FLOOD CONTROL AND ASSESSMENT OF ACCRA USING THE WEAP HYDROLOGICAL MODEL

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Declaration

I hereby declare that this submission is my own work towards the award of the MPHIL and that, to the best of my knowledge, it contains no material previously published by another person or 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

The increase in the frequency and intensity of flood in some parts of Greater Accra Region is becoming a matter of great concern to the entire nation due to its negative effects on the development of the region. These floods have over the years been attributed to numerous factors including; climate change, urbanization, poor drainage systems, sea level rise and over population. The study used Water Evaluation and Planning (WEAP) hydrological model to estimate the surface runoffs for the sub-basins and also to find the correlation between Standardized Precipitation Index (SPI) and the historical flood events in Greater Accra. The study also determined the surface runoffs generated within each sub-basin. The WEAP model was used to generate surface runoff from 1990 to 2040 taking 1990 as the base year. ArcGIS 10.3 was used to delineate eight sub-basins and thereafter determined the characteristics of the sub-basins. Rainfall normalization was performed using the Standardized Precipitation Index and the results were verified against historical flood events for the basin over the study period. The model output was compared to observed stream flow measurement. In general a good correlation of 0.81 and 0.71 were obtained for correlation coefficient and coefficient of determination respectively. The study revealed that, a minimum rainfall of about 60 mm would cause flood across all the eight (8) sub-basins. Also, extreme rainfall with SPI of 1.5 or more would cause flood in Greater Accra. The month of June was found to produce the highest volumes of surface runoff while December generated the least volumes of surface runoff with average runoffs of 2.4×10^6 m^3 and 1.0×10^6 m^3 respectively. It was confirmed from the research that, higher volumes of rainfalls in the sub-basins generates higher surface runoffs and therefore there are higher tendencies for floods to occur when rainfalls are high.

Table of Contents

List of Tables

List of Figures

Abbreviations

AMA = Accra Metropolitan Assembly

CCC = Cities and Climate Change

CFC = Chlorofluoro Carbons

DD = Drainage Density

DEM = Digital Elevation Model

ET = Evapotranspiration

GDP = Gross Domestic Product

GHSD = Ghana Hydrological Service Department

GMA = Ghana Meteorological Agency

GIS = Geographical information System

GSD = Geological Survey Department

GSS = Ghana Statistical Services

GW = Groundwater

GWCL = Ghana Water Company Limited

HEC = Hydrologic Engineering Centre

IDRC = International Development Research Center

IPCC = Intergovernmental Panel on Climate Change

IWRM = Integrated Water Resources Management

LC = Land Cover

LEKMA = Ledzokuku Municipal Assembly

LU = Land Use

NASA = National Aeronautics and Space Admininstration

NNE = North-North-East

RCPs = Regional Climate Projections

RIPS = Regional Institute of Population Studies

RMS = Root Mean Square

SPI = Standardisation Precipitation Index

SRI = Soil Research Institute

SWAT = Soil Water Assessment Tool

TMA = Tema Metropolitan Assembly

TIN = Triangular Irregular Network

USGS = United States Geological Survey

WEAP = Water Evaluation and Planning

WGS = World Geodetic System

WRI = Water Research Institute

WSW = West-South-West

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Chapter 1

Introduction

This chapter introduces flooding and its occurrence around the globe, Ghana and in Greater Accra region. Insights are given on the various researches that have been conducted, its observations and conclusions. Further review have been done on the major contributors to flooding in some flood prone areas.

1.1 Background

The upsurge in flooding in many communities has led to the increase of interest by researchers to investigate the phenomenon and this has resulted in the upspring of numerous definitions for flood. Flooding occurs, when water that has escaped its channels inundate small to vast areas of dry lands through the entire flooding period (Change, 2005). This event occurs within areas with or without streams, rivers, lakes and other water channels. That is to say, irrespective of the presence of a drain, the vulnerability of an area tp flood is still possible. Nevertheless, drainages are major factors that contribute to flooding, therefore drain characteristics, such as its position, is very important when it comes to the topic of flooding. The wrong positioning of drains, especially within areas of low elevation have higher possibility to carry huge volumes of water greater than its carrying capacity and hence resulting in the inundation of the surroundings or basin by water (Burke et al., 2013).

During ancient times, flood has been thought of as a natural event which occurs with negative impacts and on very few occasions comes along with some positive benefits. These rather very few positive impacts of flood, such as spreading of organic materials and sediments over flood prone areas helps agricultural lands and farms (White, 2001). Currently, there are chunks of natural disasters occurring of which flood is ranked very high on the danger scale with high frequency of occurrence and destruction (Iddrisu, 2012). Huge areas of lands are rendered inaccessible due to inundation by flood water and therefore impedes productivity (Yaghobi et al., 2012). The rate at which flood water returns to its channel is slow and depends on the intensity of the flood and channel characteristics which makes the recovery of an affected area very slow and difficult (Zhao et al., 2013b).

There are natural and artificial factors that contribute to flooding in the world (Aboagye, 2012). The natural factors are mostly hydrological phenomena which depend highly on precipitation, evapotranspiration, temperature and humidity (Lofgren et al., 2013). Human or artificial factors like urbanization, encroachment of river banks are just but a few of the artificial factors that contributes to flooding. The causes of flooding in the world currently have been attributed to; climate change, natural geology of the area, human activities such as urbanization and others (Root et al., 2003).

Water cycle across the globe differs due to climate change and its associated climate phenomena. These phenomena are responsible for the change in surface runoff contents after downpours (Bijlsma et al., 1996). On the other hand, sea level rise, which is a major contributor to flooding, has also been partly attributed to climatic variations

(Hoozemans et al., 1993). The entire globe is currently experiencing major variations in temperatures and this may continue to increase between 1.4 ∘C and 5.8 ∘C by 2100 due to the emission of greenhouse gases that contribute to global warming (Nyarko, 2002). All these factors have contributed immensely to the prevalence of flooding across the globe.

Since the 1930s Greater Accra has battled with flash floods which have been attributed to climate chamge, human activities and the geology of the area (Ludlow, 2009). It has caused a lot of harm and has led to various degrees of damages ranging from the destructions of properties to the loss of lives and the retardation in growth of the area. The occurrence of flood has been observed to be very rampant during the rainy seasons where there are a lot of generated surface runoffs from rain water (Amoako and Frimpong Boamah, 2015). This increases the volumes of water to be carried in drains and may eventually overflow into the surroundings and hence cause flash floods.

1.2 Problem Statement and Justification

The occurrence of flood in a country does not only halt productivity, but goes a long way to affect the Gross Domestic Product (GDP) of the nation. This occurs through the destruction of factories, buildings, good crops and other valuable materials that would have comtributed to the increase in the GDP of the country. Governments therefore spend a lot of resources to implement measures to control floods (Mitchell, 2017). Hydrological models are basically used for planning and policy making in order to mimic real life activities (Clark et al., 2008).The ability for such models to make climate predictions makes it essential in flood management (Zhao et al., 2013a).

Government of Ghana has tasked institutions like Lands Commission, Ministry of works and housing, Accra city engineers and others to find lasting solutions to the prevalence of flooding in Accra (Nyarko, 2002). This is because huge sums of money are spent annually in other to control floods in Accra (Oteng-Ababio, 2013). These institutions brought about several intervention measures such as building of levees, drainages, desilting of drains among others, has contributed to the process of flood control in Accra. In the construction of drains, the elevation of the area must be considered and there should be hydrological models that describe the hydrology of the area in other to prevent the flow of water into the land and also to enhance the flow of water out of the land. Surprisingly, this have not been done and still not being done and hence the occurrence of rampant flash floods in Accra (Amoako and Frimpong Boamah, 2015). About US$ 660 million worth of contract was given to the Conti group of companies to help in flood management in Accra (Gyau-Boakye and Adinku, 1997) while several sums of tax payers monies are spent annually to restore flooded areas to their original state.

For the purpose of this research, the WEAP hydrological model was used to generate hydrological models that would predict and help find solutions to the prevalence of floods in Accra. THe WEAP model employs the use of water balance, which makes it easier to use and also effective in the prediction of surface runoffs in comparison to the other available hydrological models. The flexibility of the tool makes the model easy customized in other to suit the specific objectives of the work being undertaking (Levite et al., 2003). This´ model is not only restricted to large catchments, as is the case of some models, but it can also be used for smaller catchments (Ingol-Blanco and McKinney, 2009). This made the choice of the model appropraite for the purpose of the research.

Flood impact assessment based on generated climate scenarios would activate effective decision making. The results of the research would aid town planners, city engineers and other stake holders to plan efficiently and effectively towards a flood free era. It would also aid private estate developers to add value to their services and reduce the risk flood posses to inhabitants. The research work is to generate hydrological model as a tool to access and manage flood in the selected water basins in Accra.

1.3 Objectives

1.3.1 Main Objectives

To develop hydrological model for the Greater Accra region.

1.3.2 Specific Objectives

- To determine the correlation between standardized precipitation index and historical flood events.
- To determine the surface runoff of individual sub-basins.

1.4 Research Questions

The research work seeks to develop hydrological models and specifically seeks to answer the following questions;

1. What is the correlation between rainfall and surface runoffs?
2. How does surface runoff contribute to flooding?

3. At what rainfall threshold can flood occur in the sub-basins?

4. Does the occurrence of flood only depend on the sub-basin?

1.5 Organisation of Thesis

Chapter one gives a general background to the work, the aims and objectives backing the work and make the study worthwhile. The second chapter discusses literature about floods in Accra and across the globe. Further discussions are made on the various works that have been done and the gaps identified. The various theories backing the works made on flooding and the methods used have also been discussed. Chapter three looks at the study area, its location, climate, vegetation, soil and its general geological setup. Also, it discusses the various methods and processes employed in the data collection for the work. Chapter four discusses the result from the model and other GIS related processes that were employed in the research work. Chapter five finally gives a conclusion and recommendation of the work.

Chapter 2

Literature Review and Theory

This chapter talks about works that have been done on floods, its causes, impacts, controls methods and what needs to be done about its occurrence. It also considers the conclusions made from available literature in other to use them as building blocks for this research. A further review is done on the major contributors to flooding, which include; climate changes, sea level rise, urbanisation and geology of the area. Various hydrological models that have been used for flood assessment were also reviewed.

2.1 Climate change and flooding

The variation in climate factors over time have been termed as climate change. These variations results in the average increase or decrease in temperature, rainfall, humidity, evapotranspiration and other climatic phenomena (Trenberth, 2011). These inevitable changes in climate phenomena is occurring at a faster rate and that has been of great concern for a lot of people especially climate scientist (Valipour et al., 2017). Various natural and artificial factors contributes immensely to the variations of climate among which include; loss of vegetation, increase in burning, release of aerosols into the atmosphere and many others (Buytaert et al., 2011). The impact of climate change across the globe has triggered a lot of investigations into it. These investigations resulted in the conclusions that; aerosols such as methane and other Chlorofluoro Carbons (CFC) are major causes of climate change when they are released into the atmosphere (Berg et al., 2015). They contribute to the destruction of the ozone layer and changes the hydrological cycle therefore leading to the increase in precipitation and changes in other hydrological parameters.

2.1.1 Impacts of climate change

Climate change have been observed to be the cause of some natural disasters that are being experienced in the world currently (Change, 2016). Rampant floods and droughts being experienced in the world have been attributed to the fast growing variability in the climate (Arnell and Gosling, 2016). The intensities of the menace caused by climate change across the world is dependent on the localized damages that have been caused to the climate and its related climate phenomenon. The subject, climate change, is in no doubt a big challenge due to the fact that, there is no single solution to it (Bellard et al., 2012). According to Intergovernmental Panel on Climate Change (IPCC), climate change can be attributed to the sudden rise in global temperatures and the irregular rainfall patterns (Newman, 2017).

The impacts of climate change have made the topic of great importance to Ghana due to its possible effects on the economy and the agricultural sector (Schlenker and Lobell, 2010). When rainfall is very minimal, there is the possibility of droughts which may affect the productivity of the agricultural sector and eventually affect the economy of the country (Jones and Thornton, 2003). On the other hand, when precipitation is high, the risk of experiencing flooding is high and in the event of its occurrence, work activities are halted and productivity is affected (Nelson et al., 2009). Flood is one of the major effects of climate change that is frequently esperienced in Accra. In view of that, factors that contribute to climate change such as; depletion of vegetation, land use changes, burning and others, must be controlled effectively to minimise rate of change of the climate (Howden et al., 2007).

The hydrological cycle of any region is highly affected by climate changes and these are the causes of the unexpected rainfalls in periods which were previously not producing much rainfall. Thus, climate change has led to changes in months in which rainfall was esperienced and the lenght of time that it occured (Piao et al., 2010). The erratic nature of the major seasons, as is being observed in many countries, has led to long periods of droughts and floodings in some countries. The prediction of rainy and dry seasons has been very difficult recently due to the erratic nature of the climate (Shi et al., 2010). As a result, much preparations are not made towards the rainy days and flooding may occur as a surprise (Bijlsma et al., 1996).

Due to climate changes, the southern sector of Ghana has experienced drought accompanied with high temperatures during the dry seasons. This led to the decline in crop products obtained from the southern sector and rendering a lot of people hungry and jobless (Muller et al., 2011). On the other hand, the increase in rainfall with the eventuality¨ of flooding has in the past and presently rendered scores of people homeless, increased the outbreak of diseases and adversely affected productivity of industries within Accra (Asumadu-Sarkodie et al., 2015).

Climate change has led to global warming which has on the other hand contributed largerly to the rate of floods across the globe (Shi et al., 2010). The effects of global warming can be felt in the management of water resources in the country. The increase in rainfall as a results of global warming has had effects on the volumes of water carried by the major drainage systems in Accra and these lead to the inundation of surroundings during heavy downpours (Kuma and Kakuya, 1996). Evidently, lagoons along the coastline of Greater Accra Region, such as Sakumo, Songor, Chemu, Mokwe and others, have shown a sharp increase in volumes over a period of time (Gyau-Boakye and Adinku, 1997). This changes causes an increase in the volumes of lagoons indirectly and this can be attributed to high rainfall and sea– level rise (Kankam-Yeboah et al., 2011). Increase in rainfall volumes leads to the generation of high surface runoffs which may exceed the carrying capacities of most drainages and cause the inundation of the surroundings of the drains. As a results, proper measures must be put in place to accomodate the volumes of waters and prevent or minimise the occurrence of flooding (Asumadu-Sarkodie et al., 2015).

The impacts of climate variability on water resources can be minimized by taking steps to decrease the emission of climatic change agents into the atmosphere (Piao et al., 2010). There is the need for proactive adaptive measures to be taken in order to reduce the impacts of climate change on the environment and its water resources (Brennan et al., 2010). The effectiveness and efficiency of the measures put in place would lead to the curbing natural disasters that are caused by climate changes in the world.

2.1.2 Adaptations to climate change

Adaptation to climate change may be defined in myriads of manners. In all, the common message being passed across is the adjustments made by human beings to be able to respond effectively and efficiently to changes occurring in the climate over time (Nakicenovic et al., 2000). In adaptation, individual stakeholders gain the power to overcome the effects imposed on the society by climatic changes. The process of adaptation to climate changes also provides individuals ways to take advantages of the impacted and better lives for them (Both et al., 2009). There are anticipatory factors that makes adapting to the changes in climate easier and such factors include past and current occurrences (Eriksen and Naess, 2003). The knowledge of these trends and other factors helps in the reduction of the effects of climate change on the environment and maximize the benefits derived out of it (Smith, 2013).

It has been concluded that climate adaption is a collective affair and the quest for safety has triggered interest across the globe (Aall, 2012). The adaptation processes are expressed in many forms in terms of economic situations and social networks (Adger et al., 2004). The effectiveness of climate adaptation process depends on; the individual, through communities to districts, regions and the nation as a whole (Parry et al., 1999). There should be strong coherence among participating parties based on political and jurisdictional boundaries in other to maximize the outcome of flood adaptation (Lindseth, 2004).

In climatic change adaptation, there should be clear boundaries between policy formulation activities and policy implementation in other to reap their maximum benefit (Adger et al., 2004). An adaptation policy is evaluated through the rate of reduction in climatic change impacts on the people and environment (Jones, 2001). Steps taking in flood management mostly consider short term measures than long term ones and this has made it necessary for proper adaptation measures to be taken in other to increase its impacts
(Lehner et al., 2006).

2.2 Flooding

Flood is simply defined as the overflow of water from its channel into surroundings for a period of time (Nyarko, 2002). It is also described as a hazard which occurs naturally and displaces inhabitants by causing a lot of destruction to their lands, residence and valuables (Asumadu-Sarkodie et al., 2015). The period of flooding depends on the intensity of rainfall and the nature of the land within the area in which it occurred. A heavy rainfall which last for a long time produces a lot of surface runoffs and if the land is not very permeable, there would be a lot of overland water (Werritty et al., 2007). Rain water seeps into the ground during rainy days but impervious surfaces prevents the seepage and hence leads to the accumulation of water overland (Sophocleous, 2002). The accumulation of water overland leads to soil saturation and eventually to flooding (Lerner, 2002). Flooding has affected a large percentage of the world and its impact is felt immediately during and after its occurrence and depending on the degree of damage, the impacts of floods may be for a long while or for shorter periods (Guha-Sapir et al., 2012).

There are natural and artificial factors which have been identified to contribute to flooding in the world (Aboagye, 2012). The natural factors are mostly hydrological phenomena which depend highly on precipitation, evapotranspiration, temperature and humidity (Lofgren et al., 2013). Human factors like urbanization, encroachment of river banks are just but a few of the artificial factors that contributes to flooding. The causes of flooding in the world currently have been attributed to; climatic change, natural geology of the area, human activities such as urbanization and others (Root et al., 2003).

