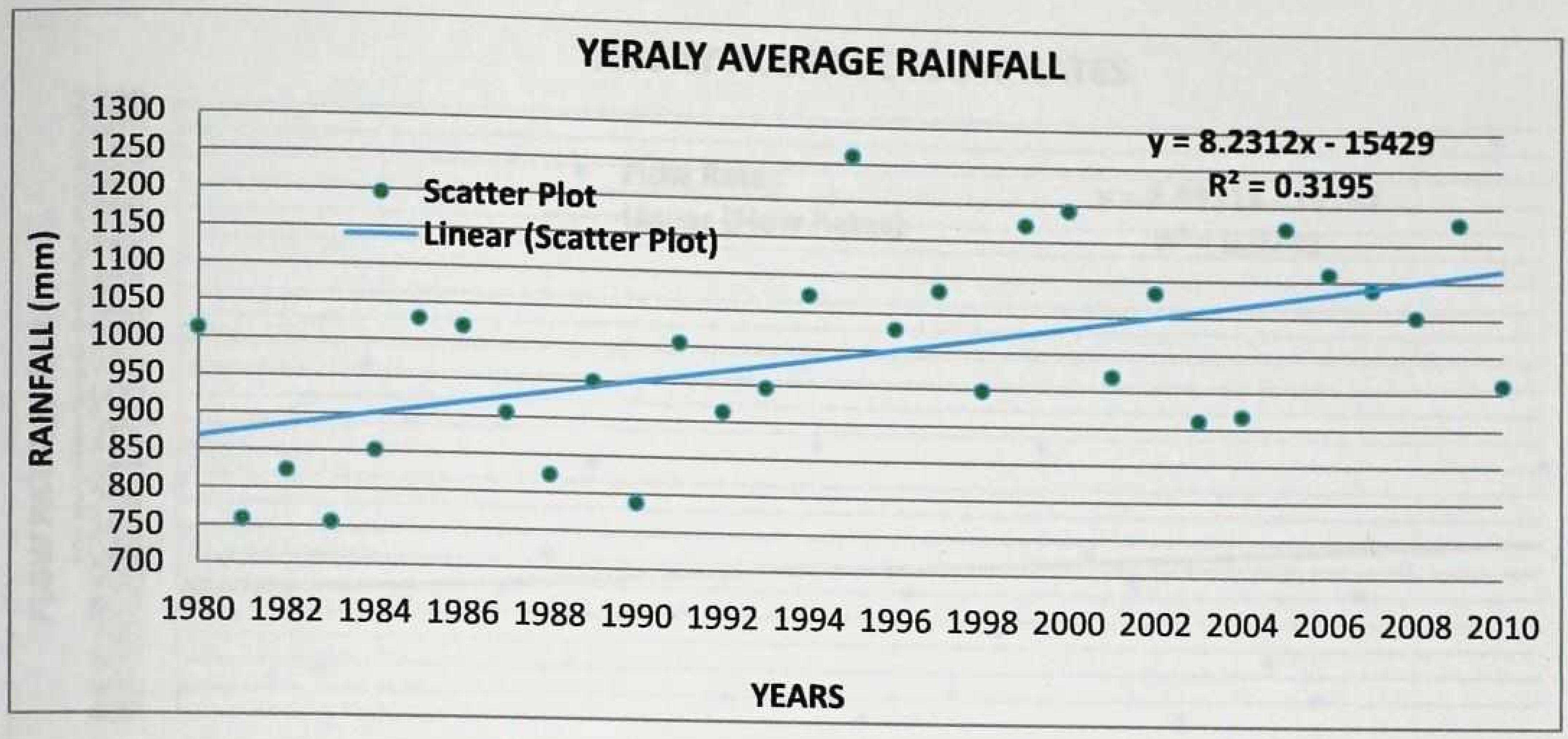

Figure 4. 2 Plot depicts normal distribution over the entire region. Slope = 8.2312, Intercept = 860.933

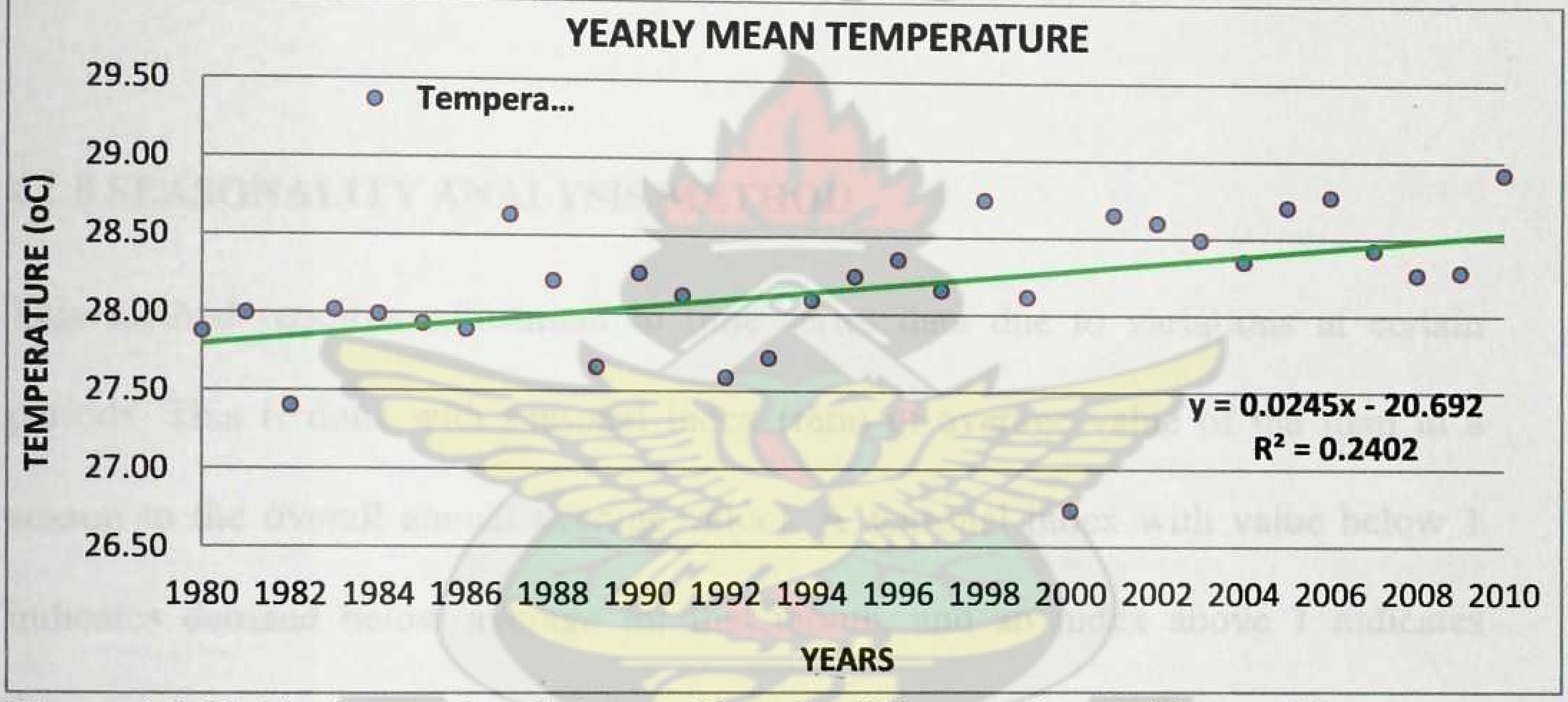

Figure 4. 3 Plot is close with only two outliers signifying a rather stable trend in temperature. Slope = 0.025, Intercept = 27.7759

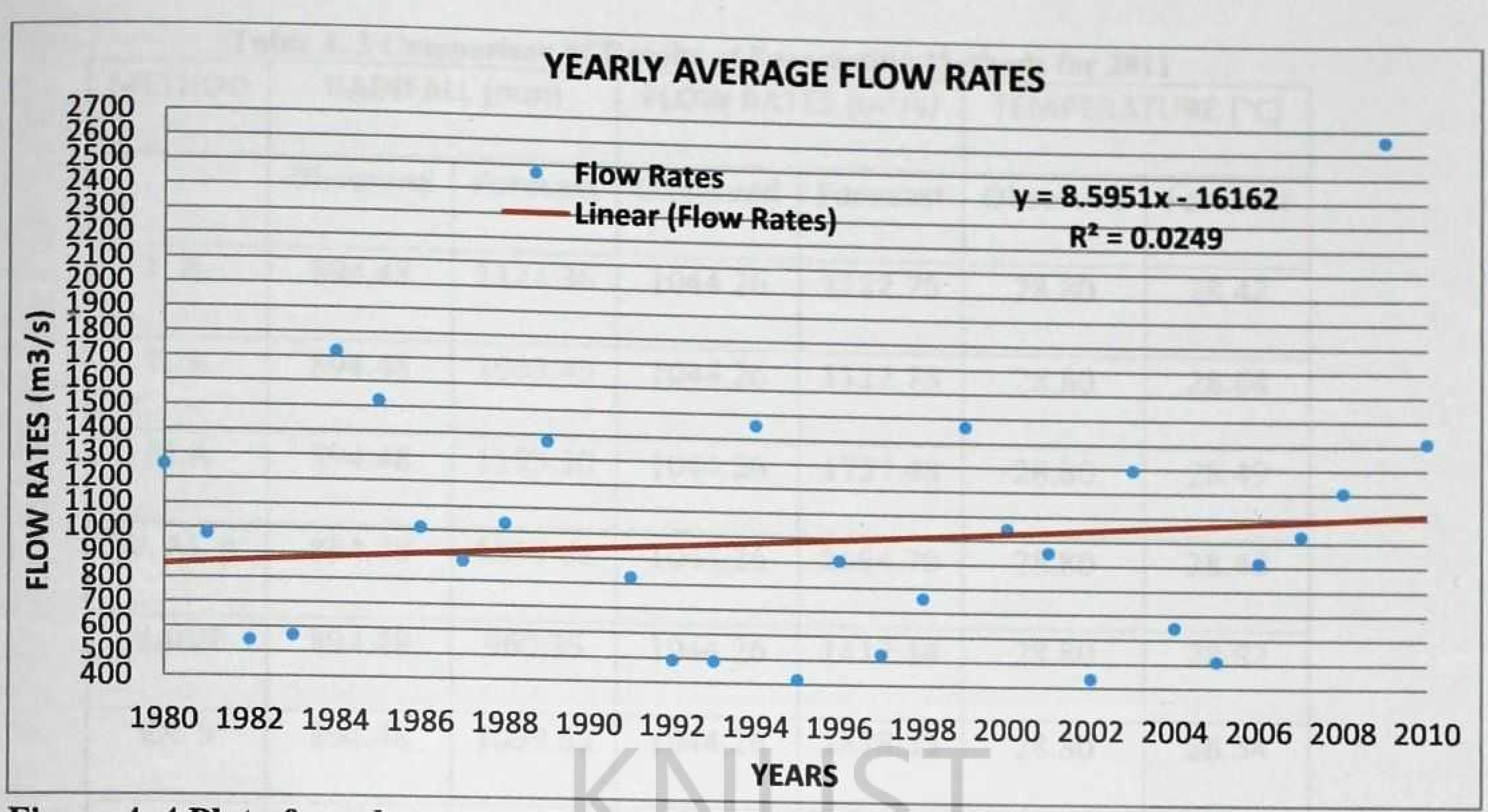

Figure 4. 4 Plot of yearly average flow rates. Slope = 8.595, Intercept = 847.717

4.1.8 SEASONALITY ANALYSIS METHOD

This method requires adjustment to time series data due to variations at certain periods. This is done with seasonal index (ratio of average value of the item in a season to the overall annual average value). A seasonal index with value below 1 indicates demand below average for that month, and an index above 1 indicates demand above average for that month. Using these seasonal indices, the future demand for any future month can be adjusted. Recent years 2009 and 2010 were used to predict the seasonality variation for 2011. Table 4.6 puts all the results together comparing for best suit.

Table 4. 3 Comparison of Results of Forecasting Methods for 2011

METHOD	RAINFALL (mm)		FLOW RATES (m^3/s)		TEMPERATURE (°C)	
	Observed	Forecast	Observed	Forecast	Observed	Forecast
T. A.	894.48	1124.36	1044.26	1122.75	28.80	28.42
T. S.	894.48	1063.45	1044.26	1122.75	28.80	28.64
M.A	894.48	1193.30	1044.26	1757.48	28.80	28.49
W. M. A	894.48	1059.68	1044.26	1694.79	28.80	28.48
NAÏVE	894.48	960.35	1044.26	1412.14	28.80	28.92
EX. S	894.48	1099.53	1044.26	1878.35	28.80	28.34
P. G.	894.48	1011.83	1044.26	2144.28	28.80	*27.88*
S. A	894.48	902.52	1044.26	1056.26	28.80	28.70

TA = Trend Analysis, TS = Time Series, MA = Moving Average, WMA = Weighted Moving Average, EX = Exponential Smoothing, PG = Percentage Growth, SA = Seasonality Analysis

Rainfall responded to weighted moving average better than the others. Trend analysis and time series gave similar values for flow rates with seasonality analysis for temperature. The results of the rest can be found under Appendix 2. Notice the decreased value in temperature for percentage growth which goes to confirm IPPC prediction of slight decrease in the global temperature.

4.2 ANALYSIS ON FLOW RATES

There were a lot of limitations in this area as the Hydrological Services department was unable to provide the discharges for the years under investigation, therefore a good analysis could not be made as a single-day discharge measurement is inadequate to generalize or do any meaningful prediction. Flows on the other hand were adequately obtained thus statistical analysis is made using these values. For the thirty-one year period of study, the annual values are represented and then their respective means calculated. These means give an indication of how much water flows through the river channel at the Lawra stage. Between the sixth and eleventh month gives the period where high values are recorded. Because flood in semi-arid regions generally results from high intensity rainfall, it is an indication that floods can occur only within these months of high flow or better still the onset of floods occur during this period. Monthly values for the thirty-one years are summed and divided by 31 to obtain the means for the various months. The curve shows that we experience large flow between the sixth and eleventh month. This indicates the seasonality or variation in a year.

Raw monthly values were summed up and plotted indicating the total annual flow rates. Trend shows a gradual rise, though individual year cumulatively presents alternate trend of high and low values. The trend analysis predicts $1131.34m^3/s$ for 2012 and $1139.94m^3/s$ for 2013 from the equation provided. The plot reveals a pattern of high and low alternating flow rates indicating that the volume of water passing through the river channel increases and decreases alternately with the square of the deviation at 0.0249. These flow rates yield an occurrence probability of 39.62% and 39.08% respectively.

4.3 ANALYSIS ON TEMPERATURE – Climate Prediction

Percentage Growth Method is a simpler approach to investigate any rate existing within the data available since these data also satisfy the assumption underlying the method.

- The Total Percentage Change in annual mean temperature is

$$P\Delta = \left[\frac{1980\ annual\ mean - 2010\ annual\ mean}{2010\ annual\ mean}\right] \times 100$$

$$= \left(\frac{27.88 - 28.92}{28.92}\right) \times 100 = -3.596\%$$

- The Yearly Percentage Change is

$$\frac{P\Delta}{N} = \frac{-3.596\%}{31} = -0.116\%$$

where N is the number of observations

- The Forecasted temperature for year 2011 is

$28.92 \times (1 + -0.03596) = \mathbf{27.88°C}$ for Upper West region

Regression analysis of the plot shown in appendix 2 is very interesting results where the slope fit of the mean temperature is 0.0339. Trend analysis using figures give mean temperature for 2011 as 28.642°C and for 2012 as 28.676°C indicating a rather small increase of 0.33°C– 0.36°C which corresponds with the slope of approximately 0.03 as the difference between successive years. However there is a general gradual rise in temperature year after year.

The trend line shows a gradual rise indefinitely but this is misleading as successive years show rather small increase and decrease alternating. However, cumulatively, trend is indicative of the gradual increase in atmospheric air temperature which may be due to global warming. Opposing to the argument made above, the return period curve reveals a rather stable condition over long periods whereas the probability of small changes (1°C-1.5°C) occurring is very high falling between 86% and 98%.

4.4 ANALYSIS AND DISCUSSION OF MODEL RESULTS

Establishing a relationship between rainfall and runoff helps to determine direct runoff from rainfall. A curve drawn through a plot of total storm runoff versus total storm rainfall for many storms on a watershed is concave upward and shows that no runoff occurs for small storms. The trend as storm size increases is for the curve to become asymptotic to a line parallel to a line of equality as seen in appendix 3. Annual rainfall that are suspected to have caused flood during the flood years resulted in flow rates above 1000m^3/s. In the same vein annual rainfall recorded in these years are above 1000mm, recorded within the rainy season of March to November with very high probability of occurrence. Values from the remaining three months sum up to an insignificant factor to the annual total and therefore can confidently be ignored or included in the analysis. They were included though and the raw annual rainfall totals have been used (or assumed) as the amount that could cause flood. The bigger the percentage the higher the chances of a particular flow rate to repeat in history. Appendix 2 has the various plots and tables.

Table 4. 4 Direct Runoff (Q) Estimation from annual rainfall in inches

Year	Rainfall P (mm) Ann. total ave.	P (in)	$Q = \frac{(P-0.2S)^2}{P+0.8S}$ (IN) in	m	Volume (m³) = Q x A	Ref. Year 2009	HEC HMS MM/m³
1986	**1019.33**	40.131	**38.397**	**0.9753**	**31,012,782.27**	AUG	**1,549,596.72**
1995	**1260.63**	49.631	**47.887**	**1.2163**	**38,676,147.92**		**10,316,440.2**
1999	**1171.65**	46.128	**44.387**	**1.1274**	**35,849,288.14**	SEP	**1,632,207.89**
2002	**1082.64**	42.624	**40.887**	**1.0385**	**33,022,428.36**		**10,866,424.1**
2005	**1170.73**	46.092	**44.351**	**1.1265**	**35,820,669.77**	OCT	**1,521,645.84**
2007	**1089.23**	42.883	**41.145**	**1.0451**	**33,232,296.47**		**10,130,357.2**
2008	**1051.63**	41.403	**39.667**	**1.0075**	**32,036,684.23**	**TOTAL**	**4,703,450.45**
2009	**1178.38**	46.393	**44.652**	**1.1342**	**36,065,515.89**		**31,313,221.5**

According to Figures 4.5-4.7 ~~Dikpe~~ is mainly savannah with alluvium soils. These give a curve number of 87 which correspond to S value of 1.49 according to appendix 3. For year 2009 the annual value P is 1178.38mm from table 4.8. These values put into $Q = \frac{(P-0.2S)^2}{P+0.8S}$ in inches results in a runoff of **44.652in**, and for 2007 we get **41.145in**. From the plot of annual rainfall for flood years all values are above

1000mm which is an indication that flood will occur only when we have annual rainfall average exceed 1000mm.