In order to be able to assess, control and manage flood, flood modeling has been adopted by many scientist to arrive at lasting solution that are still being implemented around the world (Marchi et al., 2010). These models provide the world with better ways to compromise between real life phenomena and ideal case phenomena which lead to the realisation of better methods to solve flood problems in the world. Thus, flood models helps to simplify a rather complex natural phenomenon into a much more understandable ones so as to effectively find solutions to the occurance of floods in communities (Amoako, 2016). The models lead to the realisation of suitable methods the would be used to control and prevent the occurrence of flood but it is faced with the problem of difficulties in finding appropriate mitigation measures and accurately defining targeted areas as flood prone (Menoni et al., 2012). In general, flood modellling has been a major breakthrough in the control and management of flood occurrences despite the challenges that it is facing.

2.2.1 History of flooding in the World

The frequency of flooding in the world have since ancient times been observed to be on the rise (Bradshaw et al., 2007). Most research works have shown that Shanghai as one of the most vulnerable cities to flood across the globe with rising rate of flood events (Hu, 2016). Even though, the city is of great economic importance to the nation, its vulnerability to flood has made it a problematic city through the frequent use of high sums of monies that are spent annually to replace lost resources due to the occurrence of floods. This is evident in the fact that, huge sums are spent each year in the form of compensations, constructions and others in other to satisfy the families of about 20,000 people that are lost annually and about 20 million people that are rendered homeless (Yang et al., 2013).

In 2005 and 2009, Cumbria spent about £450 million to control flood and its impacts to the detriment of other developmental activities (Mayes et al., 2006). These flood events led to the destruction of about major roads, bridges, houses and many more and also displaced about 460 people from their places of abode. A lot of people suffered psychological traumas that also added to the cost the country bore on due to the occurrrence of the flood event in the state. In 2005, England spent about £3.2 billion to cater for damages caused by floods across the nation in the form of provision of clothings, shelter, food and medical cares just to mention but a few (Asumadu-Sarkodie et al., 2015). These sums of monies and resources could have been invested in other beneficial sectors to help develop the nation but were rather used to help in flood interventions. The periodic occurrences of flood events in such a country leads to a retardation in the growth of the nation.

2.2.2 History of flood in Accra

Accra has been battling a lot of natural disasters of which floods stand tall among; deforestation, poor sanitation and fire outbreaks (Rain et al., 2011). The issue of flood management and the control of its related destructions have been high on the scale of developmental projects but the purposes have been defeated due to the recurrence of the disaster year after year (Karley, 2009). Flash floods have been a torn in the flesh of inhabitants of Accra since the 1930s with some major floods known to have been recorded in 1955, 1960, 1963, 1973, 1986, 1991, 1995, 1999, 2001, 2002, 2010, 2011 and 2015 (Twumasi and Asomani-Boateng, 2002).

The causes of flooding in Accra has been of great concern for researchers in and around the world due to the economic importance of the city and the damages floods cause in the city each year. It is said that, the major contributors to flooding in the region is the relatively low elevation of the land, high amount of clay and clay materials in the soils and the relatively high rainfall experienced during the rainy season (Abeka, 2014). Also, indiscriminate dumping of waste, poor drainage network and small volumes of drains have also been identified as some of the major contributor of flooding in Accra (Ludlow, 2009).

The occurrence of flood in the Greater Accra Region comes with a lot of problems that hinders the progress of the region and its surrounding towns and cities. This mostly leads to the dislocation of a lot of people and the destruction of many properties such as; companies, roads, houses and others, that may be either owned by the state or individuals (Tabiri, 2015). A lot of human resources are invested into returning the city to its natural state or even better. This leads to the retardation in growth and also decrease productivity of the jobs that are located within the area of occurrence. Due to the fact that, some of the companies would have to be closed down for a period of time in other to put things in order (Amoako and Frimpong Boamah, 2015).

Almost all the drainage basins within the Greater Accra Region, periodically do experience flash flooding especially: Odaw, Sakumo and Kpeshie Basins and these have led to a great dent in the developmental tend of the city (Dakubu, 1997). One of the most prominent floods is the July 3rd, 1995 flood, which is considered to be highest disaster within a 50 year period. It took about 30 lives and damage about GHC 50 billion worth of properties (Aboagye, 2012). This flood was attributed to high rainfall together with poor drainage networks in the capital of Ghana. The 27th June 2001 flood took about 11 lives together with a lot of damages to properties and resources (Black, 2008).

The impacts of floods on the economy of Accra and Ghana as a whole, is evident in the huge sums of monies that are spent on repairs and disaster management. A typical example is the huge sums of monies and resources that were used to restore Accra to its state after the floods which occurred between 1955 and 1997 (Gyau-Boakye and Adinku, 1997). This event was a hinderance to the establishment of schools, construction of pipe borne water and the building of infrastructure due to the fact that, unbudgeted expenses were incurred and this affected the economy of the nation. One of the most recent and dangerous flood events is the one that took place on the third day of June, 2015 which coupled with a fire outbreak from a filling station led to the demise of about 125 people and the destruction of several properties owned by both individuals and the state. The government of Ghana spent about GHC 52 million on disaster management during that period so as to restore the city to its initial state and also compensate families that lost their members (Amoako, 2016). Some of the most significant flood that have been recorded in Accra are shown in the table 2.1.

2.2.3 Floods in Greater Accra

Flood have been attributed to a lot of factors ranging from global problems such as climate change to localized problems such as geomorphology and soil material (Yaghobi et al., 2014). In Accra, series of research have been done to clearly find the causes of floods in the region and possibly find lasting solutions to it (Yaghobi et al., 2012). The soil materials of the Greater Accra region are mostly clay dominant soil types. These soil have very low porosity and hence prevents the infiltration of water into the ground (Twumasi and Asomani-Boateng, 2002). The soil component of Accra is chiefly acrisol, fluvisol, arenosol and other clay dominant soil material, this implies that infiltration of water into the ground is very minimal and as a result, high volumes of surface runoffs are generated during the rainy seasons and hence the rampant floods being experienced annually (Amoako and Frimpong Boamah, 2015). Clay soils form a lot of waterlogged areas and the slightest addition of water in the form of rain leads to the inundations of surrounding areas (Gyekye, 2011). The prevalent floods have been attribute partly to the soil materials of Accra (Ewusi et al., 2015).

Poor and inadequate drainage systems have been realized to be a major cause of flooding in Accra over the years (Karley, 2009). Surface water naturally flows through areas of low elevation and if drains are not well positioned to convey these waters, they tend to inundate the basins and cause destruction of properties (Amoako, 2012). In the construction of drains, the elevation of the area must be considered and there should be hydrological models that describe the hydrology of the area. This can be a way to prevent flooding but surprisingly, this have not been done and still not being done and hence the occurrence of rampant flash floods in Accra (Amoako and Frimpong Boamah, 2015).

Urbanization has been attributed to be the cause of improper location of drains and the inadequate size of drains to carry surface water and hence it is a contributor to flooding in Accra (Clawson et al., 2001). Due to rapid improvement of the environment, there has been the increase in the population density which has necessitated the construction of a lot of infrastructure in Accra. Due to this event, buildings are being sited in water ways and the planning of communities are not being done properly (Arguello et al., 2013). The planning of most flood prone areas in Accra have been noticed to be improper, which leads to the creation of slums and hence the onset of flooding (Amoako and Frimpong Boamah, 2015).

Accra being a coastal area is inevitably exposed to sea level rising and as a results it has contributed to the observed floods in the area (Addo and Adeyemi, 2013). The rise in the level of the sea hinders the outflow of water from within the land into the sea and hence causes the overflow of water from drains during rainy days (Crooks, 2004). Dredging of drains as a way of controlling flood can also be a cause of the menace if the necessary engineering principles are not employed (Sagoe-Addy and Addo, 2013). This is because, dredging of drains below the level of the sea would rather draw water into the land and fill the drains hence leading to flooding (Hinkel et al., 2012).

Dealing with the negative impacts associated with flooding is a very difficult task and as such, better measures must be considered. The threats that accompanies floods have been termed as flood risk. Flood risk have been defined as; "factors, elements or courses that include danger on lives associated with flooding" (Nyarko, 2002). These risks are diverse and many works have been conducted to explain their occurrence in diverse fields of study (Nyarko, 2000). In Accra most of the preventive and resilient measures taken towards flood management have been based on, acquisition of insurance, restructuring of some flood prone areas and dredging of drainage networks (Amoako and Frimpong Boamah, 2015).

Nevertheless, the rampant and indiscriminate dumping of refuse into drains and the erosion of soil debris to choke drains have in a way been neglected in the quest to curb flooding since these activities are still on the rise despite the enormous damages it cause in the form of floods (Karley, 2009). Furthermore, climate change impacts and projections have not been considered much as a way of providing early flood warning signals to the area. This study seeks to base on the changes that climate change would possibly have on rainfall coupled with the history of rainfall and its relationship to flooding to provide early flood warning signals as a means of providing climate resilient solutions to Accra.

2.2.4 Sea level rise and flooding

The occurrence of flooding in the world has been attributed to a lot of factors, among these factors is sea level rise. Sea level rise is simply the increase in the volume of the sea due to the melting of ice sheets and glaciers or the expansion of sea water (Bijlsma et al., 1996). The global increase in temperature causes the melting of the glaciers and the expansion of the sea water that leads to the increase in the mean sea level. The level of the sea has been observed to have changed over the years especially between the period of 1900 to 2015, where the level of the sea was observed to have increased between 13 cm to about 20 cm. This has led to the increase in the intensity of flooding and its frequency within the 21st century (Hoozemans and Hulsbergen, 1995).

The coastal plains, which is occupied by about 200 million people have had its fair share of flooding due to the rise in sea levels across the globe (Hoozemans and Hulsbergen, 1995). Floods have been observed to be relatively very rampant in the coastal regions and this has been proven to be partly due to the rise in sea level. The coastal areas are mostly made up of low lands and in view of that, the rise in the sea may lead to the intrusion of sea water into the land instead of moving out of the land (Hoozemans et al., 1993). The intruded waters may fill the drains and cause flooding when they exceed the carrying capacities of the drains. This event leads to the inundation of the drainage basin which could be be severe depending on the intensities. Some parts of Accra have experienced floods due to sea level rise and other factors like poor drainage systems and others. A typical example is Gleef, a suburb in Accra, which is characterised by its relatively low elevations and poor drainage networks (Addo and Adeyemi, 2013).

Sea level rise has been esperienced over the years and its contribution to flooding is now very much evident. This has led to the growing demand to find a lasting solution to its increase and inevident impacts. The quest to find solutions to the effects of sea level rise, has lead to the implementations of findings from researches that would help curb the situation especially along the coastal areas (Lehner et al., 2006). Many measures are being taking to protect occupants of the coast from flooding using different mitigation and adaptive measures and these measures are helping in the control of flooding (Douglas et al., 2008). These mitigation methods include the use of dikes and levees as flood barriers and other sea defense mechanisms (Nicholls, 1995).

2.2.5 Urbanisation and flooding

Urbanization and industrialization have contributed to the frequency of flooding and the generation of greenhouse gases (Houghton, 1996). The emission of such gases contribute to climatic change and its adverse impacts on the Earth (Joachimski et al., 2009). Scientifically, the negative effects of the release of greenhouse gases into the atmosphere have been proven to continue due to recurrence of the activities leading to it (Warrick et al., 1996). Due to urbanization, a lot of vegetation are cleared to make way for developmental projects. This exposes the soil to high velocity surface runoffs during raining seasons (Geleta et al., 1994).

Planning an area is as important as implementing developmental projects within the area. Proper planning gets rid of a lot of disasters including flooding and its associates. Poor planning is a contributor of flooding and an inhibitor of development (Lo and Diop, 2000). The quest for development has led in the use of modern methods of beautification, such as; pavement blocks, floor tiles and others, by contractors. These modern ways of beautifying the environment practically prevents infiltration of water into the ground and hence causing an increase in the surface runoffs (Korah and Cobbinah, 2017). The gradual increase in the use of pavements as a replacement for natural cover have enormous effect on the volumes of water that run on the surfaces (Aboagye, 2012). The storage capacity of the ground may not be reached but high volumes of runoffs may be generated due to the prevention of impermeable surfaces to water. Drains available may not be able to carry the high volumes of surface runoffs that are being generated and these may lead to the inundation of the water basins (Andjelkovic, 2001).

Urbanization comes along with increase in population and the generation of waste which are factors that lead to flooding in urban areas (Doan and Oduro, 2012). Improper waste management may lead to the blockage of drains and the eventuality of flood occurring. Population distribution and densities vary from place to place and it results in a lot of adverse impacts on countries (Mba, 2010). Over populated communities have the tendency of experiencing pollution and its associated effects such as flooding (Van Aalst et al., 2008). In Accra, indiscriminate waste disposal has been realized to a major contributing factor to the rampant floods since the volumes of the drains are reduced by waste (Owusu, 2010). Waste generation does not necessarily cause flooding but rather the problem of indiscriminate disposal (Appeaning Addo et al., 2011). Increase in population growth leads to encroachment of river banks and this factor together with other human activities have been considered by very few scientific works on flooding (Kleinen and Petschel-Held,

2007).

2.3 Hydrological Models

Hydrologic models are systems that mimic the actual or real life system (Chow, 1988). These models are basically to study the real life situations and predict possible output. They are constructed by using equations that link the input parameters to the output parameters in simple to complex relations (Luijten et al., 2000). Hydrological models basically deals with flood control, pollution management, watershed management, drainage studies, reservoir simulation and water utilization (Devia et al., 2015). These models operates on the basis of the hydrological cycle.

There are three (3) basic categories of hydrological models, these are; Conceptual models, empirical models and physical models. Apart from the physical models which relate the inputs to outputs using simple to complex laws, the empirical model and conceptual models operates basically on the statistical relationship between the real and virtual situations (Devia et al., 2015). Some examples of the empirical models are classical unit hydrograph and regression analysis.

There are other categorization of hydrological models which groups the models into groundwater models and surface water models (Sood and Smakhtin, 2015). The surface water models are used mostly for pollution control, flood management, soil erosion and water quality assessment while the groundwater models are used for soil water test, groundwater potential and others (Thirel et al., 2015). TOPMODEL, USGS-SFM and Hydrologic Engineering Centre-6 (HEC-6) Model are some examples of surface water models used for various varied purposes.

Almost all hydrological models operate on the basis of the hydrological cycle and the laws of hydrology (Devia et al., 2015). The hydrological cycle describes the distribution of water among the lithosphere, biosphere, atmosphere and the hydrosphere. The entire cycle depends on the law of conservation of mass, which states that 'the total water that serves as an inflow into a system is equal to the mass of water that flows out of the system' (Oki et al., 2004).

Total inflow of water (I) = Total outflow of water + storage (O)

$$I = P + GW_i + S_i \quad (2.1)$$

$$O = ET + GW_o + \delta S \quad (2.2)$$

Therefore, I = O

$$P + GW_i + S_i = ET + GW_o + \delta S \quad (2.3)$$

According to (Allen et al., 1998), for precipitation to be able to generate surface runoff, there should be a total water volume greaterthan 5 mm and the volume of water available as effective precipitation is 75 % of the total precipitation volume. Therefore;

$$P_{eff} = (P - 5) \times \frac{75}{100} \quad (2.4)$$

$$P_{eff} = (P - 5) \times 0.75 \quad (2.5)$$

$$P + GW_i + S_i = (P - 5) \times 0.75 + GW_o + \delta S \quad (2.6)$$

where; P is Precipitation, ET is Evapotranspiration, GW_i is Groundwater inflow, GW_o is Groundwater Outflow, S_i is Surface water inflow, δS is Storage and P_{eff} is Effective Precipitation.

Surface water hydrological models deals with drainages and drainage characteristics. The rate of flow of water through a channel is known as the discharge of the drain. It is dependent on the drain's physical properties like; length, depth, width and others. The discharge is given as;

$$Q = A \times v \quad (2.7)$$

But

$$v = \frac{s}{t} \quad (2.8)$$

Therefore;

$$Q = A \times \frac{s}{t}$$ (2.9) But,

$$A \times s = V \quad (2.10)$$

Thus,

$$Q = \frac{V}{t} \quad (2.11)$$

Where; Q is volume flowrate (m^3/s), A is Area of cross-section (m^2), s is displacement (m), t is time (s), V is volume (m^3) and v is velocity (m/s)

2.3.1 Groundwater Flow rate

Darcy's law states that 'the instantaneous discharge of a fluid through a porous medium is proportional to the viscosity of the fluid and the pressure drop along a given distance of travel by the fluid within a porous meduim (Manning, 2016).

This is mathematically expressed as;

$$Q \propto -A \times \frac{\delta h}{\delta l} \quad (2.12)$$

$$Q = -K \times A \times \frac{\delta h}{\delta l} \quad (2.13)$$

The negative sign infront of the equation depicts a decrease in the hydraulic head in the direction of the flow of the fluid.

Where; Q is Volumetric flowrate (m^3/s), K is Hydraulic Conductivity (m/s), A is Crosssectional Area (m^2) and $\frac{\delta h}{\delta l}$ is Hydraulic Gradient.

Darcy velocity considers the flow of a fluid to be through the entire cross-sectional area of the soil sample under consideration.

$$Q \propto A \tag{2.14}$$

$$Q = q \times A \tag{2.15}$$

This implies that,

$$q = \frac{Q}{A} \tag{2.16}$$

Therefore;

$$\frac{Q}{A} = -K\frac{\delta h}{\delta l} \tag{2.17}$$

$$v = \frac{q}{\phi} \tag{2.18}$$

$$\frac{q}{\phi} = \frac{Q}{A \times \phi} \tag{2.19}$$

Where; q is Volumetric Flowrate per area, φ is Porosity and v is Seepage Velocity.