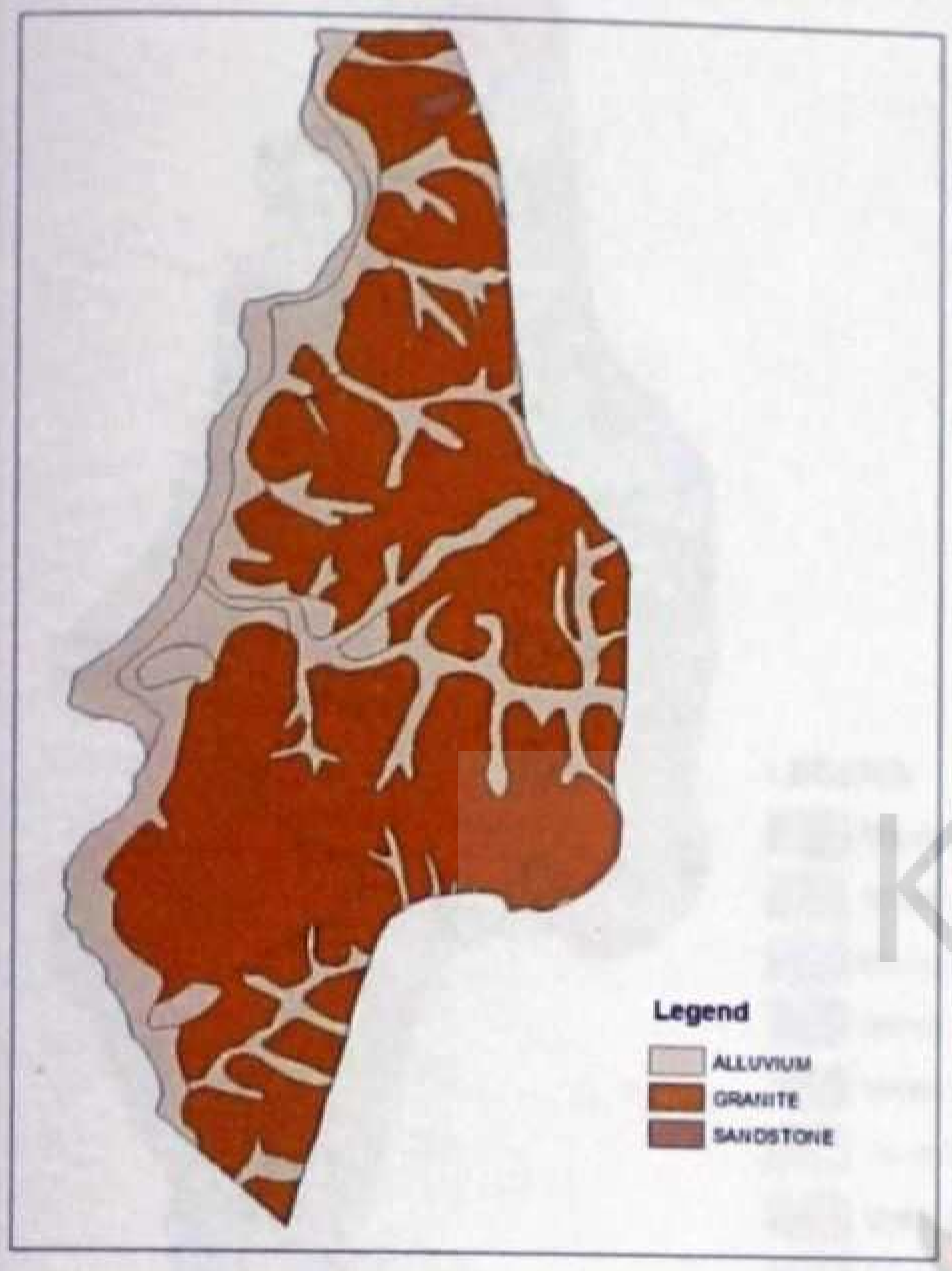

Figure 4. 5 Soil types of Lawra District

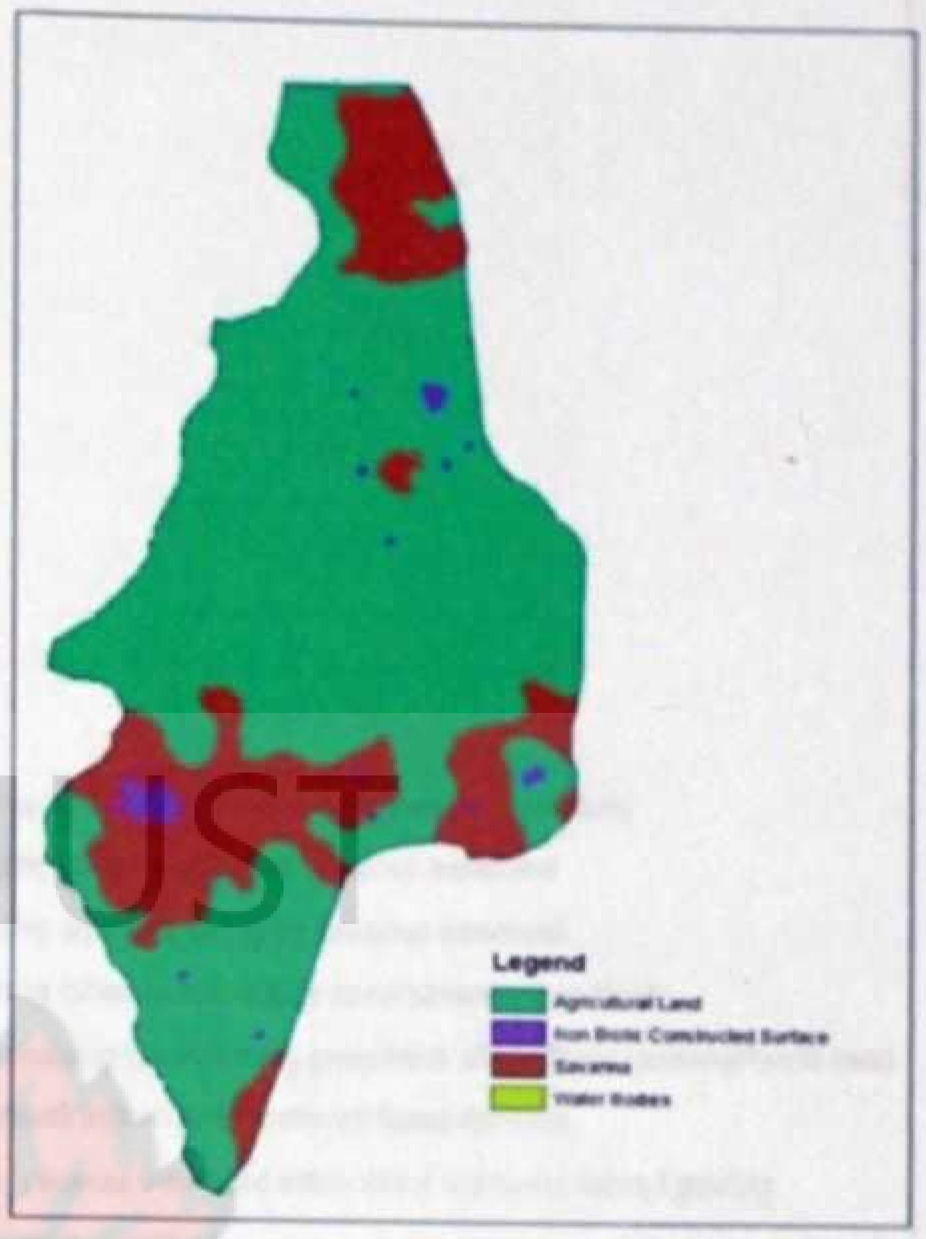

Figure 4.6 Land-cover of Lawra District

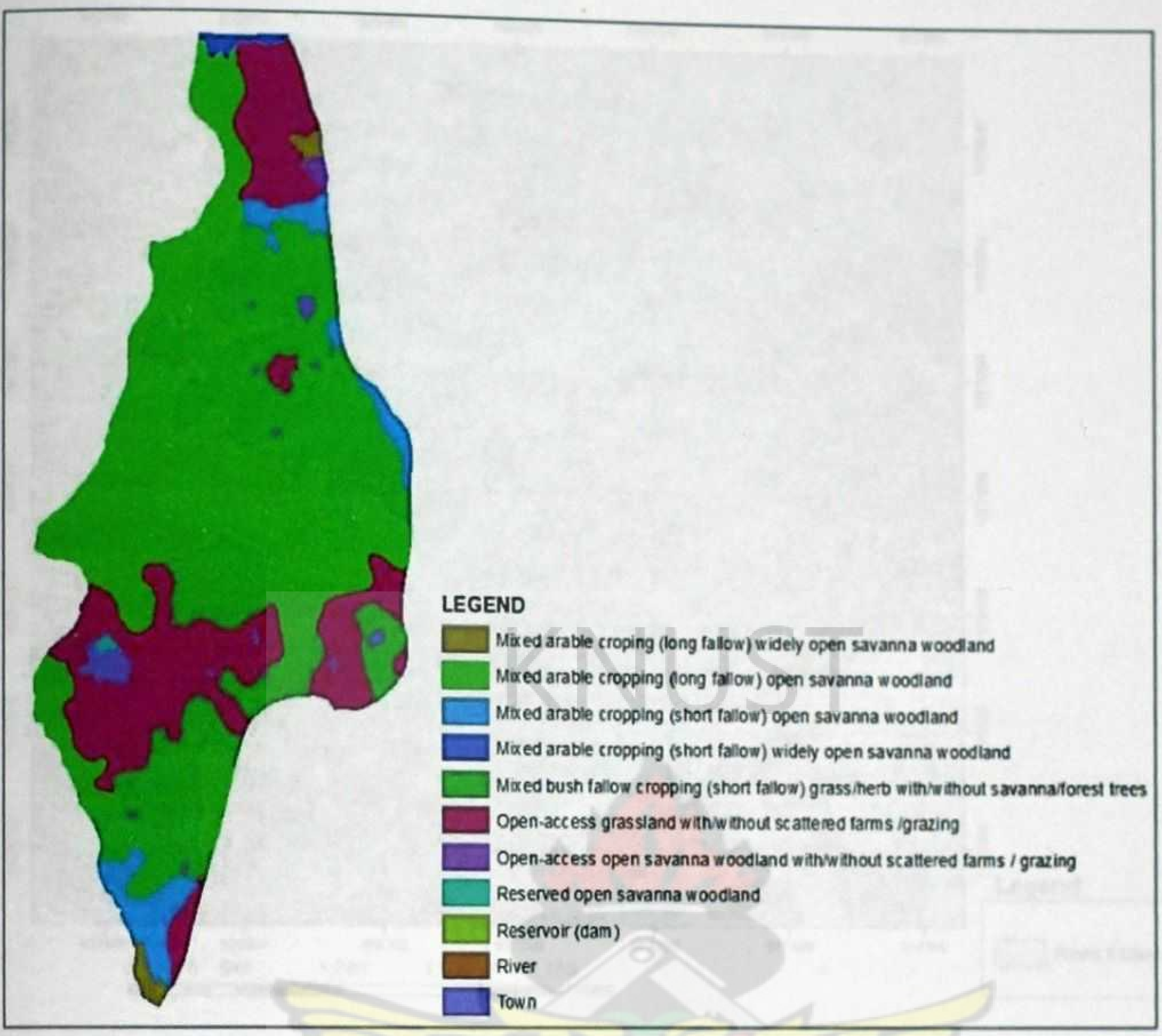

Figure 4.7 Land-use of Lawra District

The channel capacity of the Black Volta is 21,085,440m^3 up to the Dikpe outlet, which means it can hold water to that capacity. Figure 4.8 gives water volumes, obtained by multiplying runoff height by area of 31,798,197.75m^2, above which signifies the excesses that caused flood. These values are greater in 1995, 1999, 2005 and 2009 implying that the flood events in these years were much severe. All these years have rainfall intensities above 1100mm, indicating that rainfall above 1000mm and runoff above 39inches will cause flood in the Dikpe community.

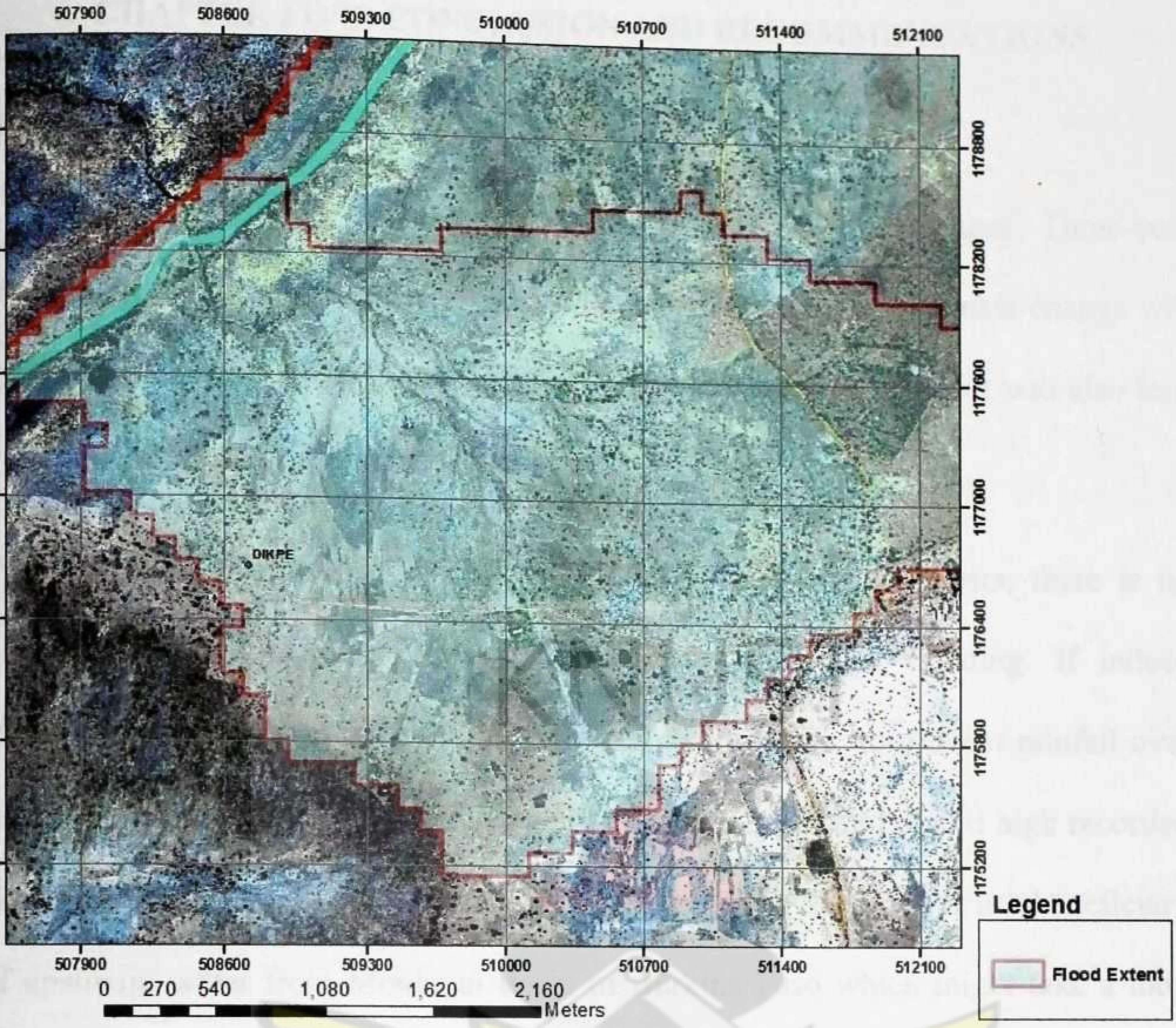

Figure 4.8 Flood area with a runoff height of 1.134m

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

There is an increasing importance of contemporary climate changes. Three-year shifting arithmetic means also prove it. This is even more so, as climate change will not only affect rainfall, evapotranspiration and river flows directly, but will also lead to an increase in water demand for irrigation.

Whereas the indigenous affirm 2008, 2002 and 1986 as flood years, there is no official empirical report or record that Dikpe experienced flooding. If indeed flooding did occur then it might not have resulted directly from event rainfall over the catchment. There is a close relationship between high rainfall and high recorded flow rates or discharges. It is worth noting that the Black Volta River is a beneficiary of upstream water from Mouhoun Basin of Burkina Faso which might take a long time to reach the river channel downstream in Ghana, thus river volume may increase not necessarily from direct event rainfalls but from base flows from all over the catchment especially upstream flow from Burkina Faso.

Another explanation may be due to the following. The Mouhoun Basin (which carries the Mouhoun River) is one of the biggest rivers in Burkina Faso situated directly on the Black Volta (in Ghana). The Bagri dam built on this river for irrigation withholds water till ~~it is full~~ before spilling or released. Coupled spillage from the Kompeinga dam may have released water downstream to increase river flow and water height. Annual rainfall for 1986, 2002 and 2008 were 1019.33mm, 1082.64mm and 1051.63mm