In flood modelling and management, a lot of hydrological model have been used previously and are currently being used for such a purpose. These models have their individual strengths and weaknesses based on the functions and what the user requires (Boyle et al., 2000). They range from simple user friendly models to complex cost and time demanding models. The TOPMODEL for instance is a simple surface water model that operates with the rainfall-runoff method for catchment and watershed analysis

(Vincendon et al., 2010). It analyze the catchment's physical properties such as topography in all its predictions. This model can be used for flood management, soil erosion analysis and other environmental assessment (Niu et al., 2005). Other models such as Hydrologic Engineering Centre-6 (HEC-6) and USGS-SFM have been used in previous times for flood forecasting in order to reduce the effects of possible floods which may occur.

For effectiveness in hydrological modeling, there have been the need to use integrated approch for effectiveness and efficiency Liu et al. (2008). In view of this, a lot of Integrated Water Resources Management (IWRM) Models have been developed, used and currently still in use. The effectiveness of such models have made it easy for water resource management and allocations to be done in basins (Tang et al., 2005). The RiverWareTM DSS have been used to generate reservoir and river simulations which may be used as storage systems, irrigation and hydropower reservoirs. It works on individual river characteristics such as river diversions, reaches, and stream flows (Zagona et al., 2001).

The SWAT model have been developed and used for numerous purposes including, flood control, water resource allocations and several irrigation purposes (Arnold et al., 2012). The model is a sophisticated physical model that analyze watershed characteristics, rainfallrunoff relations and agricultural modules to generate outputs for planning and policy making (Romanowicz et al., 2005). The SWAT model has been used in different locations for varied purposes ranging from flood modeling, soil water characteristics and irrigation processes (Douglas-Mankin et al., 2010).

2.4 WEAP Model

The WEAP model conducts its calculations mostly on monthly basis. All calculations made for a system is independent on the previous month except for reservoir and aquifer storage (Amato et al., 2006). Water entering the system are; flow into groundwater as recharge, river headflow and runoff into reaches. Inflows are stored in various systems like aquifer, catchment or resevoir. The water that serves as outflow are based on evapotranspiration, return flow into the supply section and transmission into the environment (Sieber and Purkey, 2011).

The WEAP Model calculates the parameters based on the mathematical equations;

$$P_{ET} = P \times A \times 10^{-5} \times P_{eff} \qquad (2.20)$$

where; P_{eff} = Precipitation Available for Evapotranspiration

$$ET_{POT} = ET_{ref} \times K_c \times A \times 10^{-5} \qquad (2.21)$$

where; ET_{POT} is Potential Evapotranspiration, K_c is Crop Coefficient, A is Area, P_{ET} is Effective Precipitation and ET_{ref} is Reference Evapotranspiration

In the calculation of surface runoff using the WEAP Model, the precipitation available for evapotranspiration, potential evapotranspiration and the water supply is given as;

$$R = (P_{eff} - ET_{POT}) + (P \times (1 - P_{eff}) \times S_p) \qquad (2.22)$$

where; R is Surface Runoff and S_p = Supply into the system.

Some of the runoff water percolate to serve as a recharge for groundwater.

$$GW_R = \Sigma(SurfaceRunoff \times GroundwaterFraction) \quad (2.23)$$

$$R_s = \Sigma(R \times (1 - GW_R)) \quad (2.24)$$

Where; R_s is Runoff to surface water and GW_R = Runoff to Groundwater

The volume of surface runoff in an area also depends on the nature of crops that are located in the area. The basic factors of the crops that affects the surface runoff is the rate of transpiration. Nevertheless, evaporation also has a major impact on the volume of water that serve as surface runoff. The combined effect of both transpiration by crops and evaporation on the surface of the Earth is termed as evapotranspiration. In hydrological modeling, a base case of evapotranspiration, known as reference evapotranspiration is used in the determination of surface runoff. Reference Evapotranspiration is an arbitrary crop that covers the ground and has a height of 0.12 m, an albedo of 0.23 and a surface resistance of 70 sm^{-1}.

2.5 Standardization Precipitation Index (SPI)

The Standardization Precipitation Index (SPI) was initially designed for drought events and to check years of severe droughts and excess water. It is an easy to use method due to the fact that, only rainfall is considered (Okyere et al., 2013). The negative and positive SPI values represent rainfall deficit and rainfall excess respectively (McKee et al., 1993). The method is mostly used by agriculturist to determine periods of extreme water and extreme dryness to help in planning (Bloomfield and Marchant, 2013). The

Standardization Precipitation Index can be estimated for any time scale, thus, from monthly through to long terms (Guttman, 1999). The table 2.2 shows the values standardized anomalies and thier implications

Table 2.1: Major floods in Accra and their corresponding rainfall

Date	Flood-day Rainfall (mm)	Rainfall before flood-day (mm)	Sources
14 July, 1991	157.2	2	+, *
4 July, 1995	243	0	+ , ++, *
28 April, 1997	124.1	0	++
12 June, 1997	113.7	38.7	*
27 June, 2001	81.1	27.3	+, ++
09 June, 2002	123.3	0	++
10 June, 2003	89.2	1.6	+
26 March, 2007	59.2	0	+++
18 May, 2008	151	0	+++
25 October, 2011	97.7	58.3	+++
5 June, 2014	74.7	0	**
3 June, 2015	212.8	12.5	**

[++] (Rain et al., 2011)

[+++] (Okyere et al., 2013)

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[*] http://www.em-dat.net - Universite Catholique de Louvain - Brussels - Belgium

[**] http://www.ghanaweb.com/GhanaHomePage/NewsArchive/artikel.php?ID=361061

[+] (Twumasi and Asomani-Boateng, 2002)

Table 2.2: Standardization Precipitation Index (SPI)

SPI range	Implication
2.00 +	extremely wet
1.50 to 1.99	very wet
1.00 to 1.49	moderately wet
-0.99 to 0.99	Normal
-1.00 to -1.49	Moderately dry
-1.50 to -1.99	Very dry
-2 and below	extremely dry

Chapter 3

Methodology

Chapter three (3) of the work deals with the detailed description of the study area and the major types of data that were used for the research. The acquisition of data, methods used in the collection of data and the generation of scenarios that were employed in the study have also been described in the chapter. The section further gives detailed explanation of the tools used in data processing.

3.1 Study Area

3.1.1 Location and Physiography

The Greater Accra Region of Ghana is located within the coastal sector of Ghana. The region covers a surface area of 3245 km^2 which is 1.4 % of the total land area of Ghana (Mensah, 2006). The study area stretches from Kokrobite to Ada Foah on the east coastline through a total distance of 225 Km (Ghana, 2011). Greater Accra Region is located in the south-central part of Ghana and shares boundaries with the Central Region, Volta Region, Eastern Region and Gulf of Guinea to the west, east, north and south respectively

(Service, 2005). It lies within latitude 5.8143 °N and 0.0747 °E with an average elevation of 31 m above mean sea level (Junner and Bates, 1945). The region is divided into ten (10) districts as shown in figure 3.1, which are; Ga South, Ga East, Ga West, Accra Metropolitan Assembly (AMA), Ledzokuku Municipal Assembly (LEKMA), Tema Metropolitan Assembly (TMA), Ashaiman Municipality, Adenta Municipality, Dangbe East and Dangbe West districts (Service, 2005).

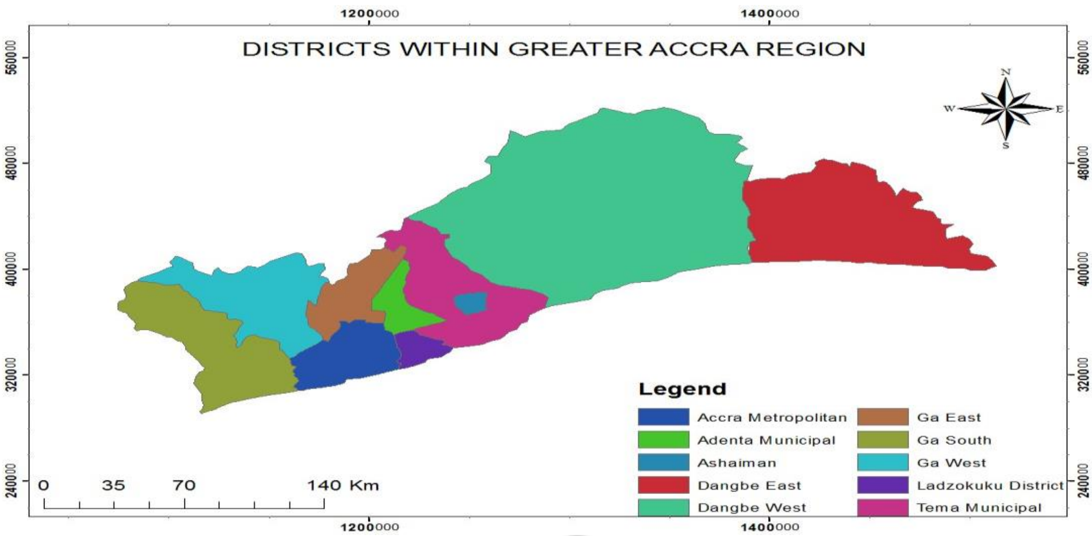


Figure 3.1: The various districts located within Greater Accra Region

3.1.2 Climate

Greater Accra Region is located within the dry equatorial climatic region which is characterized by a double maximum rainfall coupled with a long dry season and harmattan condition (Addo and Adeyemi, 2013). It is located within an area where the moist monsoon winds blow parallel to it and has a climate which comprises the tropical savanna climate and semi-arid climate along the coast (Lawson and Jenik, 1967). The region experiences two major rainy seasons thus,the April to June rainy season and the September to October rainy season with annual rainfall of 635 mm along the coast and 1140 mm in the northern parts of the region (Kwaku and Duke, 2007). The temperature ranges between 20 $^{\circ}$C and 30 $^{\circ}$C due to the climatic zone within which it is located. During the dry months, the region experiences a dry breeze which is higher in temperature called harmattan and records its highest temperature values (Codjoe and Owusu, 2011).The cooler months are more humid with fog and mist in the early times of the days while the hotter months are less humid (Le Houerou, 2009).´

The location of Accra, which is closer to the Equator, makes it have a relatively uniform conditions during daytimes with humidity being generally high of about 65% in the afternoon to about 95% in the night (Muff and Efa, 2006). The Wind direction in Greater Accra region has been observed to be moving from West-South-West (WSW) direction to North-North-East (NNE) direction. The wind travels with average velocity between 8 Km/hr to 16 Km/hr (Xorse, 2013). The highest and heaviest wind velocities and intensities are recorded during thunderstorms which mostly cause a lot of damage along the coast (Jenik and Hall, 1966).

3.1.3 Vegetation

The vegetation of the study area is similar to that of Guinea Savanna and Sudan, which lies north of the Accra plains (Van der Geest et al., 2010). The vegetation of the region is divided into three (3) main zones namely; Coastal lands, Shrub land and Grassland (Decher and Bahian, 1999). The Shrub land is mostlylocated near the Aburi hills in the western side and the northern side of Greater Accra Region (Hall and Swaine, 2013). The cluster of trees and the shrubs grow at an average height of about 5 *m* and some of them include; very few dense forest, coconut trees and palms with small remnant trees (Stow et al., 2013). The grassland found within the area is made up of vast land that is used for agricultural purposes with vegetable production known to be the most widely practized (Ghana, 2011). The Coastal zones are made up of two (2) main divisions of vegetation types which are the Wetlands and the Dunes (Quaye et al., 2010). The coastal wetlands provides a great field for marine and terrestrial habitat, which is much productive as compared to other similar vegetation types found within the region. The wetland comprise of mangroves which are made up of two (2) main species of plants that thrive well in tidal zones of the estuaries and lagoons located within its vicinity (Okorley et al., 2004).

3.1.4 Demography

According to the 2010 population census, the Greater Accra region is made up of a population of about 4,010,054 people, which makes it one of the most densely populated regions in Ghana based on the ratio of its total land area to the number of people inhabiting the area. The population density is estimated to be 1235.80 persons/Km^2 and this proves the possibility of experiencing over crowding in the region. The is found to be growing at a population growth rate of 3.10 % of the total population annually (Van Rooijen et al., 2010). The region is an ethnocentric area with people from various ethnic groups including, Ga, Ada, Ashanti, Bono, and others, inhabiting it due to the avialability of of employment and other forms of jobs.

3.1.5 Hydrogeology

Drainage System

The main waterbodies that drain the region are the Densu river and other inland streams. There are small streams which flow mostly from the Akwapim Ridge into the sea through numerous highly polluted but economically good lagoons within the region (Mensah, 1979). The Volta River has an estuary delta at Ada in the Dangme East District which is of economic importance to the population. Some of the renowned streams identified within the study area include; Lador, Sakumo, Odaw, Dzorwulu and Mahahuma (Agyenim and Gupta, 2012). Groundwater found in the region has been proved to have some amount of salt in them due to the nearness of the region to the sea. The location of groundwater in the Subsurface water may be located within a distance of about 4.80 m to 70 m in areas like surface at places like Ofankor, Kantamanso and others (Alfa, 2010).

Geology

The geology of the Greater Accra region as shown in figure 3.2 falls within the Accra-Keta basin under which the Accraian formation can be located. The Accraian series spreads over an area of 11.7 km^2 and it is within the vicinity of Accra. This series is underlain by the Dahomeyan basement complex (Kjemperud and Fjeldskaar, 1992). Along the beaches of Accra, the sedimentary rocks found within the vicinity are exposed and also can be found along the base of cliffs which have existed for over 350 million years during the Devonian period (Blundell and Banson, 1974).

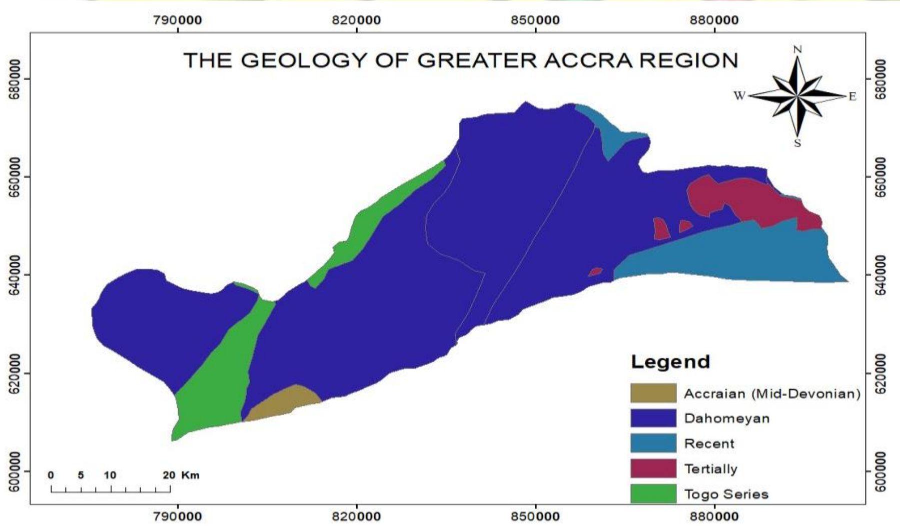


Figure 3.2: The various soil classifications in Greater Accra Region

The geology of Greater Accra Region is made up of Precambrian Granodiorites, Dahomeyan Schists, Gneiss, Granites and amphibolites to late Precambrian Togo Series comprising mainly Quartzite, Phillites, Phylitones and Quartz Breccias (Kesse, 1985).

There are other types of geological materials found within the region, which are; Palaeozoic Accraian Sediments which comprise of Sandstone, Shales and Inter-bedded Sandstone-Shale with Gypsum Lenses (Erdelyi, 1965). The region is divided into five (5) main terrains which are; Akwapim Range, Coastal Lowlands, Eastern Lowlands and the Western Lowlands and the Lagoons (Muff and Efa, 2006). Joints and shears which are mostly areas of weakness in the rock formation of the Western lowland and also faults that are steeply dipping with some intrusions of dikes (Hirst, 1946).

The Accraian formation is sub-divided into three (3) main division which are;

1. Lower Sandstone Formation
2. Middle Shale Formation
3. Upper Sandstone Shale Formation

The lower sandstone formation is the bottommost formation found within the Accra series and can be located between the Osu fisheries in the Eastern direction and towards the end of the rocky shores on the Western direction (Arku, 2012). They are sandstones with reasonable amount of sandy soil which are course in nature with high rate of water infiltration (Blundell and Banson, 1974). It is made upof pebbles, grits, breccias and fine shales (Arku, 2012).

The middle shale is characterized by the presence of fossils and high content of clay making water infiltration slow and difficult (Antobreh et al., 2012). While the upper sandstone formation is identified predominantly by its inter-bedded nature and consist of fine grained quartizitic sandstones and argillaceous shales (Mascle et al., 1998). The actual thickness of the formation have not been identified but the individual beds have been identified to be about 30 cm. The age group of the formation is presumed to be within the age range of the middle Devonian (Tevendale, 1957).

Soil Types

The major soil formations that have been identified within the Greater Accra Region are; acrisols, arenosols, cambisol, fluvisol, gleysol, leptosol, lexisol,luvisol, plinthosol, vertisol and solonetz as shown in figure 3.3 (Eze et al., 2010). Most of the soil materials are hard and resistive due to the occurrence of erosions especially along the Akuapim Ranges and the Weija mountains (Commission et al., 2007). The coastal section of the region has large deposits of salt and have economic potentials (Dudal, 1965). A large area of the North Western part is underlain by tertiary and recent deposits (Odame-Ababio, 2003). Within the deltaic areas around the Volta lake, there exist recent unconsolidated sand, gravels and clay around the Songor Lagoon (Amate, 1999). Within the Odaw and Chemu basins exist laterite gravels which are about a meter deep and are known as the red Earth soil. This soil type is mostly used for construction works and other mining activities.

3.2 Data Acquisition and Processing

3.2.1 Desktop studies and Reconnaissance Survey

The research work commenced with the assembling of materials that were needed for the study. These materials included; published journals and other relevant papers, drawing of timetable for the work, collection of data from the appropriate institutions, acquisition of tools to aid in data processing, generation of thematic maps and others. There

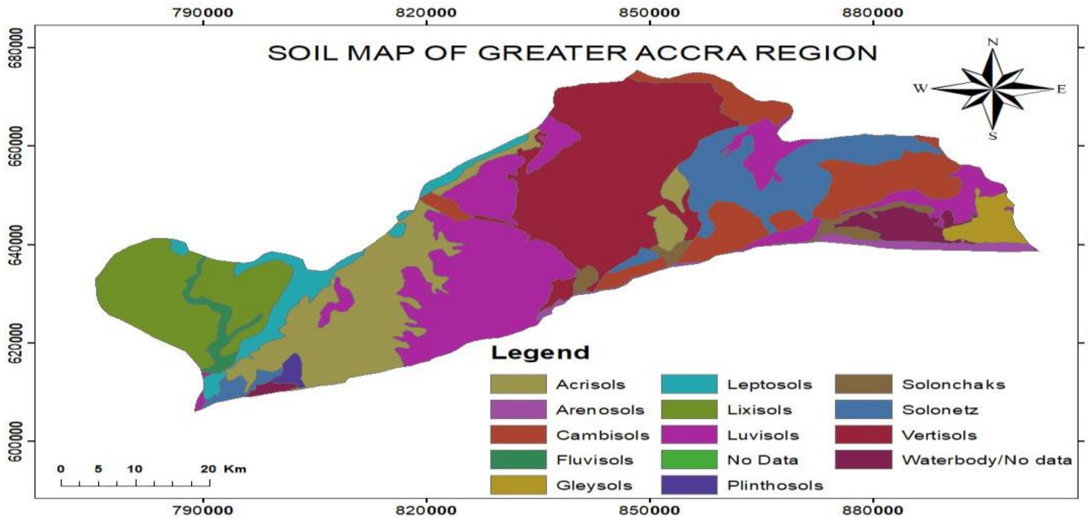


Figure 3.3: The various soil classifications in Greater Accra Region

are established institutions that are in charge of the acquisition, storage and management of various data for the research work. These institutions include; Soil Research Institute (SRI), Ghana Meteorological Agency (GMA) where climatic data were obtained, Town and Country Planning Department, Ghana Hydrological Service Department, Geological Survey Department, Ghana Statistical Services, Ghana Water Company Limited (GWCL), Integrated Water Research management (IWRM), Water Research Institute (WRI) and others.

3.2.2 The Water Evaluation and Planning (WEAP) System

The WEAP system was developed to aid in water policy making and also help in the effective management of quality water. It is used for hydrological modeling that helps to curb some disasters associated with water. This tool is a computer tool that has been designed to be used for integrated water resource planning and evaluation. This tool is used for policy analysis due to its comprehensiveness, user-friendliness and flexibility (Sieber and Purkey, 2011).

A lot of countries are faced with the challenge of managing water resources and other adverse situations that escorts surface and groundwater management. For a while now, the use of integrated approach to manage water resources have emerge and this has been inculcated in the WEAP model and as a results, it stands unique among other models (Sieber and Purkey, 2011).

WEAP operates on the principle of a water balance and as such the various water use and supply are based on it. Due to the flexibility of the tool, the model can easily be customized to suit the objective of the work being undertaking (Levite et al., 2003). WEAP´ model has diverse areas of application from small catchments through to municipal and regional systems all the way to trans-boundary systems (Ingol-Blanco and McKinney, 2009). The model does not only deal with water allocations but also helps in the management and preservation of the ecosystems which are found around us (Ingol-Blanco and McKinney, 2009).

In order to use the WEAP application effectively and for the purpose of flexibility, the model has been divided into four (4) basic steps. These steps are;

1. boundary selection
2. setting up time frame
3. setting up the system component
4. problem configuration

The model has special aspects that makes working with it easy and user friendly. This includes;

1. The Current Accounts: This section of the model is considered to be the step usedfor model calibration in the process of modeling using the WEAP application. It provides an avenue to model a situation that can be used to predict future and past possibilities. It involves the input of various supply and demand needs that would be used for the modeling processes.

2. Key Assumptions: The WEAP model provides a means to enable the representationof common sections such as; costs, demand and supply, policies, pollution and hydrology in order to avoid a repetitive entry of the same data into the model. The Key assumptions are based on the current account and can be used by several scenarios and branches.

3. Scenarios: This is generated to exploit future possibilities that may occur whencertain decisions are made and this may be used in the formulation of policies. It helps to know how sensitive a model is and how effective it can be.

The WEAP model works on the basis of monthly time step, thus, it starts from the very first month of the water year through to the last month in the last year of the scenarios. But for aquifer and reservoirs, each of the months does not depend on the month that precedes it. This implies that all the water that serves as input for each of the months that marks the beginning of the current account year either leaves the system at the end of each month or are stored in reservoirs and aquifers. The time step for the various processes such as withdrawal of water from rivers, consumption of water and the return flow of water are taken to be instantaneous due to the relatively long period time steps, thus monthly (Sieber and Purkey, 2011).

The model's structure consists of five (5) main views which are:

1. Schematic View
2. Data View
3. Results View
4. Overviews
5. Notes.

Schematic view: This view provides the opportunity for the hydrologist to create the boundaries for the model and also to input the various nodes (such as demand, catchment, rivers etc) into the study area based on a drag and drop approach. There is a provision for the input of GIS images, being it vector or raster as background into the schematic view to help in the accurate mimicking of the original state. The nodes are dragged and dropped according to the supply of water to the consumption, thus, from rivers to demand sites. The demand sites and the supply sites are linked to each other by transmission links and the return flow links for their individual purposes.

Data view: This is where data can be added to the various branches that have been added to the schematic view. This view is structured in a form of a tree with its branches being the individual nodes that were inserted at the schematic view. The branches of the data view are; Key assumptions, Demand sites, Hydrology, Supply and Resources and Water quality. The user friendliness of the model allows the user to further divide the branches into sub-branches. This allows the user to create assumptions, mathematical expressions and the like.

Result view: This view allows the user to see the outcome of the various calculations and simulations that needs to be done for the model to be complete and worthwhile. The various simulations are started upon clicking of the results view node on the left hand side of the model. The display of the results provide means for the user to view either monthly or yearly values of the simulated model. The results can be observed in a chart form, graphs or tables and can be exported through various allowable file formats. The results are grouped into five (5) categories based on how it is presented in the model. These are:

1. Demand
2. Supply and Resources
3. Catchments
4. Water Quality
5. Financial

3.3 Collection of input data

The data used for the study had varied sources and nature depending on their types. The entire data collection process involved literature reviews, Government Agencies, research institutions, site visitation and others.

3.3.1 Hydrometeorological Data

The datasets that were used as input under Hydrometeorology includes; temperature, evapotranspiration, humidity, rainfall and stream flow. Some of the climate data that were used for the research were obtained from the Ghana Meteorological Agency (GMA) while others were obtained from literature. The stream flow dataset used for the research is a historical dataset obtained from Ghana Hydrological Service (GHS), due to the highly limited numbers of functioning stream guagues within the confinement of the study area.

The climate dataset obtained from GMA was within the period from 1990 to 2015.

3.3.2 Landuse / Landcover (LULC) Data

Landsat images were downloaded from www.usgs.gov and both unsupervized and supervized classification performed on them using ArcGIS 10.3 desktop software. The classified images were validated using site visitation and the help of Google Earth this was done due to the unavailability of updated LULC maps. The various LULC were categorized into water bodies, vegetation, undeveloped lands and developed lands. Other landuse data such as area, crop coefficient were obtained from satellite imagery and its validity tested using tools like Google Earth, confirmation from literature and visitation to the field.

3.3.3 Irrigation / Dam data

There are some irrigation schemes located within some of the sub-catchments that can be found within the study area. Data on the dams were mostly obtained from literature due to the unavailability of up to date reliable data. Some of the dams are out of use while others are still functional and this is the reason for the variations in the volumes of data obtained for the individual irrigation or dam systems. Projected data were used to obtain possible changes in the hydrological characteristics of the sub-catchments and the impacts they could have to attain the aim of flood management.

3.4 Data Input structure and Processing

The WEAP model has been divided into five (5) sections in terms of data input and processing. These processes have been described below in the order in which it was done during the study. The model was set to simulate from 1990 to 2040 with the year 1990 serving as the base year of simulation.

3.4.1 Schematic View

The sub-basins were delineated by inserting the already generated shapefiles of the subbasins and the drainage system of the study area. The insertion of the vector image is to help the accurate and precise placement of the needed nodes for the model to function properly. The drainage systems were inserted by drag and trace method. The image was traced closely to increase the precision of the drainage network as observed in the various sub-catchments. The drains were traced starting from the head towards the outlet for accurate processing. The final view of the model is shown in figure 3.4.

In the generation of the hydrp;ogical model, the rainfall-runoff method was used in the modeling process and in view of that, catchment nodes were dragged and dropped into their respective locations to represent each sub-catchment. The various peculiar nodes that contributes to the hydrological cycle of the sub-basins were inserted at their respective positions using the same drag and drop approach as permitted by the WEAP hydrological model. These nodes include; reservoirs, stream gauges and others. The nodes were linked to their various sources and outlets using the appropriate links to complete the cycle for processing to be possible. These links include the runoff/infiltration link among others.

Groundwater was not included in the model due to the lack of reliable data.

3.4.2 Data View

The required data for the model is dependent on the type of node that is being considered.

The data input for this model was done mostly by using the monthly time series for the

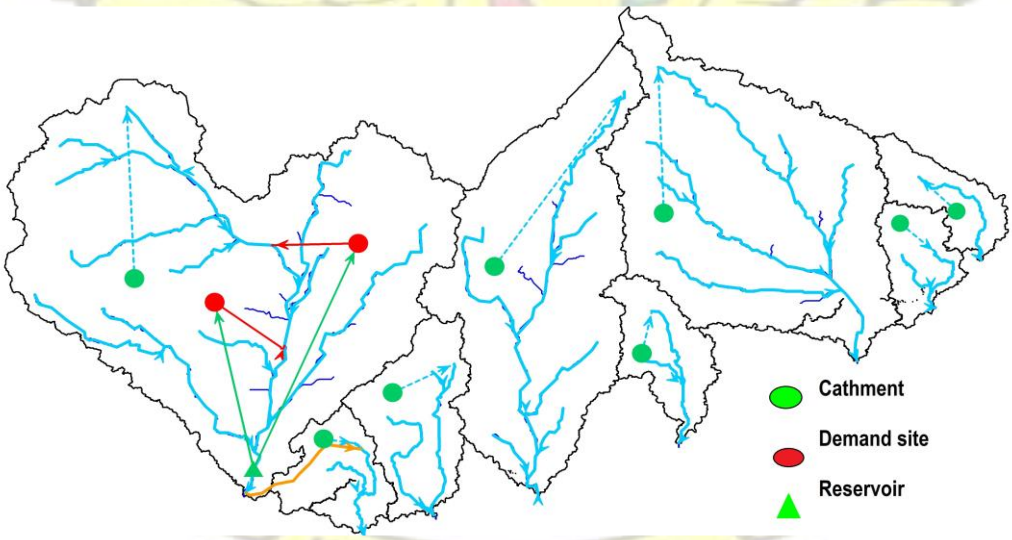


Figure 3.4: The shematic view of the model setup

current account and the read from file option. The water year method for the country was used and the month March was set as the first month of the water year.

3.4.3 Current Account

The year 1990 was used as the current account due to the availability of the needed data to serve as input for the model. The data required by the catchment node have been grouped into categories. For the purpose of this research work, the land use and climatic dataset were used. Under the land use section, the model requires the input of the surface area, crop coefficient and effective precipitation. The crop coefficient values used for the simulation varied from 0.5 to 0.85 depending on the level of development and the vegetative cover of the basin under consideration. The various basins and their sizes have been given in the table 3.1.

Rainfall below 5 mm were assumed to produce no surface runoff as stated by (Allen et al., 1998). This implies that, rainfalls that were recorded to be below 5 mm produced no surface runoffs since all the water wikll infiltrate into the ground. The expression builder in the WEAP model was used to generate the effective precipitation values.

Table 3.1: Sub-basins and their surface area

No.	Sub-basins	Area(Km^2)
1	Upper Densu	484
2	Odaw	242
3	Sakomo	277
4	Lower Densu	42
5	Densu Delta	67
6	Kpeshie	43
7	Mokwe	31

8	Ashaiman	33

3.4.4 Scenarios

Scenarios are used to estimate the possibilities that could be observed within a catchment due to some possible changes in the characteristics of the catchment. The scenarios that were simulated are: reference scenario and three additional scenarios which may also be called the "what if" scenarios.

3.4.5 Reference Scenario

This is a default scenario that works by projecting the data input for the current account to predict future occurrences provided conditions remain the same. The reference scenario provides an avenue for comparison to other scenarios in order to make meaningful deductions and help in possible policy making.

3.4.6 Rainfall Projection

This scenario was generated based on the rainfall data projected from the CMhyd tool which operates on the assumptions of IPCC to forecast future possibilities in climate. The data obtained were bias corrected and the corrected data was used in the model to observe the possible results. This scenario would help to know the possibilities of flood occuring in any of the basins assuming the projections of IPCC takes effect in future.

3.4.7 Standardization Precipitation Index (SPI) of rainfall

This scenario computes the standardized deviations for the rainfall values that have been recorded over the period from 1990 to 2015. This scenario is to compare the documented flood history of the basin to the rainfall pattern in other to strike the correlation between them and also to make predictions of the volume of rainwater that can cause hazard in the basins. The standardized anomalies were obtained from the following equations:

$$x^0 = x - X \quad (3.1)$$

$$SPI = \frac{x'}{\sigma} \quad (3.2)$$

Where; x is monthly rainfall, X is long term mean of rainfall from 1990 to 2015, σ is standard deviation and x^0 is deviation from the mean.

3.4.8 Generation of Thematic maps

The individual maps needed for the research work were developed using the ArcGIS 10.3 desktop tool. These maps were used to mainly help the processing of the data and also to aid the WEAP model.

Digital Elevation Model (DEM)

For the purpose of this research work, a digital elevation model for Greater Accra region was acquired from Http://www.usgs.gov. The ASTER DEM was generated by NASA and all other necessary processing were done using basically the ArcGIS 10.3 software as shown in figure 3.5. The resolution of the DEM is 30 m × 30 m with a vertical RMS error of 10 m - 25 m and a geographically referenced to UTM WGS 1984 (WGS84) projection system (http://ipdaac.usgs.gov).

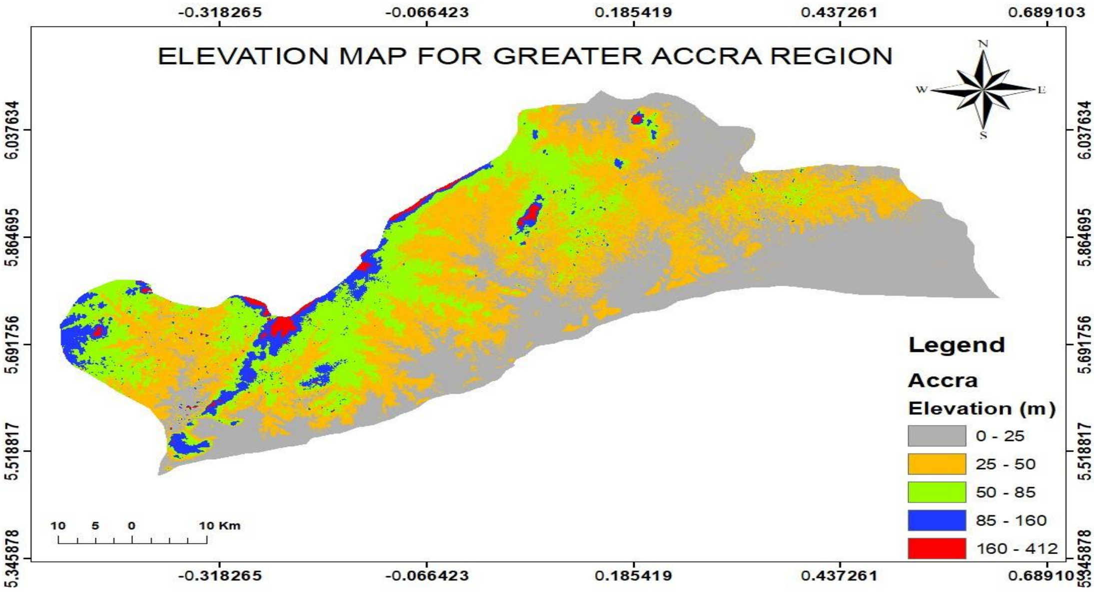


Figure 3.5: DEM of Greater Accra Region

The obtained DEM was extracted to the shape of the Greater Accra region using the shapefile for the region in other to work within the boundaries of the study area. An elevation map was generated and a Triangular Irregular Network (TIN) map was also generated for the region using the 3D analyst toolbox located in the arc toolbox to clarify the nature of elevation of the area as represented in figure 3.6.