respectively. Southern Burkina Faso share the similar climatic conditions with Upper West Region, thus the Sourou Larry Reservoir upstream in Burkina Faso may have received about the same amount. However because of the dams and reservoirs, much drainage was withheld and released later (coupled with event rainfall at that time) which may have resulted in inundation of low-lying farmlands close to the banks of the river, hence giving an impression of flooding.

5.1.1 What is the existing climatic trend as against future trend?

The temperature change in the averages give for minimum 21.59 - 23.42°C, maximum 30.81 - 34.47°C, and mean 26.81 - 28.89°C which is 5.035% change for the thirty-one year period. This means that for every 31 years the change in temperature will be 5% which is quite alarming when this is extended 50 or 100 years and beyond. The slope of the regression line provides only 0.03 increases for every unit of temperature. For the year 2020 the mean temperature per the model (equation) is 28.947°C showing an increase of 0.147°C in 9 years.

5.1.2 What rainfall amount and height of runoff is necessary for flood?

The model provides the runoff volumes in column 4 of Figure 4.8 in inches. This is an indication that runoffs over land will have heights above 38.897in for ordinary flood and above 47.654in for worse flood events according to history if we expect similar events or worst. Forecasted annual rainfall values for 2012 ranges from 1011.8mm-1247.8mm using percentage growth method and moving average method respectively. A 13.2% percentage change has a return period of between 6.97-8.9 years, thus in every 7-8 years there will be a repeat of conditions of referenced year. Rainfall amount likely to cause flood from the model are annual average intensities above 1000mm. According to the model the Black Volta River catchment receives above 31,012,782.27m^3 of water during flood and this could be harnessed to meet the water demand of the district.

5.1.3 In which years will flood occur and which communities will be affected?

The model did not concentrate on predicting flood years but rather computing volume of water during flood events. However based on the rainfall forecasting we are likely to experience floods in 2012, 2015 with reference to 1995 and 2019 with reference to 2009. Communities around Dikpe likely to be affected during flood events depending on the severity are Bagri, Dikpe, Kulbonour, Gopare, Gberi, Lawra, Tuori-Tansztuori and Kouli.