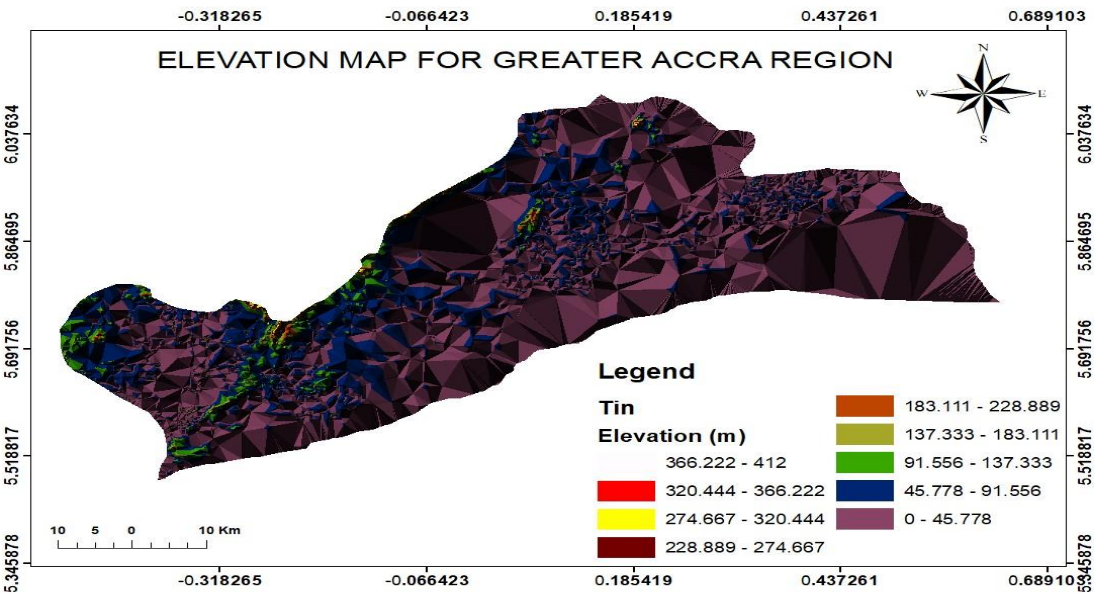


Figure 3.6: TIN of Greater Accra Region

3.4.9 Watershed and Drainage Network

The generated DEM was used to produce the watershed for the various basins using the ArcGIS extension known as ArcHydro. The possible sinks that may be within the DEM were filled. Under the data management tool within the ArcHydro tool box, the fill sinks option was selected to deal with the voids. The flow direction of the DEM was generated together with the flow accumulation using the terrain processing section in the ArcHydro toolbox.

Stream definition and segmentation were performed on the flow accumulation results to generate a stream segmentation map. The individual sub-basins were further generated using the catchment grid delineation tool. Polygons were generated for the catchments as shown in figure 3.7. similar processes were performed to generate the drainage lines and the final polygons for the drains were developed. The drains that were generated were further verified using Google Earth to test for its accuracy and it proved to be accurate.

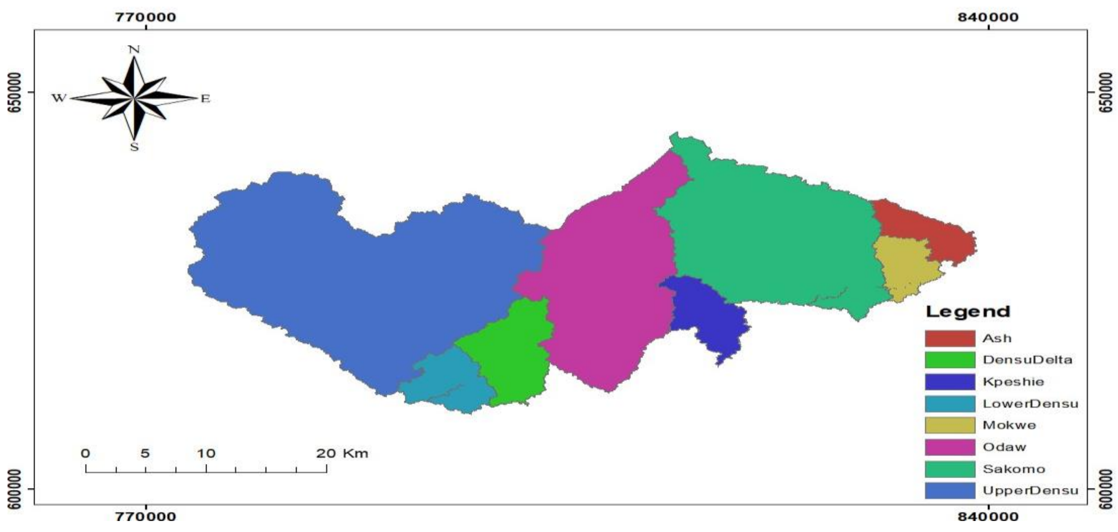


Figure 3.7: The major drainage basins of Greater Accra Region

Drainage Density

The map representing the various drainage densities of the sub-catchments were generated from the ArcGIS 10.3 tool by further processing the DEM. The arithmetic section under the tool section was used to calculate the densities using the relation provided by (Montgomery and Dietrich, 1989) as shown below;

$$DD = \frac{\Sigma(L_{ws})}{A_{ws}} \quad (3.3)$$

where; DD is Drainage Density, L_{ws} is Total length of stream in the watershed and A_{ws} is Area of the watershed

The various drainage characteristics of the various basins have been given in the table 3.2 Areas with high drainage densities, have lower tendencies of generating surface runoffs since a lot of the rainfall go directly into the drains and areas with low drainage densities have a higher tendency of generating surface runoff. The drainage densities of the various basins considered for the study has been shown in table 3.2.

Table 3.2: Drainage densities of the various basins

No.	Sub-basins	Area(Km^2)	Drainage Length (Km)	Drainage Density
1	Upper Densu	484	160	0.33
2	Odaw	242	72	0.30
3	Sakomo	277	86	0.31
4	Lower Densu	42	14	0.33
5	Densu Delta	67	26	0.39

6	Kpeshie	43	15	0.35
7	Mokwe	31	11	0.35
8	Ashaiman	33	10	0.30

Chapter 4

Results and Discussion

This chapter presents results that were obtained from the model after all the necessary procedures were undertaken for simulation. The results include those obtained from the comparison of observed streamflow to simulated streamflow and also those obtained from the scenarios that were created to work with the model. The final results have been presented in the form of tables and charts as well as diagrams where necessary.

4.1 Comparison of Observed stream flow to simulated stream flow

The stream flow model was run using the year 1990 as the base year or the current year. Stream flow data obtained at the Weija Gauge station on the Densu river for the year 1990 was compared to the stream flow data that was simulated by the model after all the needed input parameters have been included in the model. The model showed a strong correlation with the observed data that was obtained from the Weija stream gauge station. Analysis on the observed stream flow data resulted that, the annual average for the year

1990 is 5.78 m^3/s and that of the model simulated stream flow is 6.75 m^3/s. This showed a difference or residual of 0.97 m^3/s. The difference between the observed annual average for 1990 and the simulated annual averaged is about 16.78 % of the observed annual average. A correlation value of 0.81 was obtained after comparing the two data. The R^2 value that was obtained is 0.71. The above stated values have proven that the model is efficient and can be used to predict real life scenarios with good precision and accuracy. The comparison between the observed stream flow data and the modeled stream flow data is shown in table 4.1 and figure 4.1.

Table 4.1: Data used for comparison between observed and simulated values

Year	Month	Observed Streamflow	Simulated Streamflow
1990	3	0.418	4.650
1990	4	0.891	6.520
1990	5	1.103	3.210
1990	6	17.621	13.270
1990	7	26.721	23.456
1990	8	2.255	6.341
1990	9	3.199	5.984
1990	10	7.194	9.230
1990	11	3.243	7.200

1990	12	2.260	0.660
1991	1	2.563	0.010
1991	2	0.927	0.210

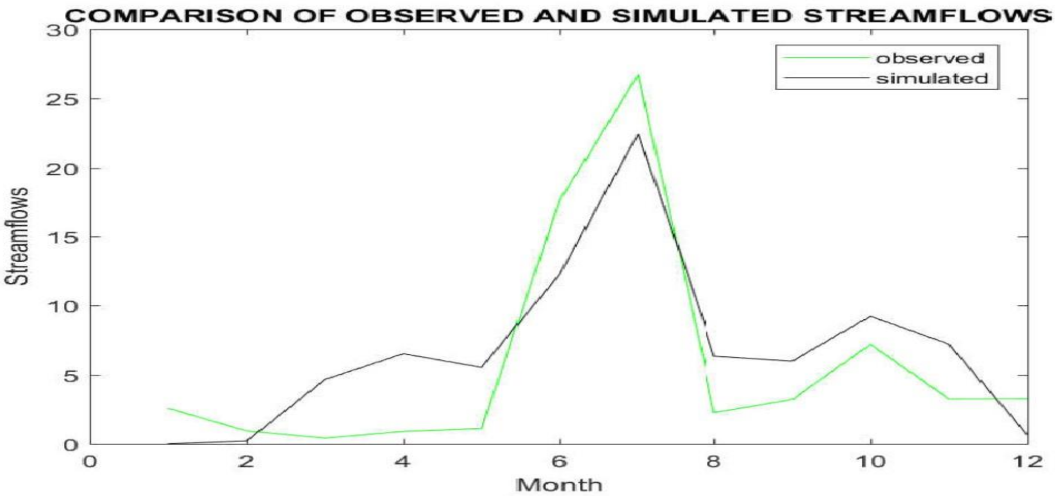
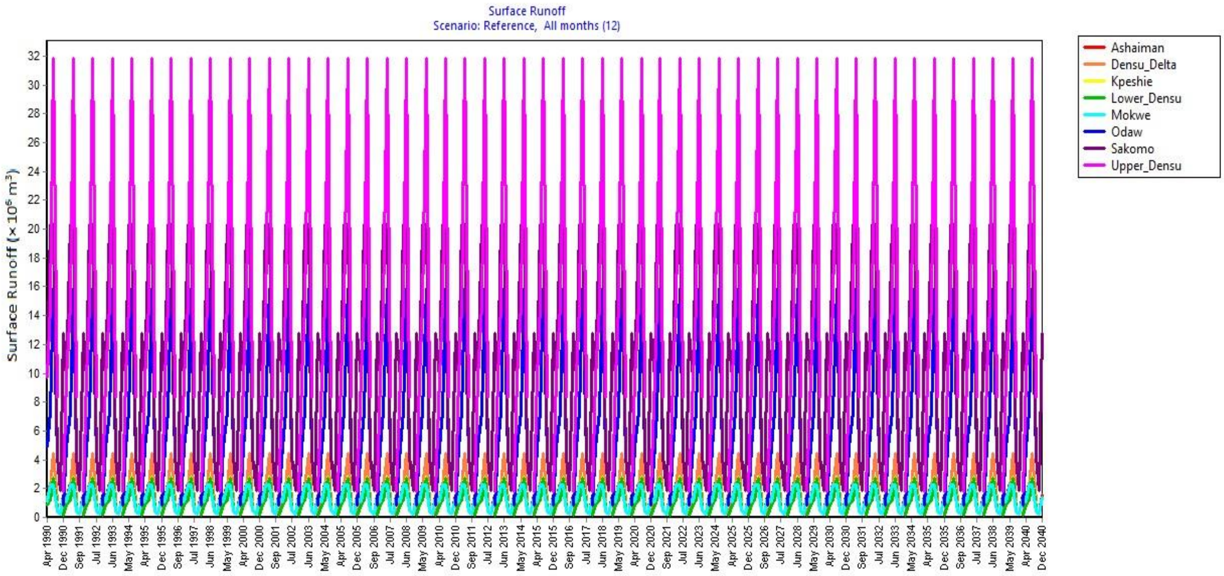


Figure 4.1: A graph of observed stream flow versus simulated stream flow.

4.2 The Reference Scenario

The reference scenario projected the characteristics of the current account to form the basis for comparison with other scenarios. This is also known as the "business as usual" scenario. The results obtained for the reference scenario showed that, the highest annual mean volumes of surface runoffs that were generated for the model were recorded in the Sakomo Basin while the lowest annual mean runoff volumes were recorded in the Lower Densu basin. It has been proven that the surface area of a basin is a major contributor to the volumes of runoffs generated in a basin.

From the results, as shown in figure 4.2, Sakomo Basin which is second to the Upper Densu Basin in terms of area generated the highest mean annual runoff of 69.22 $\times 10^6$ m^3 as compared to that of Upper Densu which is 66.38 $\times 10^6$ m^3. This could be attributed to the fact that, the Upper Densu Basin is high in vegetation as compared to that of the Sakomo Basin which is more developed and urban. Runoffs generated in urban basins are relatively higher than that of less developed basins due to the creation of more impervious surfaces in urban basins. In that same light, the Mokwe Basin generated



annual mean runoff of 7.75 $\times 10^6$ m^3 while the Kpeshie Basin and Ashaiman Basin recorded annual mean of 5.90 $\times 10^6$ m^3 and 8.25 $\times 10^6$ m^3 respectively. The Mokwe Basin and Ashaiman Basin are the smallest basin but generated runoffs greater than Kpeshie Basin. This results may be due to the highly developed nature of the basins, as they are located almost at the heart of Accra. THe developed areas has minimal infiltration of water and therfore leads to the generation of high surface runoffs.

Figure 4.2: Surface runoff generated under the reference scenario for the various sub-basins.

The average surface runoff that were generated in each month were also considered and it revealed that, across all the basins that were considered in the model, the month of June recorded the highest runoff volumes generated from rainfall. The Upper Densu Basin recorded the highest runoff volumes in the month of June with an average of 31.81 $\times 10^6$ m^3 and the minimum volume of surface runoff in the month of August with volume of 1.2 $\times 10^6$ m^3. The same trend was followed by the other basins. In general, the month of August produced the least volumes of surface runoff across the basins with a mean volume of 2.27 $\times 10^6$ m^3.

The rainfall trends for the individual basins showed that the months that fall within the rainy seasons, thus, May, June and July, generated a lot of surface runoffs due to the high amount of rainfalls and the high intensities of the rainfalls. The month of June was observed to have recorded the highest rainfalls while the month of August recorded the lowest volumes of rainfall and hence the respective recorded volumes of surface runoffs that were obtained after simulation by the model.

The drainage densities of the individual basins are averagely 0.32, which implies that there are less drains as compared to the surface areas of the basins. This means that, most of the volumes of the surface runoffs may not be able to flow into the drains and that could be a possible cause of flooding in the basins. As shown in table 3.2, the Odaw Basin, Ashaiman Basin and Sakomo Basin had the least drainage densities, and therefore makes them susceptible to flooding based on the volumes of runoffs predicted for the respective basins.

4.3 Rainfall Projection Scenario

The scenario operated base on generated rainfall data using the CMhyd tool. The tool downscales Regional Climate Projections (RCPs) to obtained projected climate scenarios based on IPCC conclusions. The forecast rainfall data were bias corrected to reduce the levels of errors in the generated data using observed rainfall data from 1980 to 2000. The results of the bias corrections is shown in figure 4.3.

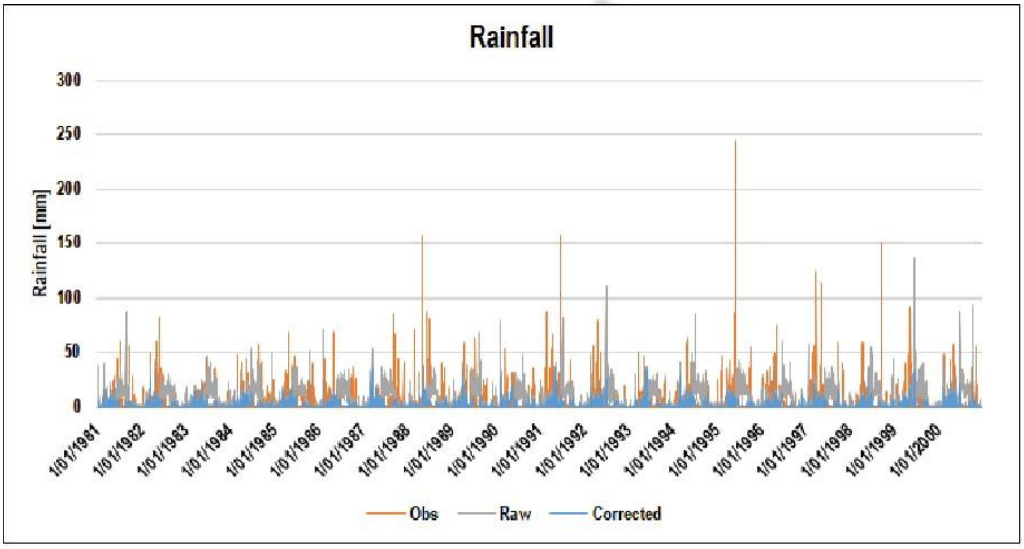


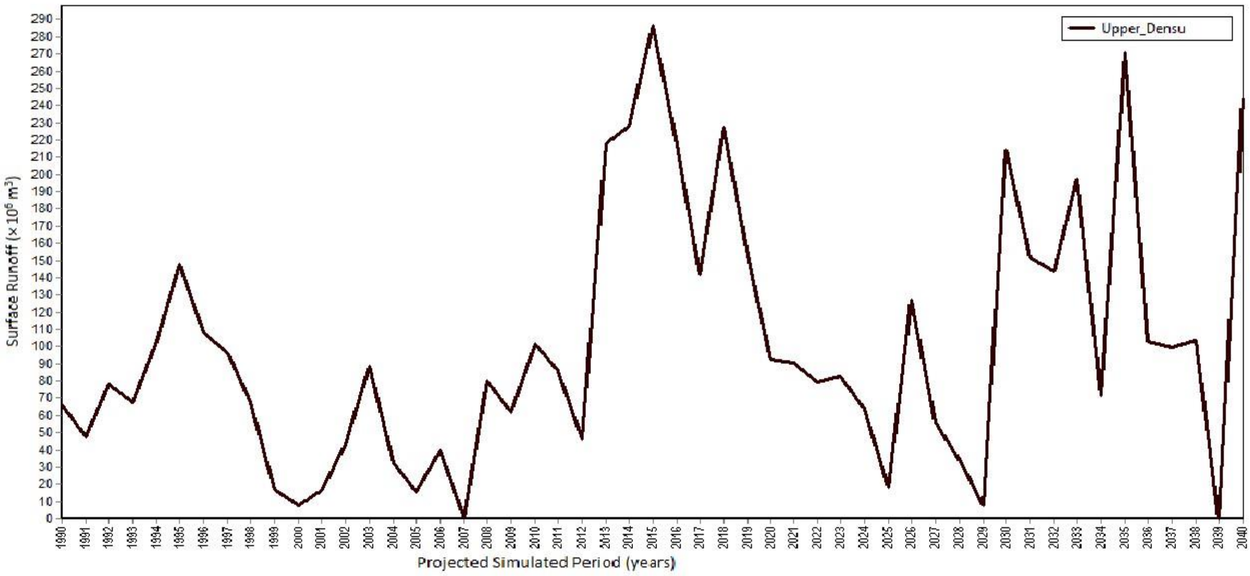
Figure 4.3: Correlation of observed rainfall data with projected rainfall data

4.3.1 Upper Densu Basin

The Upper Densu basin has a surface area of 484 Km^2, which is the largest basin that was considered in the model. The mean annual surface runoff that was generated for the basin throughout the period of simulation is about 100.84 $\times 10^6$ m^3. The maximum and minimum expected annual surface runoffs for the entire period is 286.62 $\times 10^6$ m^3 and 0.02 $\times 10^6$ m^3 respectively. It was realized that, by the end of the year 2040, a total of about 5142.88 $\times 10^6$ m^3 of water would have been generated as surface runoff, provided the prediction by the model and the projected rainfall occur in reality. Deductions made from the prediction indicates that, there is the possibility for flooding to be rampant in the basin and the right measures such as; proper drainage networks, controlled dumping of refuse, avoidance of the encroachment on water bodies must be implemented to avert the unwanted future in the basin.

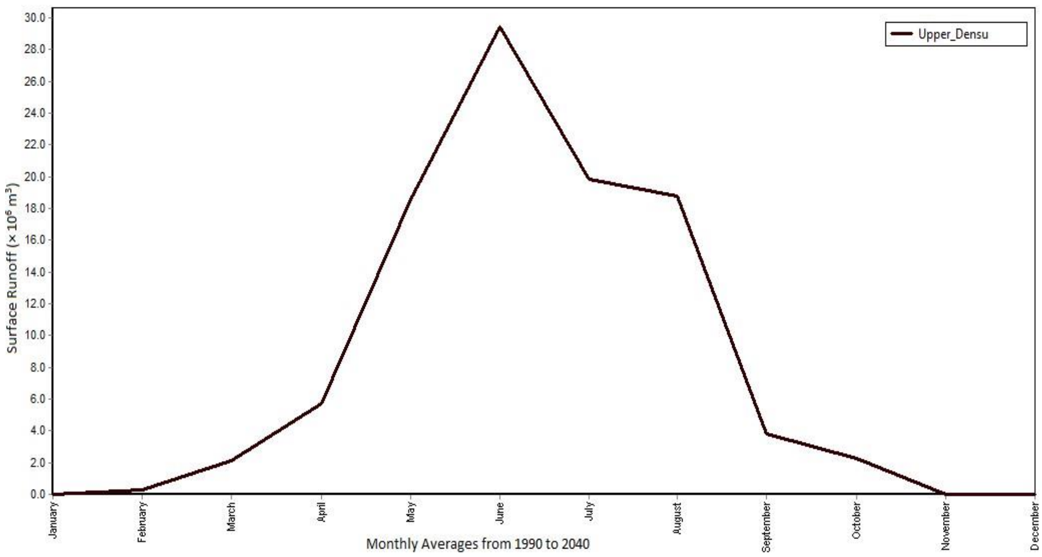
The various annual total surface runoffs that were simulated depends on the various rainfalls that were esperienced within the years. In view of this, years such as 2026, 2026 and 2036 recorded high surface runoffs due to the fact that, they recorded higher rainfall

Figure 4.4: Annual total surface runoff simulated for Upper Densu Basin



as can be seen in figure 4.4. Again, due to the inevitable growth and development of the basin, the level of water infiltration into the ground would be minimised due to the use of impermeable materials.

Figure 4.5: The monthly average surface runoffs for Upper Densu Basin



As represented in figure 4.6 the wet months, thus, May, June and July recorded the highest volumes of surface runoffs. This is to show that the volumes of rainfall within a basin is very vital to the volumes of runoffs generated. This trend makes climate change, especially rainfall a very important topic under the discussion of flood control. The high

volumes of runoff water requires adequate density of drains to be able to avoid any nega-
tive eventuality.

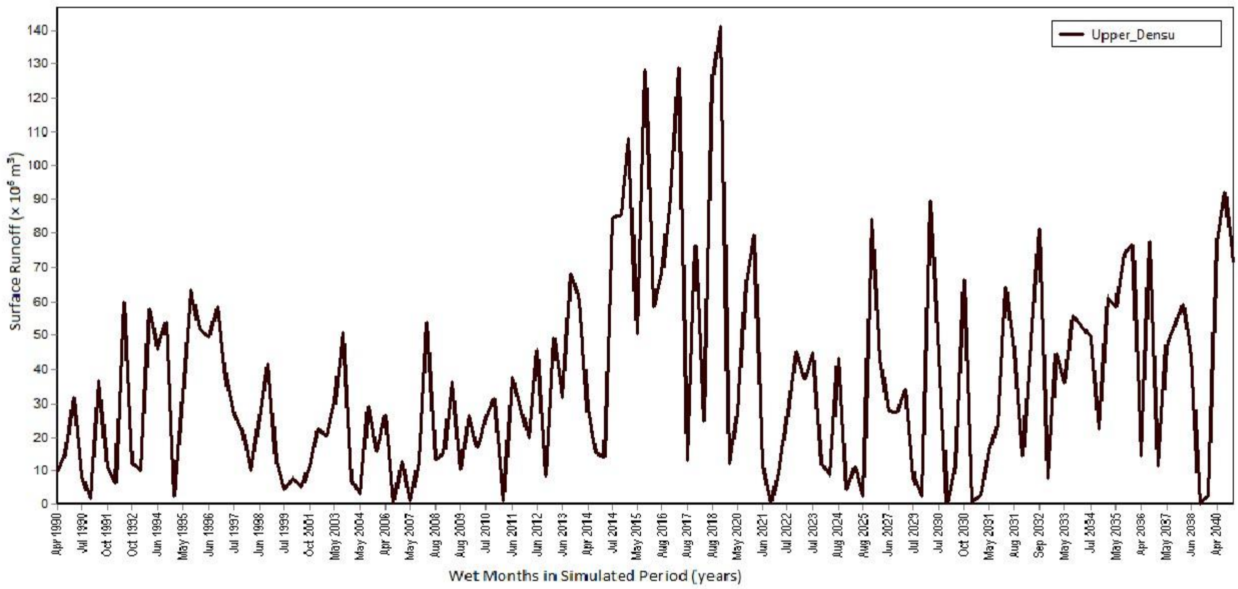
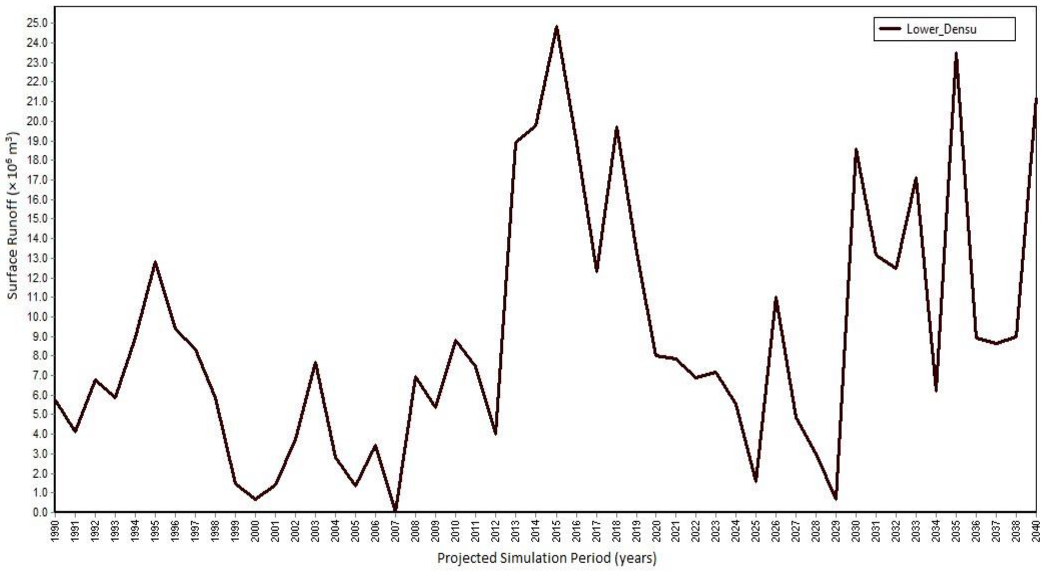


Figure 4.6: Daily surface runoffs simulated for the Upper Densu Basin froom 1991 to 2040

In reference to figure 4.5 maximum surface runoff was recorded in June with a monthly runoff of about 29.45 ×10^6 m^3. The month June, July and May recorded higher surface runoffs whiles January, November and December recorded minimum volumes of runoff of about 0.01 ×10^6 m^3. The average monthly runoff for the Upper Densu basin was estimated to be about 8.40 ×10^6 m^3, which indicates that, on the normal basis, increases in rainfall would have a lot of impacts on the basin's ability to generate surface runoffs and hence its tendency to flood.

4.3.2 Lower Densu Basin

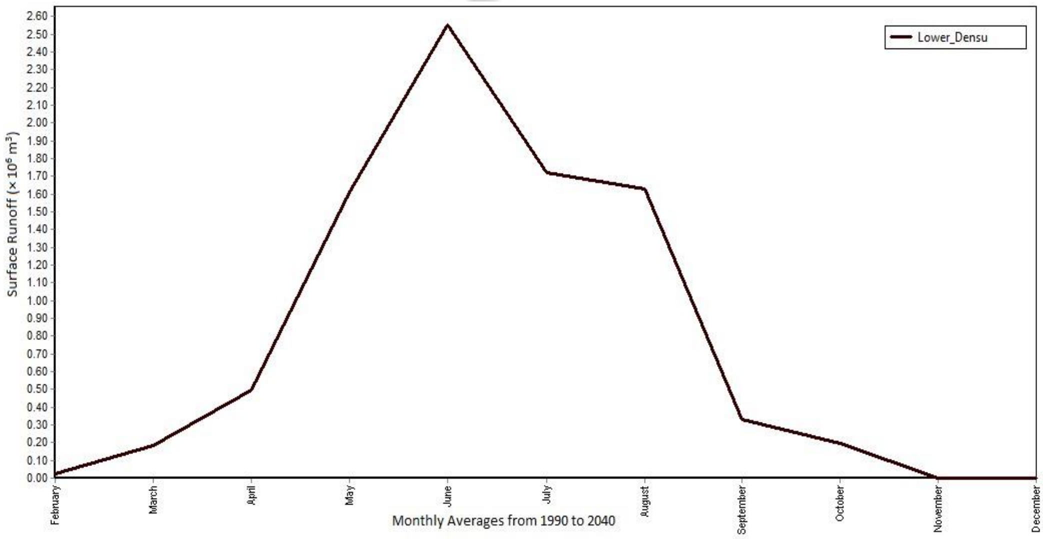
Within the Lower Densu basin, the annual surface runoff generated is within the range of about 0.08 $\times 10^6$ m^3 and 24.87 $\times 10^6$ m^3 for the minimum and maximum runoffs respectively as represented on figure 4.7. It was observed that, on the average, the Lower Densu basin generated annual surface runoff of about 7.59 $\times 10^6$ m^3. The differences between the two extremes of the annual totals possible to be generated in the basin depicts that, there are chances of generating runoffs greater than the current carrying capacities of the drains since the drainage density for the basin was estimated to be 0.34 as represented on table 3.2. As stated by (Jonkman, 2005), areas with high drainage densities have low tendencies of experiencing floods as compared to those of low densities, which makes it alarming should this results be experienced in the basin. It has been observed that, due to the relatively small area of the basin, any increase in rainfall would tend to have a very drastic change on the volumes of water that serve as runoffs and this may lead to the overflow of drains and hence causing flooding. A lot of rainfall implies that a lot of runoff would be generated per year provided all other



physiological factors remains unchanged.

Figure 4.7: The annual total surface runoffs estimated for Lower Densu Basin

Averagely, the monthly volumes of the surface runoff can be found to be maximum in the month of June and minimum in the month of November and December with volumes within the range of 0.01 $\times 10^6$ m^3 and 2.56 $\times 10^6$ m^3 as shown in figure 4.8. On the average, it was estimated that, within a year, 0.80 $\times 10^6$ m^3 of surface runoff is generated in the basin monthly. This results predicts that, the fight against flooding must focus more on the wet months due to the increase in rainfall and its ripple effect

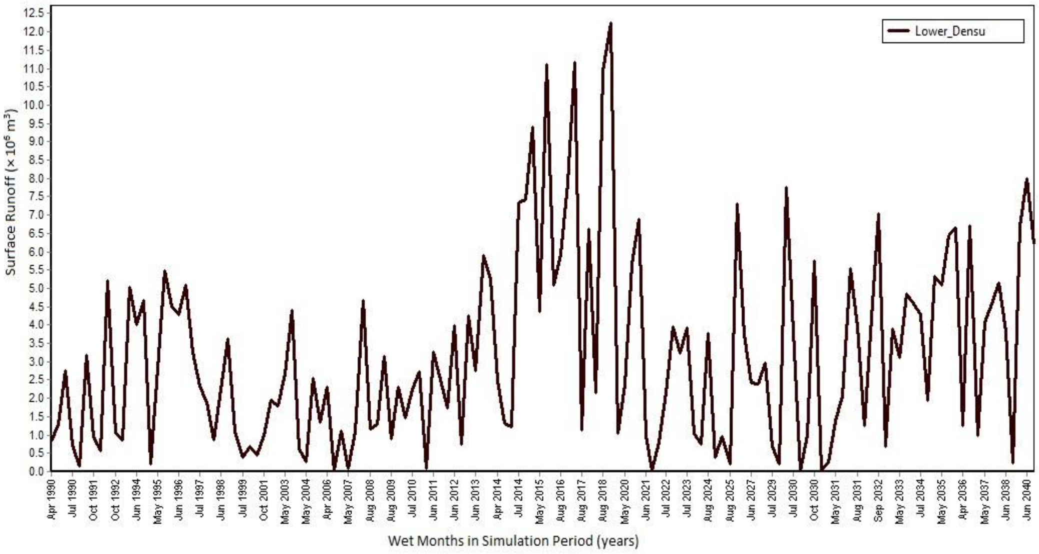


on the surface runoffs generated monthly.

Figure 4.8: The monthly average surface runoffs for Lower Densu Basin

In general, the smaller size of the Lower Densu basin have affected the surface runoffs generated but nevertheless, these volumes are still capable of causing harm since the runoffs generated also depends on factors like the drainage density, rainfall, slope and others (Pallard et al., 2009). The general trend of the surface runoff estimated to be generated within the basin is represented in the figure 4.9

Figure 4.9: Surface runoffs simulated for Lower Densu Basin

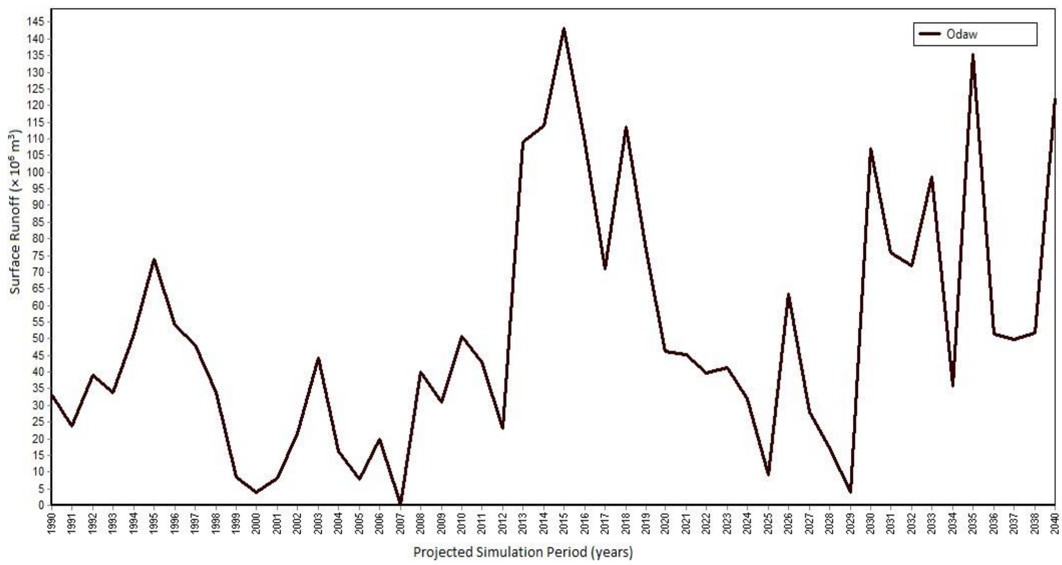


4.3.3 Odaw Basin

The scenario's prediction for the Odaw basin indicates that, there would be relatively high volumes of water that would serve as surface runoff. The model predicted that the basin would generate a maximum annual runoff of 143.31 $\times 10^6$ m^3 and a minimum surface runoff of 0.46 $\times 10^6$ m^3. The wide range of runoff estimated to be generated within the basin could be attributed to the highly urban nature of the basin (Godschalk, 2003). Urban areas generate high volumes of surface runoffs due to the large areas of the ground which are impermeable to water and hence impedes infiltration. Observing from figure 4.10, it would be noticed that, the volumes of runoffs generated annually are smaller than that of the Upper Densu Basin but greater than those of the Lower Densu Basin. This is evident that, the surface area of a basin plays a major role in the generation of runoff and its possible cause of flood.