In temperate climates, the standard deviation of annual rainfall is about 10-20 per-cent and in 13 years out of 20, annual amounts are between 75 and 125 per-cent of the mean. In arid and semi-arid climates the ratio of maximum to minimum annual amounts is much greater and the annual rainfall distribution becomes increasingly skewed with increasing aridity. With mean annual rainfalls of 200-300 mm the rainfall in 19 years out of 20 typically ranges from 40 to 200 percent of the mean and for 100 mm/year, 30 to 350 per-cent of the mean. At more arid locations it is not uncommon to experience several consecutive years with no rainfall. These are reported in the 2008 Second Ghana Dams Forum and Workshop on the Impact of Climate change on the Bui Hydropower Project. However this is not consistent with available data for Upper West region from 1980-2010 which give 755.6-1260.6mm with a 13.2% change. Comparing the simulated rainfall and streamflow for a historical time series (1980-2010) and a climate change scenario (1980-2010) the following changes are predicted:

- Increasing duration of the dry season
- Increasing unpredictability of the onset of the rainy season
- Increase and intensification of rainfall at the end of the rainy season

- Increase in flood-events recurrence

Global climate change leads to a change of the rainfall pattern in space and time for the Black Volta River sub-catchment.

- Due to a change of the rainfall pattern the overall streamflow (river flow) variability increases.
- A prolongation of the dry season causes a decrease of groundwater recharge and streamflow which increases runoff when the rains finally come. At the same time it leads to a higher demand on water for irrigation purpose.

The conclusion of the matter is that, Lumped Hydrological modelling with remote sensing data and GIS techniques for flood forecasting is possible using temperature, rainfall and flow rates.

5.2 RECOMMENDATIONS

Significant benefits will result from continued attention to scientific research and the transfer of knowledge gained from this work into the practice of hydrological measurements (observations), modelling, and forecasting. Planning and management of water (from rainfall) in arid and semi-arid zones present difficulties which are due less to the limited amount of rainfall than to the inherent degree of variability associated with it. Although the benefits of being close to water are numerous, so too are potential problems created by being so close to such a powerful entity.

Based on the results from the model the following recommendations are made;

- A flood prone map is obtained for the entire Black Volta River at specific points where farming activities are more prevalent.
- Reservoir analysis should be conducted for planning an effective system in harnessing water that cause flood for agriculture, industry, trade etc.

- A thorough exercise to measure the river morphology should be conducted for a better model generation and analysis.
- Data on temperature, rainfall and flowrates be obtained for a longer period for a better model generation and analysis.

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APPENDIX 1: MEASUREMENT OF RIVER MORPHOLOGY

Measuring the velocity and discharge of a river

Items used included an orange as a floating object, a meter stick and tape measure, two canoes, four technicians and stop watches. The first step was to locate a straight section of the river with no islands, logs, or other debris that would affect motion of the orange as it floats downstream with the flowing water. Because the orange travels slightly faster than the average velocity of the river water, a correction factor is applied to obtain the final discharge value.

Measuring River Velocity

1. The river is quiet dangerous so with a hand held GPS was used to find about 100-110m reach section of the river and recorded it on the Stream Discharge Worksheet.

2. Tech A should have at least one orange. Tech C should have a stopwatch, and Tech D will catch the floating orange.

3. Ideally all the four techs should enter the river but due to the nature of the river they stayed in the canoes separated by the length of the canoe. Figure 3.4 illustrates the arrangements for the experiment.

4. When everyone is in position, Tech A drops an orange carefully into the river, being careful to position to one side and not directly upstream of the orange.

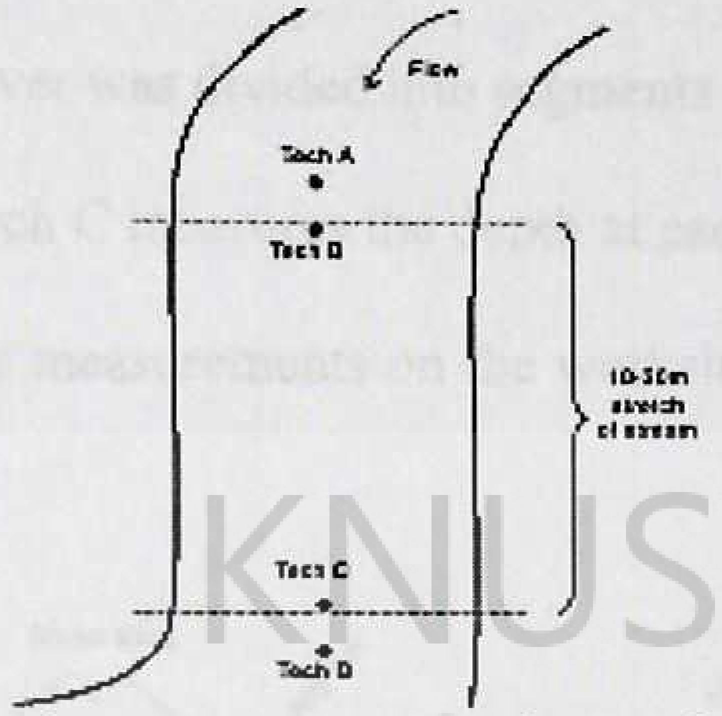
5. Tech B calls out "Start!" when the orange float past him and then Tech C starts the stopwatch.

6. When the orange is even with Tech C, he stops the stopwatch. Tech D retrieves the orange.

7. Record on the sheet the time it took the orange to travel from Tech B to Tech C, table 3.1.

9. Steps 4–7 were repeated for five times.

Record the length of the stream section in meters ………… Distance Travelled (m)



Experiment to measure river velocity

Average Time worksheet

Trial	Time Elapsed (sec)
1	
2	
Average Time (sec)	

River Discharge Worksheet

Section #	Depth (m)	River Segment Width (m)	River Segment Area (m^2)
1			
2			
Total River Cross-section (m^2)			

To calculate the stream velocity, divide the distance the orange travelled (river section length) by the average time.

$$\frac{Distance\ Travelled}{Average\ Time} = Average\ Stream\ Velocity\ (m/sec)$$

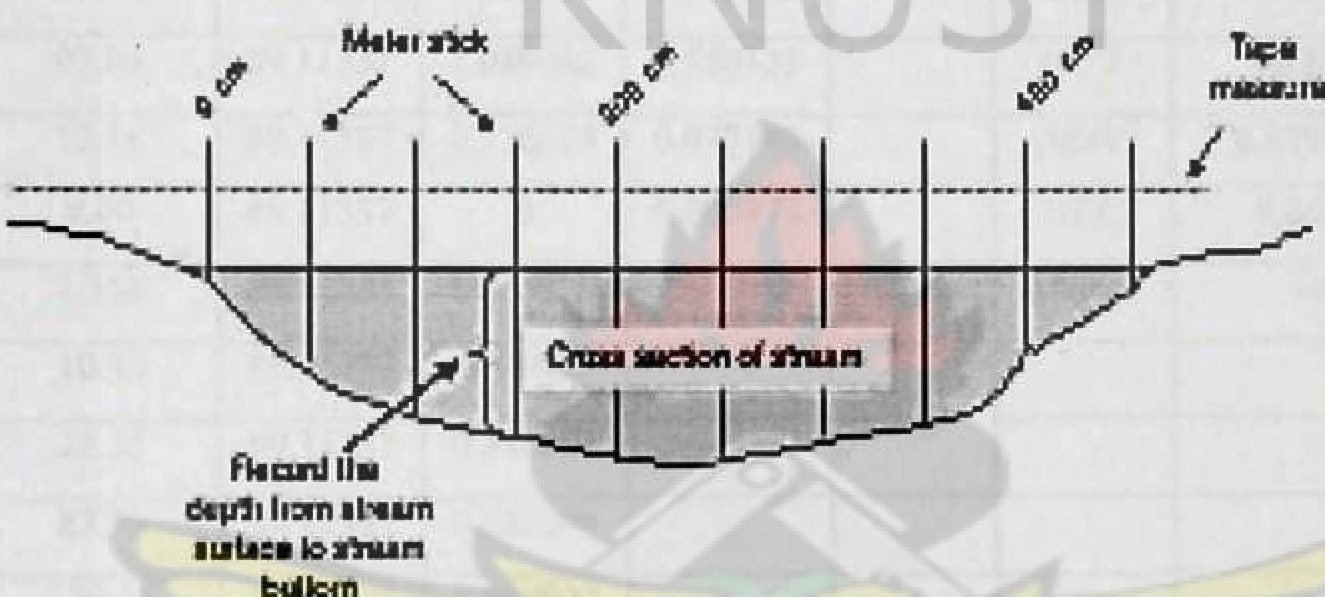
__Measuring River Depth and Cross-Sectional Area__

1. A portion of the river section that has roughly the average width of the reach was selected. Here the river was quiet shallow so there was no need for the canoes.

2. Techs A and B hold the tape measure across the river.

3. The entire width of the river was divided into segments of equal width of 3m

4. Using the meter stick, Tech C measures the depth at each point starting from depth 0m, and Tech D records the measurements on the worksheet, table 3.2. Recording is the data on the worksheet.



Measuring river depth and cross-section area

Multiplying the depth by each segment width (table 3.2) gives the segment area, and then sum them to obtain the total segments' areas to get the Total River Cross-Section Area. To calculate the "Total River Discharge," the following equations are used.

$$Total\ River\ Cross-section\ area\ (m^2) \times Average\ river\ velocity\ (m/sec) = Total\ river\ Discharge$$

To calculate the "Corrected Total River Discharge," multiply the Total River Discharge by the appropriate correction factor: 0.8 for sandy or muddy stream bottoms (Nancy Trautmann, 2004).

$$Total\ River\ Discharge\ (m^3/sec) \times Correctionfactor\ (0.8\ or\ 0.9) = Corrected\ total\ river\ discharge\ (m^3/sec)$$

APPENDIX 2: RESULTS OF STATISTICAL FORECAST METHOD ON PARAMETERS

Seasonality Analysis on Rainfall

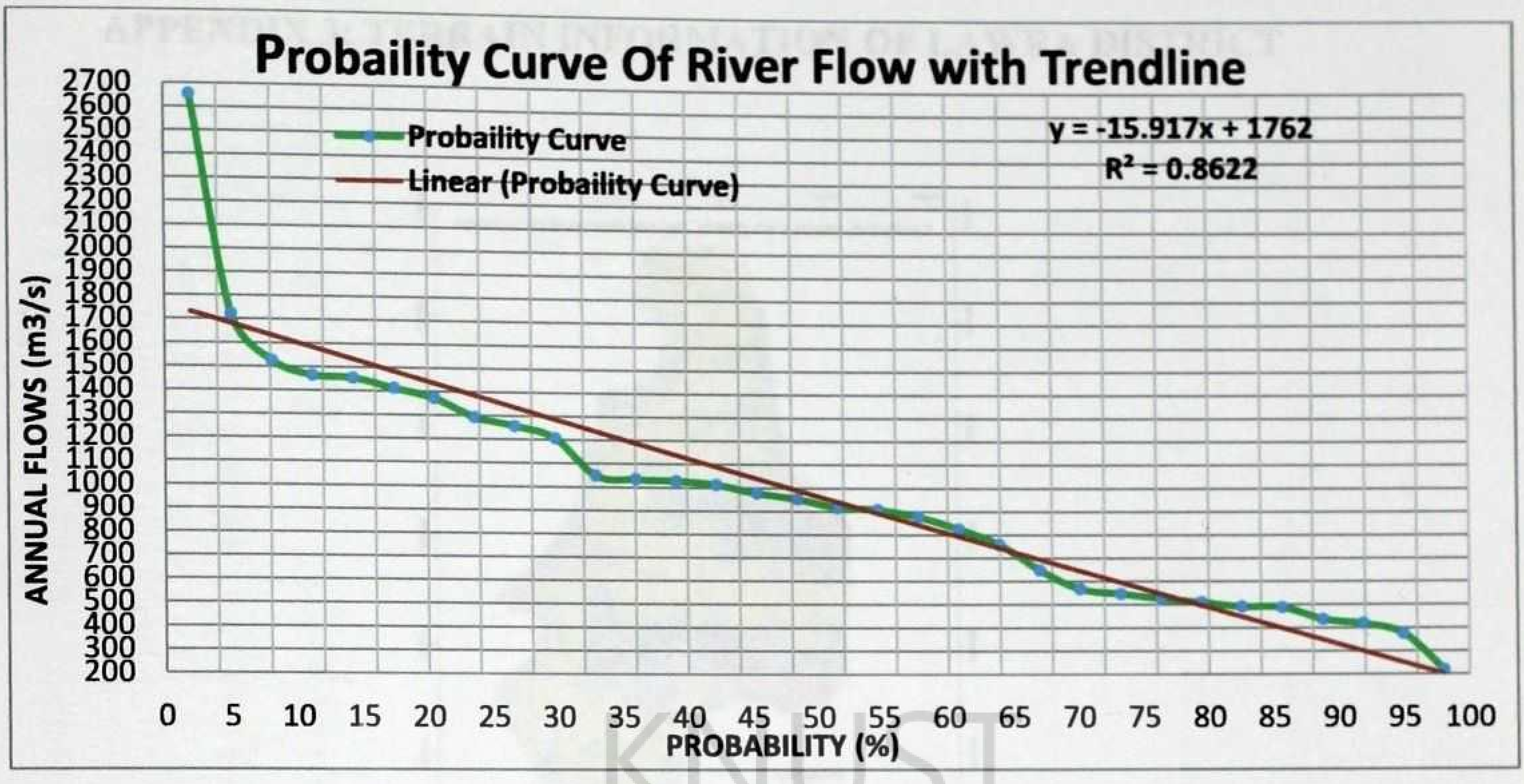
	MON	RAINFAL	AVE DMD	RATIO	SEA. INDX		MON	FORECAST	AVE. DMD
2009	JAN	0.00	89.11337	0	0.00762	2011	JAN	0.679	89.11337
	FEB	19.83	89.11337	0.222469	0.169565		FEB	15.1105	89.11337
	MAR	23.80	89.11337	0.267076	0.292635		MAR	26.07772	89.11337
	APR	81.23	89.11337	0.911479	0.948286		APR	84.505	89.11337
	MAY	110.18	89.11337	1.236347	1.623135		MAY	144.643	89.11337
	JUN	192.00	89.11337	2.154559	1.617468		JUN	144.138	89.11337
	JUL	162.23	89.11337	1.820434	1.654836		JUL	147.468	89.11337
	AUG	290.83	89.11337	3.26354	2.86333		AUG	255.161	89.11337
	SEP	189.08	89.11337	2.121736	1.992625		SEP	177.5695	89.11337
	OCT	97.05	89.11337	1.089062	0.750325		OCT	66.864	89.11337
	NOV	12.18	89.11337	0.136624	0.077196		NOV	6.879167	89.11337
	DEC	0.00	89.11337	0	0.002979		DEC	0.2655	89.11337
2010	JAN	1.358	89.11337	0.015239			ANN.V	1069.36	
	FEB	10.40	89.11337	0.11666					
	MAR	28.36	89.11337	0.318195					
	APR	87.79	89.11337	0.985094					
	MAY	179.11	89.11337	2.009923					
	JUN	96.28	89.11337	1.080377					
	JUL	132.711	89.11337	1.489238					
	AUG	219.497	89.11337	2.463121					
	SEP	166.064	89.11337	1.863514					
	OCT	36.678	89.11337	0.411588					
	NOV	1.583333	89.11337	0.017768					
	DEC	0.531	89.11337	0.005959					

Seasonality Analysis on Temperature

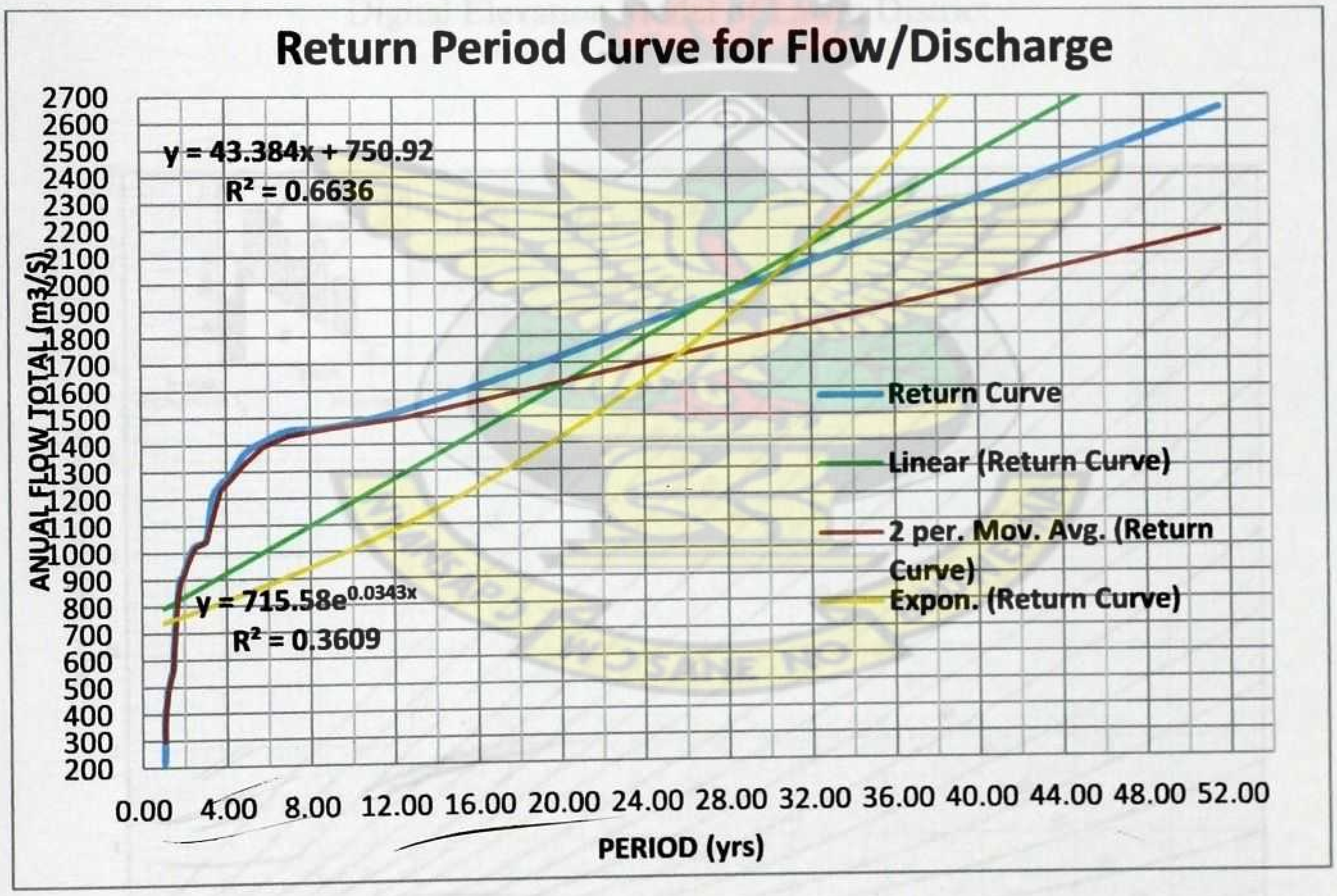
	MON	TEMP.	AVE DMD	RATIO	SEA. INDX		MON	FORECAST	AVE. DMD
2009	JAN	26.90	28.6	0.940559	0.976399	2011	JAN	27.925	28.6
	FEB	31.00	28.6	1.083916	1.097028		FEB	31.375	28.6
	MAR	31.25	28.6	1.092657	1.121503		MAR	32.075	28.6
	APR	30.80	28.6	1.076923	1.083916		APR	31	28.6
	MAY	29.75	28.6	1.04021	1.036713		MAY	29.65	28.6
	JUN	27.60	28.6	0.965035	0.975524		JUN	27.9	28.6
	JUL	26.25	28.6	0.917832	0.930944		JUL	26.625	28.6
	AUG	25.70	28.6	0.898601	0.910839		AUG	26.05	28.6
	SEP	26.25	28.6	0.917832	0.91958		SEP	26.3	28.6
	OCT	27.55	28.6	0.963287	0.961538		OCT	27.5	28.6
	NOV	28.05	28.6	0.980769	1.002622		NOV	28.675	28.6
	DEC	28.30	28.6	0.98951	0.984266		DEC	28.15	28.6
2010	JAN	28.95	28.6	1.012238				28.6021	
	FEB	31.75	28.6	1.11014					
	MAR	32.90	28.6	1.15035					
	APR	31.20	28.6	1.090909					
	MAY	29.55	28.6	1.033217					
	JUN	28.20	28.6	0.986014					
	JUL	27.00	28.6	0.944056					
	AUG	26.40	28.6	0.923077					
	SEP	26.35	28.6	0.921329					
	OCT	27.45	28.6	0.95979					
	NOV	29.30	28.6	1.024476					
	DEC	28.00	28.6	0.979021					