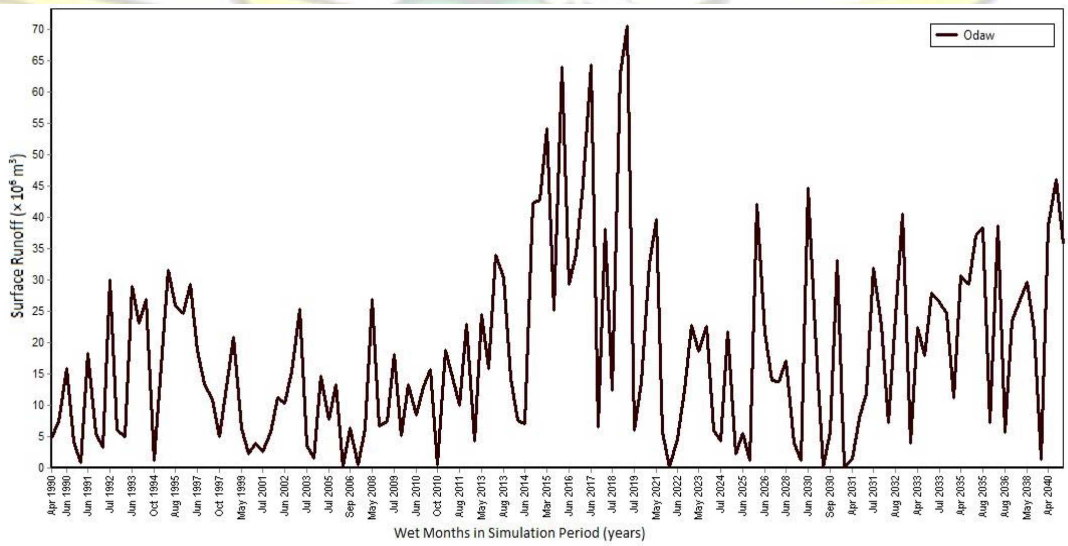
The Odaw basin was generally observed to be capable of generating high volumes of water as shown if figure 4.11. This prediction makes the basin likely to flood especially in the rainy season because it has a relatively low drainage density as shown in table 3.2.

Figure 4.10: The annual total surface runoffs simulated for Odaw Basin

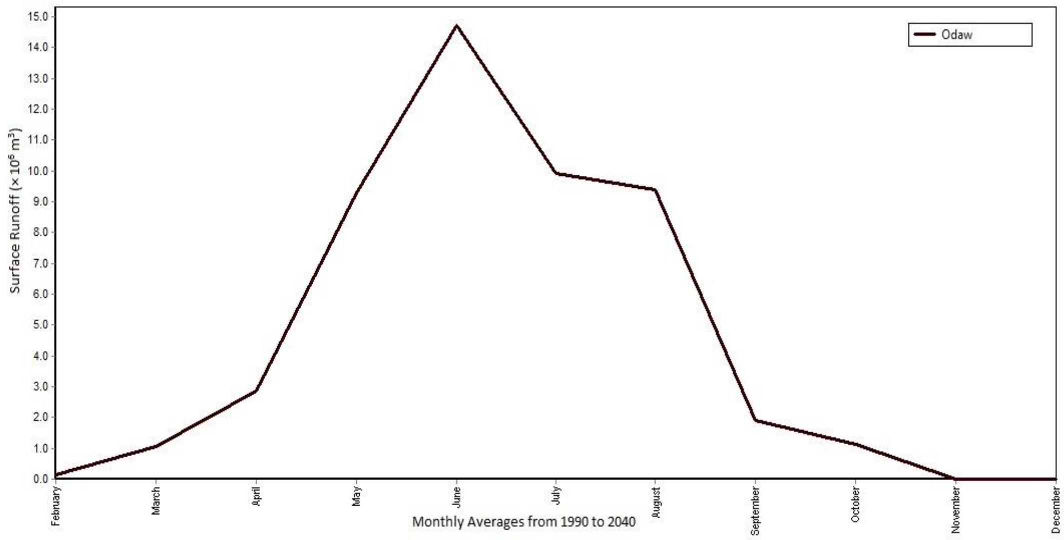


The low drainage density would decrease the flowrate of surface runoff, hence increasing the accumulation period and cause surface inundation of water.

Figure 4.11: The surface runoffs simulated for Odaw Basin



Again, the monthly estimated volumes of runoffs depicts that the month of June recorded the maximum volume of runoff generated through the period of generation while the dry months generated the minimum surface runoffs with volumes of 14.73 $\times 10^6$ m^3 and 0.01 $\times 10^6$ m^3 respectively as shown in figure 4.12. The month of June

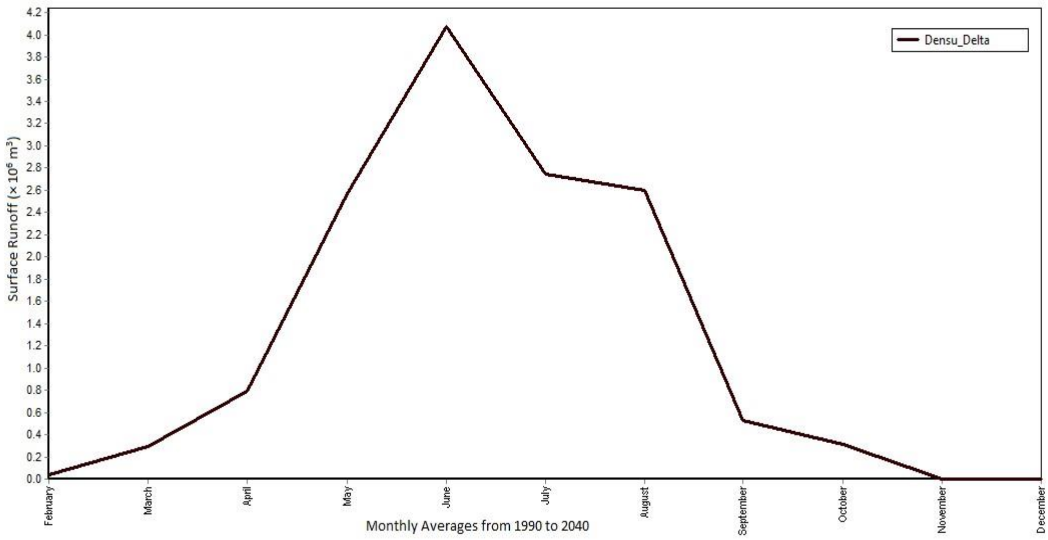


recorded high rainfall since it falls within the rainy season and the September recorded low rainfall due to its existence in the dry periods of the year. On the average, monthly surface runoffs generated were estimated to be 4.58 $\times 10^6$ m^3.

Figure 4.12: The monthly average surface runoffs for Odaw Basin

4.3.4 Densu Delta Basin

The prediction of the volumes of surface runoffs generated for the months followed the trend of the already discussed basins by estimating the maximum surface runoffs to be generated in June and the minimum in the dry months. The average monthly runoff was estimated to be 0.53 $\times 10^6$ m^3 with 0.02 $\times 10^6$ m^3 and 4.08 $\times 10^6$ m^3 being the maximum and minimum respectively. As observed and discussed for the above basins, the Densu



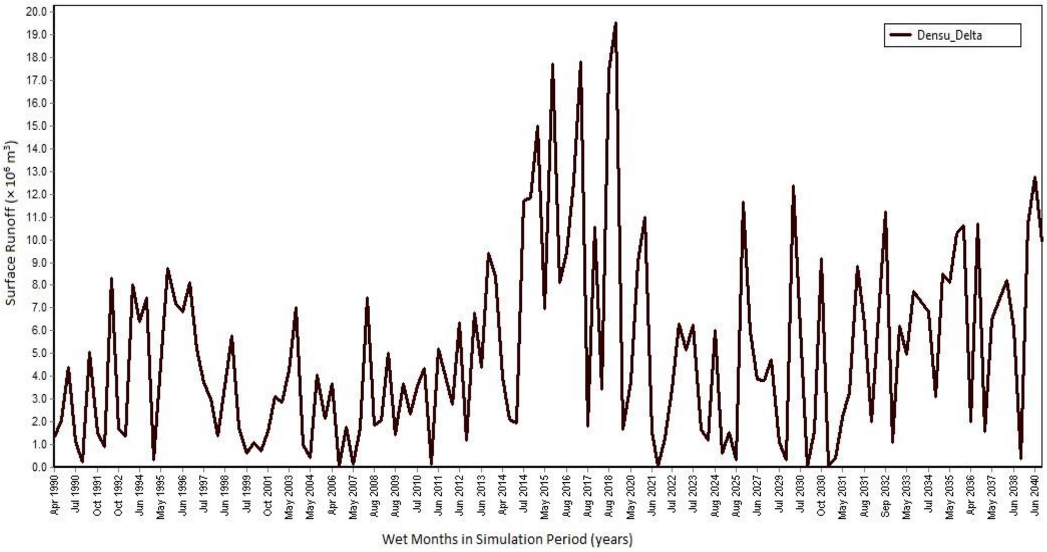
Delta basin also predicted a positive relationship between the runoff generated and the month in which it was generated. The various monthly average volumes have been summarized in the figure 4.13.

In general, the model predicted an annual average runoff of 12.11 $\times 10^6$ m^3 with the

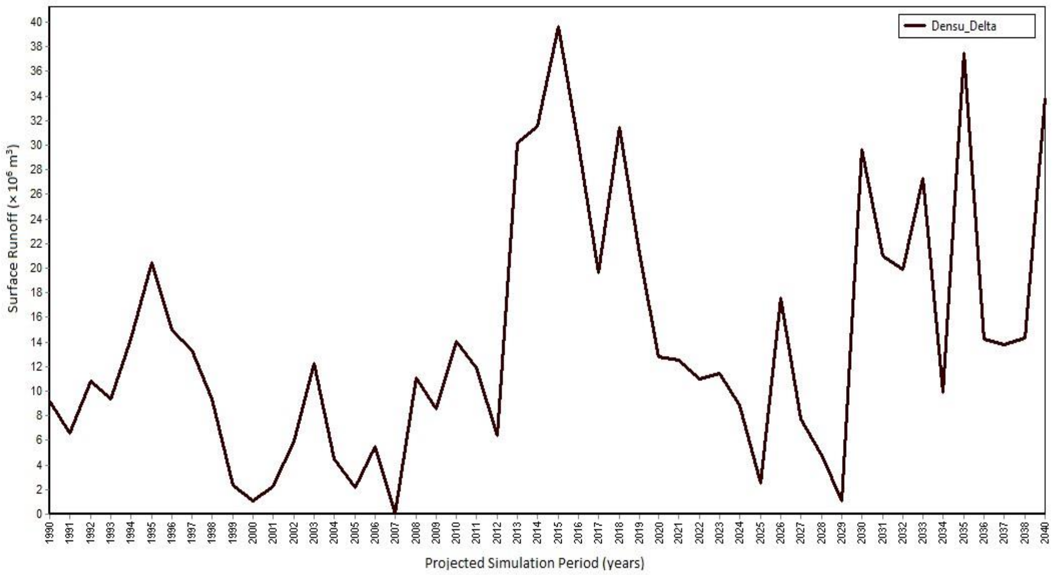
Figure 4.13: The monthly average surface runoffs for Densu Delta Basin

maximum annual volume being 39.68 $\times 10^6$ m^3 and the minimum being 0.13 $\times 10^6$ m^3. The total surface runoffs that were simulated for the Densu Delta Basin is 711.93 $\times 10^6$ m^3 throughout the period of simulation. The trend of smaller basins generating low surface runoffs has been observed in this basin too but as indicated above, there are other factors like the soil characteristics, drainage density and the likes which also contributes to the generation of runoff in a basin. Considering the drainage density and the developed nature of the Densu Delta Basin, runoff volumes shown in figure 4.14 may be problematic and have the tendency of causing floods if not controlled properly.

The annual surface runoff generated is within the range of about 0.13 $\times 10^6$ m^3 and 39.68 $\times 10^6$ m^3 for the minimum and maximum runoffs respectively as shown on figure 4.15. The differences between the maximum and minimum estimated runoff to be generated in the basin implies that, generated runoffs could be greater than the current carrying



capacities of the drains due to the low drainage density represented on table 3.2. Areas with high drainage densities have smaller chances of experiencing floods. The relatively small nature of the land enclosed within the basin, has made it susceptible to flood in



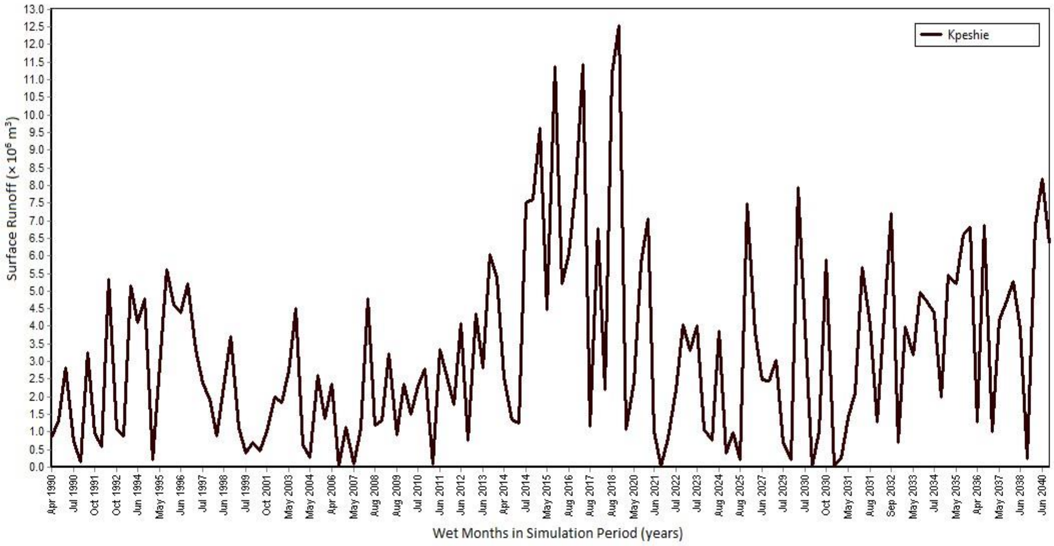
the Figure 4.14: The surface runoff simulated for Densu Delta Basin

case of increase rainfall especially during the rainy seasons.

Figure 4.15: Annual total surface runoff simulated for Densu Delta Basin

4.3.5 Kpeshie Basin

The annual surface runoff for the Kpeshie Basin is 0.08 $\times 10^6$ m^3 as the minimum and



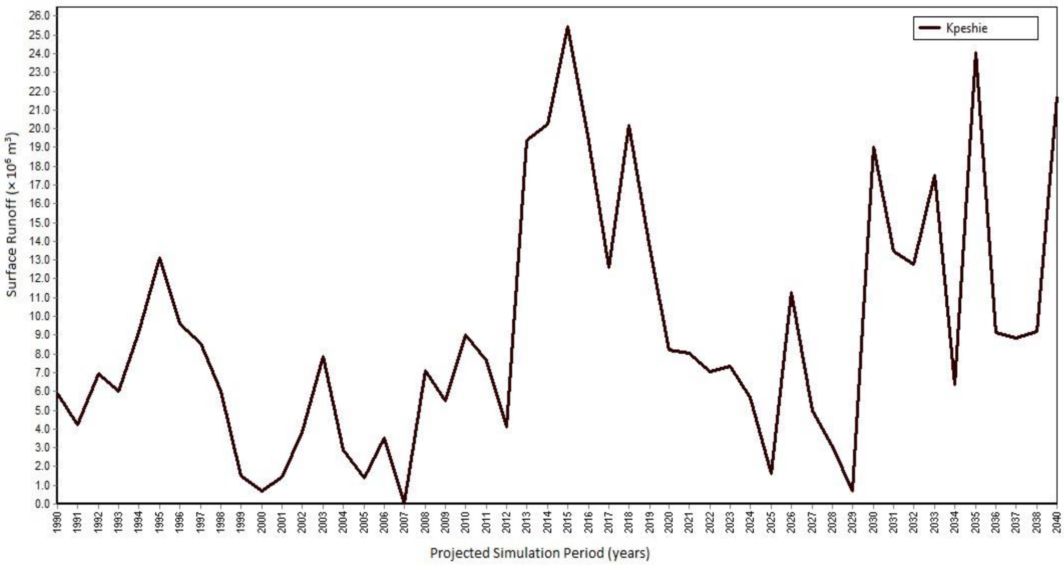
25.46 $\times 10^6$ m^3 as the maximum. It was estimated that, per the projected rainfall data scenario, there would be a generation of 7.77 $\times 10^6$ m^3 surface runoff annually, as can be inferred from figure 4.16.