Seasonality Analysis on Flow Rates

	MON	FLOW	AVE DMD	RATIO	SEA. INDX		MON	FORECAST	AVE DMD
2009	JAN	20.463	169.438	0.12077	0.109524	2011	JAN	18.5575	169.438
	FEB	12.57	169.438	0.074186	0.061114		FEB	10.355	169.438
	MAR	6.381	169.438	0.03766	0.032156		MAR	5.4485	169.438
	APR	7.56	169.438	0.044618	0.033977		APR	5.757	169.438
	MAY	12.712	169.438	0.075024	0.057794		MAY	9.7925	169.438
	JUN	104.737	169.438	0.618144	0.345067		JUN	58.4675	169.438
	JUL	587.277	169.438	3.466029	1.837147		JUL	311.2825	169.438
	AUG	717.868	169.438	4.236759	3.035842		AUG	514.387	169.438
	SEP	643.865	169.438	3.800004	3.633016		SEP	615.571	169.438
	OCT	360.033	169.438	2.124866	1.954724		OCT	331.2045	169.438
	NOV	117.596	169.438	0.694036	0.569447		NOV	96.486	169.438
	DEC	63.314	169.438	0.373671	0.330189		DEC	55.9465	169.438
2010	JAN	16.652	169.438	0.098278				2033.256	
	FEB	8.14	169.438	0.048041					
	MAR	4.516	169.438	0.026653					
	APR	3.954	169.438	0.023336					
	MAY	6.873	169.438	0.040564					
	JUN	12.198	169.438	0.071991					
	JUL	35.288	169.438	0.208265					
	AUG	310.906	169.438	1.834925					
	SEP	587.277	169.438	3.466029					
	OCT	302.376	169.438	1.784582					
	NOV	75.376	169.438	0.444859					
	DEC	48.579	169.438	0.286707					

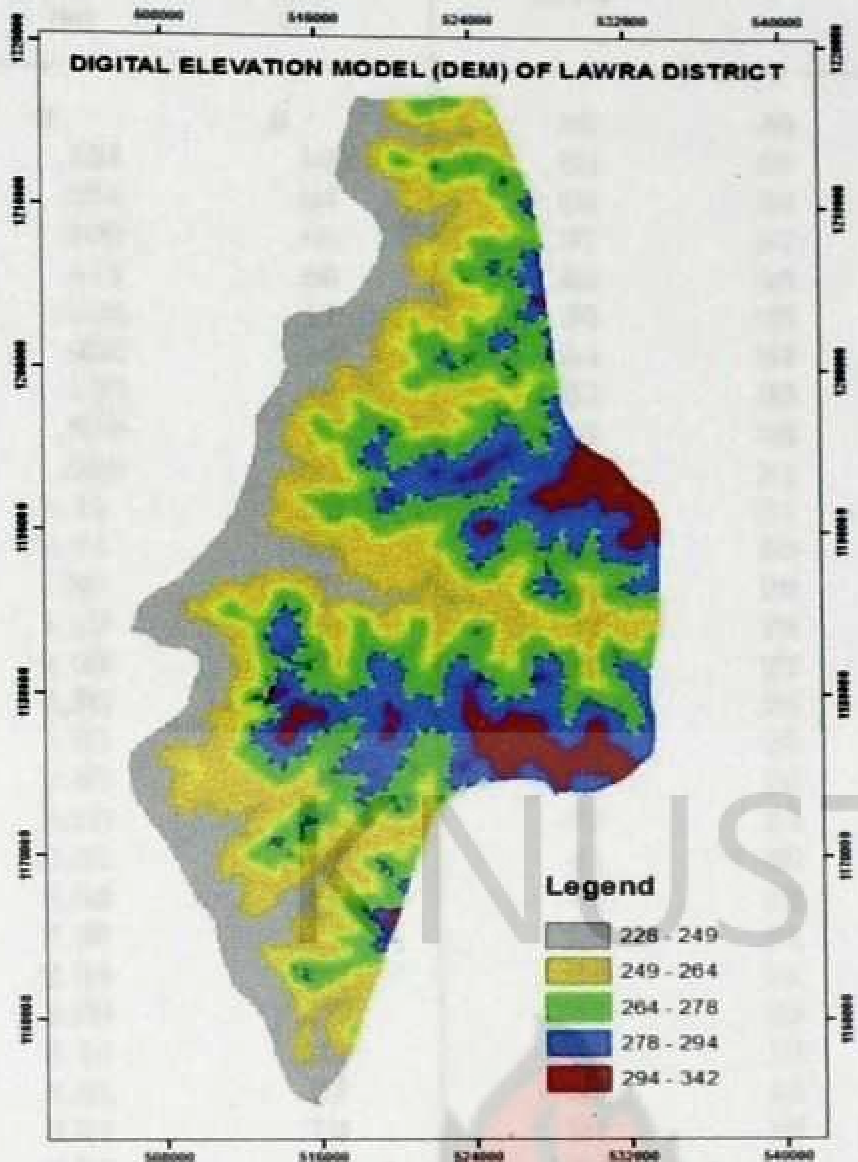


Probaility Curve Of River Flow with Trendline
Probaility Curve
Linear (Probaility Curve)
y = -15.917x + 1762
R² = 0.8622
ANNUAL FLOWS (m3/s)
PROBABILITY (%)

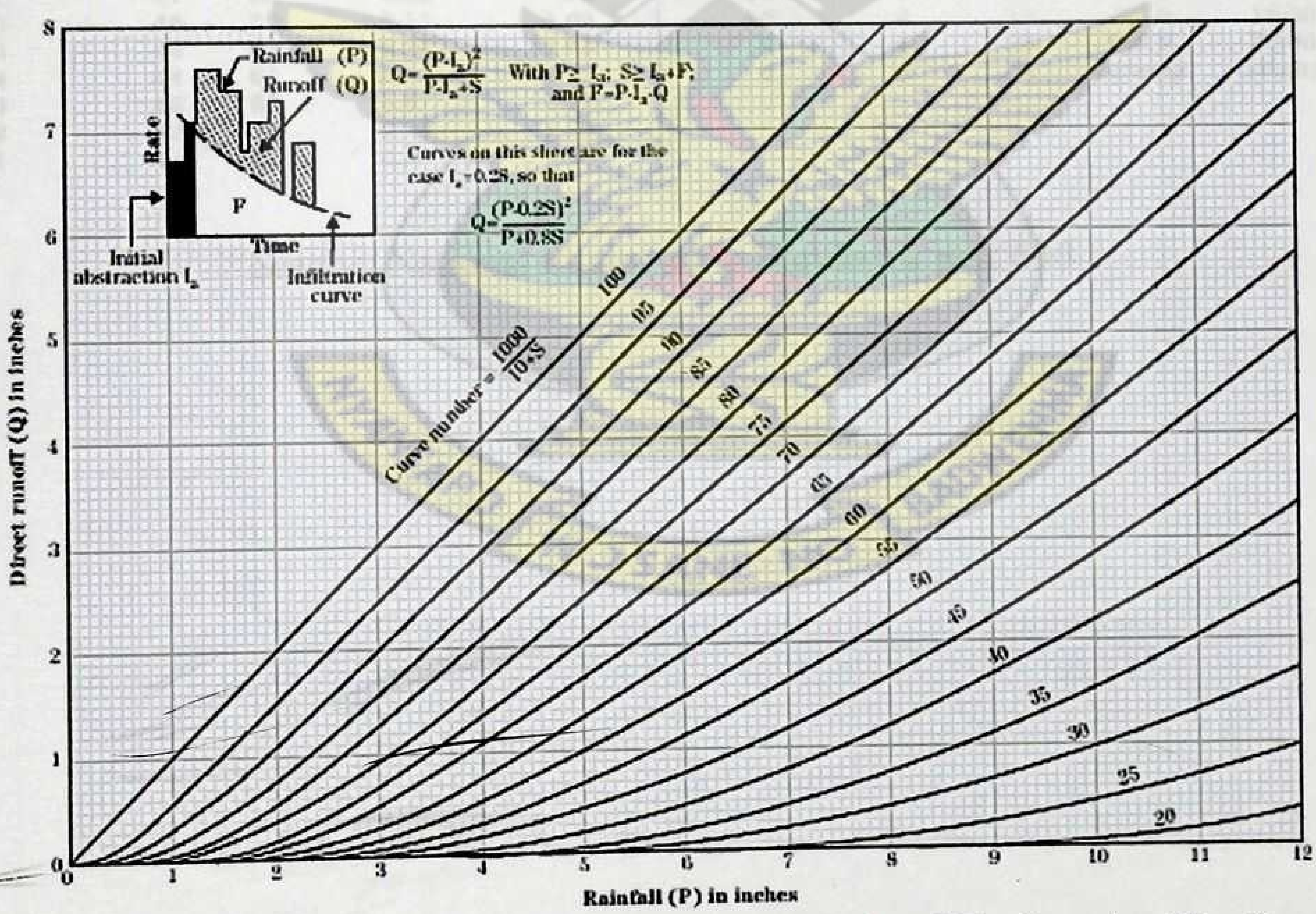


Return Period Curve for Flow/Discharge
y = 43.384x + 750.92
R² = 0.6636
y = 715.58e^0.0343x
R² = 0.3609
Return Curve
Linear (Return Curve)
2 per. Mov. Avg. (Return Curve)
Expon. (Return Curve)
ANUAL FLOW TOTAL (m3/s)
PERIOD (yrs)

APPENDIX 3: TERRAIN INFORMATION OF LAWRA DISTRICT



Digital Elevation Model of Lawra District



ES–1001 graphical solution of equation. Source: National Engineering Handbook

Curve numbers (CN) and constants for the case $I_a = 0.2S$

1	2	3	4	5	1	2	3	4	5
CN for ARC II	- - CN for ARC - - I	III	S values* (in)	Curve* starts where P = (in)	CN for ARC II	- - CN for ARC - - I	III	S values* (in)	Curve* starts where P = (in)
100	100	100	0	0	60	40	78	6.67	1.33
99	97	100	.101	.02	59	39	77	6.95	1.39
98	94	99	.204	.04	58	38	76	7.24	1.45
97	91	99	.309	.06	57	37	75	7.54	1.51
96	89	99	.417	.08	56	36	75	7.86	1.57
95	87	98	.526	.11	55	35	74	8.18	1.64
94	85	98	.638	.13	54	34	73	8.52	1.70
93	83	98	.753	.15	53	33	72	8.87	1.77
92	81	97	.870	.17	52	32	71	9.23	1.85
91	80	97	.989	.20	51	31	70	9.61	1.92
90	78	96	1.11	.22	50	31	70	10.0	2.00
89	76	96	1.24	.25	49	30	69	10.4	2.08
88	75	95	1.36	.27	48	29	68	10.8	2.16
87	73	95	1.49	.30	47	28	67	11.3	2.26
86	72	94	1.63	.33	46	27	66	11.7	2.34
85	70	94	1.76	.35	45	26	65	12.2	2.44
84	68	93	1.90	.38	44	25	64	12.7	2.54
83	67	93	2.05	.41	43	25	63	13.2	2.64
82	66	92	2.20	.44	42	24	62	13.8	2.76
81	64	92	2.34	.47	41	23	61	14.4	2.88
80	63	91	2.50	.50	40	22	60	15.0	3.00
79	62	91	2.66	.53	39	21	59	15.6	3.12
78	60	90	2.82	.56	38	21	58	16.3	3.26
77	59	89	2.99	.60	37	20	57	17.0	3.40
76	58	89	3.16	.63	36	19	56	17.8	3.56
75	57	88	3.33	.67	35	18	55	18.6	3.72
74	55	88	3.51	.70	34	18	54	19.4	3.88
73	54	87	3.70	.74	33	17	53	20.3	4.06
72	53	86	3.89	.78	32	16	52	21.2	4.24
71	52	86	4.08	.82	31	16	51	22.2	4.44
70	51	85	4.28	.86	30	15	50	23.3	4.66
69	50	84	4.49	.90	25	12	43	30.0	6.00
68	48	84	4.70	.94	20	9	37	40.0	8.00
67	47	83	4.92	.98	15	6	30	56.7	11.34
66	46	82	5.15	1.03	10	4	22	90.0	18.00
65	45	82	5.38	1.08	5	2	13	190.0	38.00
64	44	81	5.62	1.12	0	0	0	infinity	infinity
63	43	80	5.87	1.17					
62	42	79	6.13	1.23					
61	41	78	6.39	1.28					

Source: National Engineering Handbook part 630

APPENDIX 4: MODEL RESULTS OF HEC-HMS

Global Summary Results for Run "Run 3"

Project: Black Volta Simulation Run: Run 3

Start of Run: 01Aug2009, 15:10 Basin Model: black volta river
End of Run: 31Aug2009, 15:10 Meteorologic Model: Met 1
Compute Time: 17Oct2012, 08:38:01 Control Specifications: Aug 2009

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
sub-basin 1	1.3523	1207.7	01Aug2009, 15:10	3130311.6
Subbasin-2	1.3267	263.2	01Aug2009, 15:10	682214.4
s1	1.1450	1234.6	01Aug2009, 15:10	3200076.7
j1	3.8240	2705.5	01Aug2009, 15:10	7012602.7
r2	3.8240	2705.1	01Aug2009, 15:10	7011713.4
Subbasin-3	1.3485	262.4	01Aug2009, 15:10	680238.0
d2	1.3485	262.4	01Aug2009, 15:10	680238.0
s2	1.2340	750.8	01Aug2009, 15:10	1946089.8
Subbasin-4	0.2510	262.1	01Aug2009, 15:10	679330.8
j2	6.6575	3980.5	01Aug2009, 15:10	10317372.0
r1	6.6575	3980.4	01Aug2009, 15:10	10317115.3
d1	0.0000	0.0	01Aug2009, 15:10	0.0
res1	6.6575	7914.8	02Aug2009, 15:10	10316440.2
sin1	6.6575	7914.8	02Aug2009, 15:10	10316440.2

August 2009 Simulation of flood conditions

Project: Black Volta Simulation Run: Run 1

Start of Run: 01Sep2009, 14:40 Basin Model: black volta river
End of Run: 30Sep2009, 14:40 Meteorologic Model: Met 1
Compute Time: 30Jul2012, 09:57:46 Control Specifications: Sep 1980

Show Elements: All Elements Volume Units: MM 1000 M3 Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
sub-basin 1	4.4523	1207.7	01Sep2009, 14:40	3025967.9
s1	3.1450	1234.6	01Sep2009, 14:40	3093407.5
Subbasin-2	2.3267	382.9	01Sep2009, 14:40	959456.9
j1	9.9240	2825.2	01Sep2009, 14:40	7078832.3
r2	9.9240	2824.9	01Sep2009, 14:40	7077959.3
Subbasin-4	3.2510	387.8	01Sep2009, 14:40	971640.4
Subbasin-3	2.3485	373.9	01Sep2009, 14:40	936749.9
d2	2.3485	373.9	01Sep2009, 14:40	936749.9
s2	2.2340	750.8	01Sep2009, 14:40	1881220.1
j2	17.7575	4337.3	01Sep2009, 14:40	10867569.6
r1	17.7575	4336.3	01Sep2009, 14:40	10864989.8
d1	0.0000	0.0	01Sep2009, 14:40	0.0
res1	17.7575	8626.7	02Sep2009, 14:40	10864099.7
sin1	17.7575	8626.7	02Sep2009, 14:40	10864099.7

September 2009 Simulation of flood conditions

Global Summary Results for Run "Run 2"

Project: Black Volta   Simulation Run: Run 2

Start of Run: 01Oct2009, 07:30   Basin Model: black volta river
End of Run: 31Oct2009, 07:30   Meteorologic Model: Met 1
Compute Time: 08Aug2012, 20:46:32   Control Specifications: Oct 2009

Show Elements: All Elements   Volume Units: MM 1000 M3   Sorting: Hydrologic

Hydrologic Element	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak	Volume (1000 M3)
sub-basin 1	1.3523	1207.7	01Oct2009, 07:30	3130311.6
Subbasin-2	1.3267	240.9	01Oct2009, 07:30	624283.2
s1	1.1450	1234.6	01Oct2009, 07:30	3200076.7
j1	3.8240	2683.1	01Oct2009, 07:30	6954671.5
r2	3.8240	2682.8	01Oct2009, 07:30	6953784.8
Subbasin-3	1.3485	240.2	01Oct2009, 07:30	[illegible]
d2	1.3485	240.2	01Oct2009, 07:30	[illegible]
s2	1.2340	750.8	01Oct2009, 07:30	1946089.8
Subbasin-4	0.2510	241.5	01Oct2009, 07:30	626065.2
j2	6.6575	3915.3	01Oct2009, 07:30	10148441.0
r1	6.6575	3915.2	01Oct2009, 07:30	9979049.3
d1	0.0000	0.0	01Oct2009, 07:30	0.0
res1	6.6575	7784.5	02Oct2009, 07:30	10130357.2
sin1	6.6575	7784.5	02Oct2009, 07:30	10130357.2

October 2009 Simulation of flood conditions

Project: Black Volta   Analysis: Analysis 1   Run: Rur

Start of Run: 01Sep2009, 05:40   Basin Model: bla
End of Run: 30Sep2009, 05:40   Meteorologic Model: Me
Compute Time: 07Aug2012, 20:57:17   Control Specifications: Se

Analysis Point	Drainage Area (KM2)	Peak Discharge (M3/S)	Time of Peak
d2	1.35	373.86	01Sep2009, 05:40
sub-basin 1	1.35	1207.68	01Sep2009, 05:40
Subbasin-2	1.33	382.92	01Sep2009, 05:40
Subbasin-3	1.35	373.86	01Sep2009, 05:40
Subbasin-4	0.25	387.79	01Sep2009, 05:40
sin1	6.66	8628.51	02Sep2009, 05:40

Area Depth Analysis of flood model