Figure 4.16: Surface runoffs simulated for Kpeshie Basin

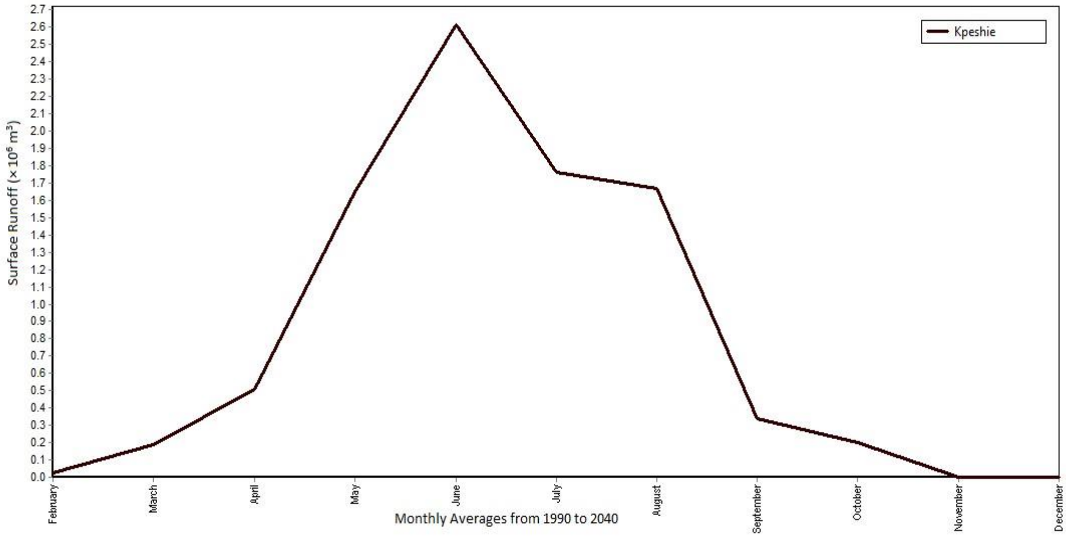
The basin is observed to be generating high volumes of surface runoffs and this could lead to flooding if the developmental progress of the basin does not include proper drainage structures to convey the volumes of water out of the basin. Deductions made from figure 4.17 suggest that if nothing is done about the increasing trend of the annual rainfall volumes, there would be a huge volume of runoff that can lead to an increase in the frequency

flooding.

It was observed that the monthly averages for the surface runoff that was estimated for the basin has the maximum value in June with runoff of 14.73 $\times 10^6$ m^3 and the minimum



runoff was estimated to be 0.27 $\times 10^6$ m^3. The basin predicted a positive relationship between the runoff generated and the month in which it was generated by estimating



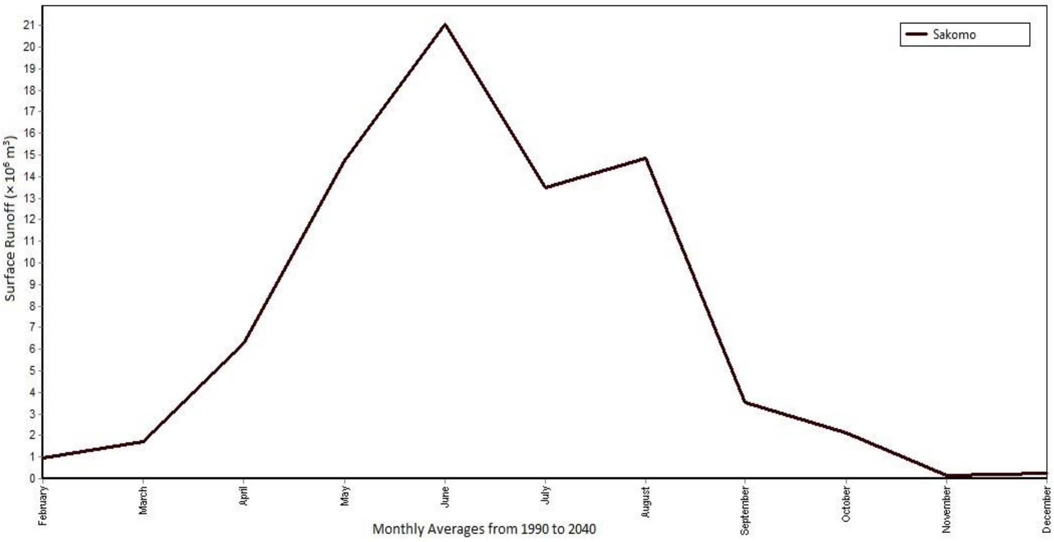
high runoffs in the wet months and low runoffs in the dry months. The various monthly average volumes have been summarized in the figure 4.18.

Figure 4.17: Annual surface runoffs simulated for Kpeshie Basin

Figure 4.18: The monthly average surface runoffs for Kpeshie Basin

4.3.6 Sakomo Basin

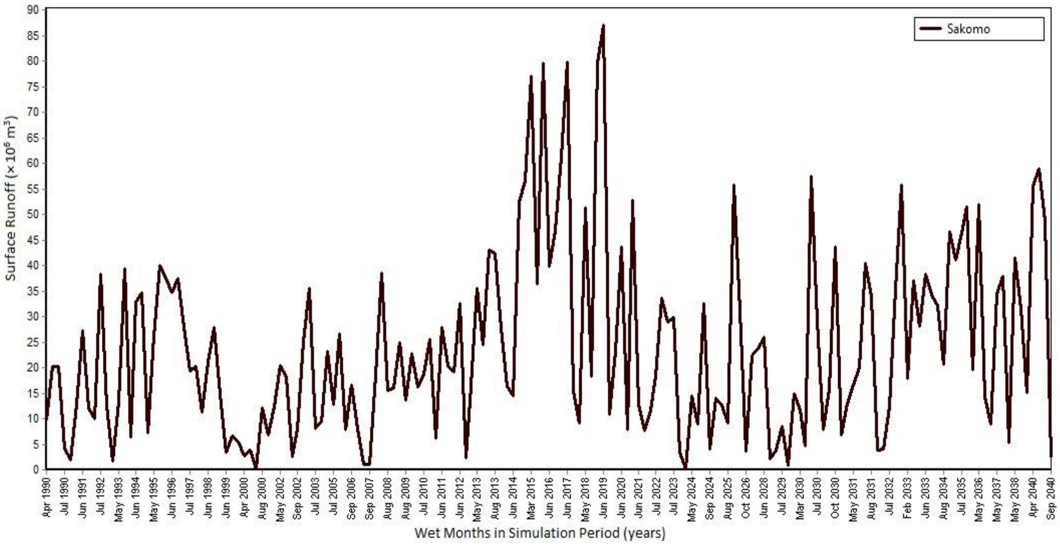
For the Sakomo Basin, the observed trend of the results for monthly averages were not very different from those observed in the already discussed basins. The highest volumes of runofs were estimated fot the wet months with June being the maximum with runoff volume of 21.08 $\times 10^6$ m^3 and November generating the least with volume of 0.13 $\times 10^6$



m^3. On the average, it was estimated that, surface runoff to be generated within a year would be 7.20 $\times 10^6$ m^3 per month as can be inferred from figure 4.19. The months with the highest volumes of rainfall were observed to generate high surface runoffs and this means that, the possibility for flood to occur in the basin is higher in the wet months as compared to that of dry months.

Figure 4.19: The monthly average surface runoffs estimated for Sakomo Basin

The total surface runoffs that were simulated for the Sakomo basin had a minimum runoff of 10.28 $\times 10^6$ m^3 and a maximum runoff of 193.22 $\times 10^6$ m^3. The area of the basin has come to play once again by estimating higher runoff volumes for the basin as, shown in figure 4.20, which is the second largest basin. It has been established above that the surface area of a basin plays important roles in the generation of runoff. Larger basins



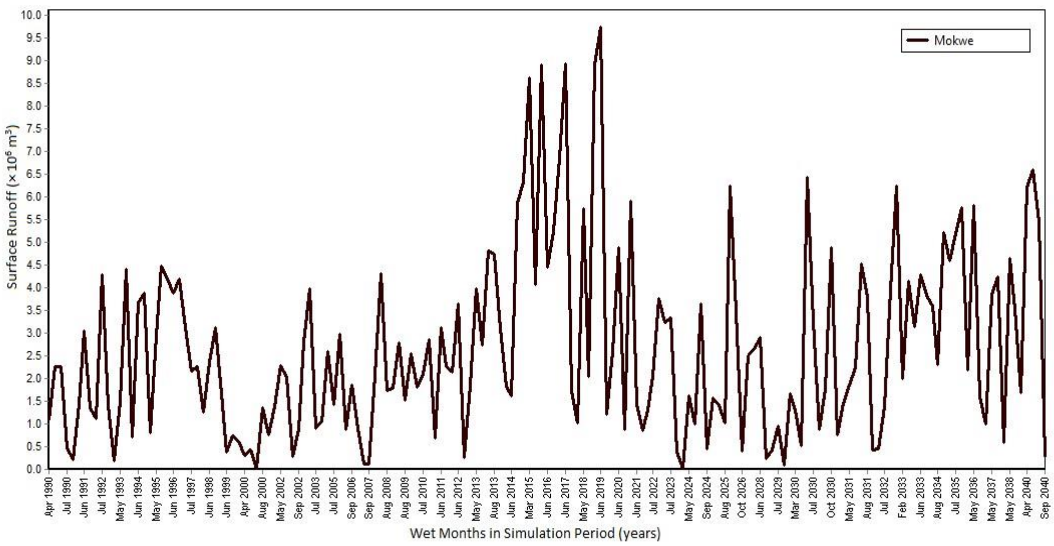
with very small drainage density is very susceptible to flooding as compared to those with a high drainage density. In relation to the Sakomo Basin, not only is it a large basin but also it is mostly urban and generates more runoff due to high impermeability of the ground to runoff water. The general trend of the estimated surface runoffs can be inferred to pose treat to the basin if the prediction is to be observed and as such, much work must be done to avert the negative eventuality.

Figure 4.20: The surface runoff simulated for Sakomo Basin

4.3.7 Mokwe Basin

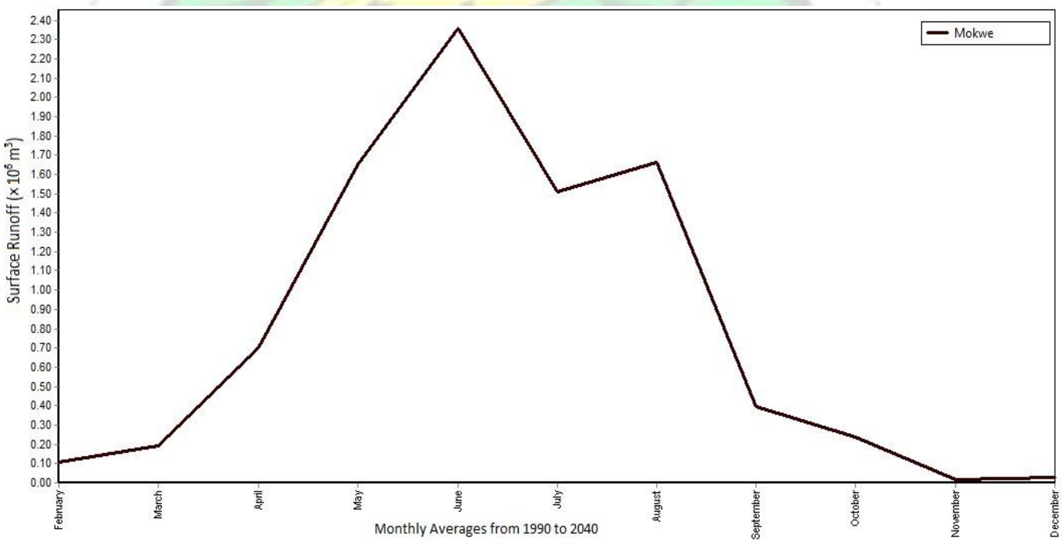
The Mokwe Basin estimated a minimum annual surface runoff to be about 1.15 ×10^6 m^3 and a maximum runoff to be 21.26 ×10^6 m^3. On the average, the basin was estimated to produce an annual average surface runoff of about 9.04 ×10^6 m^3. This is very alarming since the volumes of surface runoff generated within a basin would determine the possibility of flood occurring within the basin. These volumes are moderate as compared to the size of the basin but the other factors that control surface runoff in a basin may predict the volumes to be dangerous. The location of the basin is largely urban and as usual, there are less vegetation cover to control runoff flow rate. Figure 4.21 shows the estimated annual runoffs for the Mokwe basin.

Averagely, the monthly volumes of the surface runoff can be found to be maximum in the month of June and minimum November and the other dry months. The fact that the maximum and minimum monthly averages were obtained in a wet and dry month Figure 4.21: The surface runoff simulated for Mokwe Basin



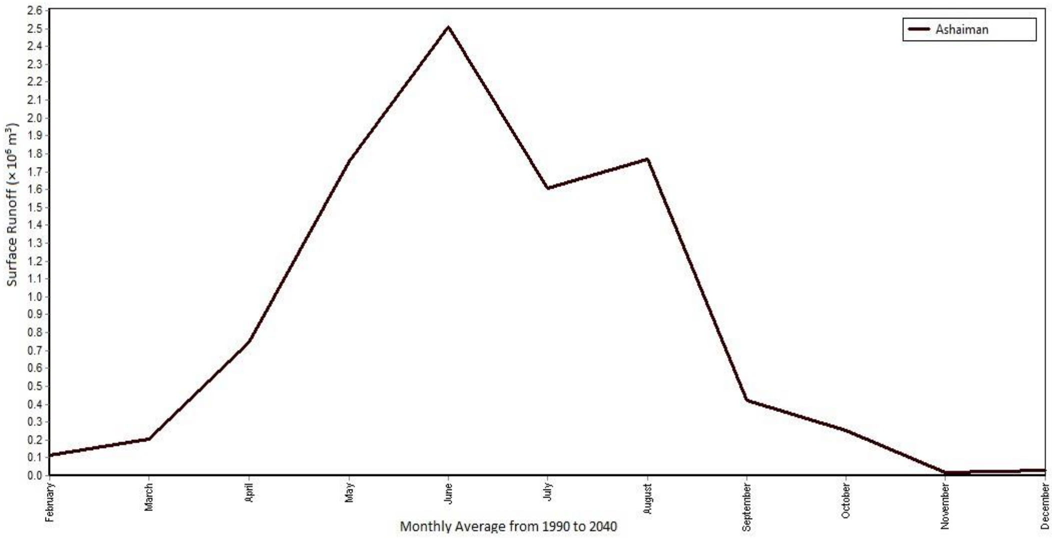
respectively proves that, rainfall is a major factor in the issue of runoff generation and flood control. The maximum and minimum volumes of generated runoffs within the basin are respectively observed to be 2.36 $\times 10^6$ m^3 and 0.01 $\times 10^6$ m^3 with monthly average of 0.81 $\times 10^6$ m^3. The average monthly runoffs estimated for the Mokwe Basin is given figure 4.22

Figure 4.22: The monthly average surface runoffs for Mokwe Basin



4.3.8 Ashaiman Basin

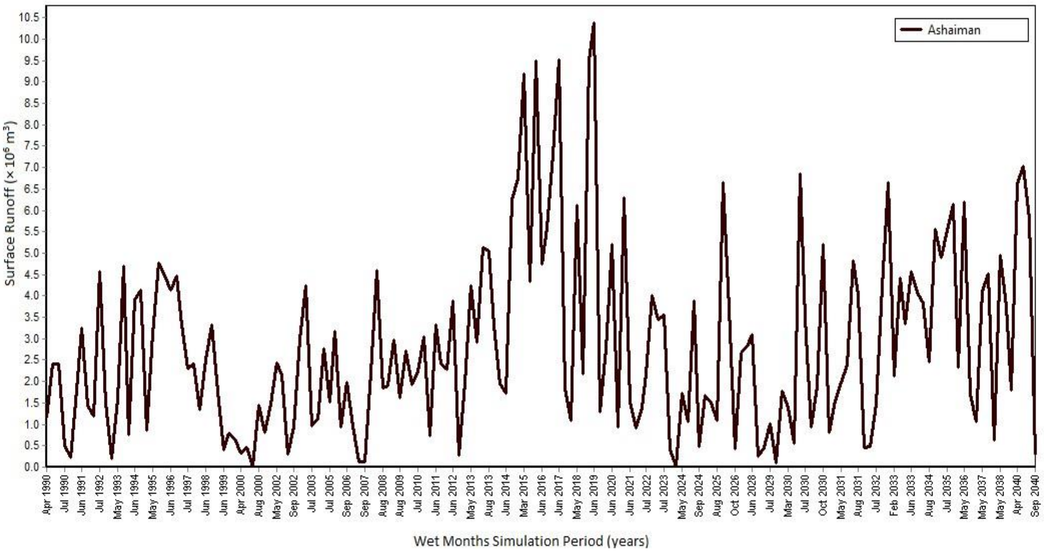
The model predicted the maximum surface runoffs for the month of June and the minimum in the dry months. The average monthly runoff was predicted to be 0.86 $\times 10^6$ m^3 with 0.02 $\times 10^6$ m^3 and 2.51 $\times 10^6$ m^3 being the maximum and minimum respectively. As observed for the other basins, the Ashaiman Basin also predicted the dry months to generate less runoffs and the wet months to generate higher runoffs as shown in the figure



4.23.

Figure 4.23: The monthly average surface runoffs for Ashaiman Basin

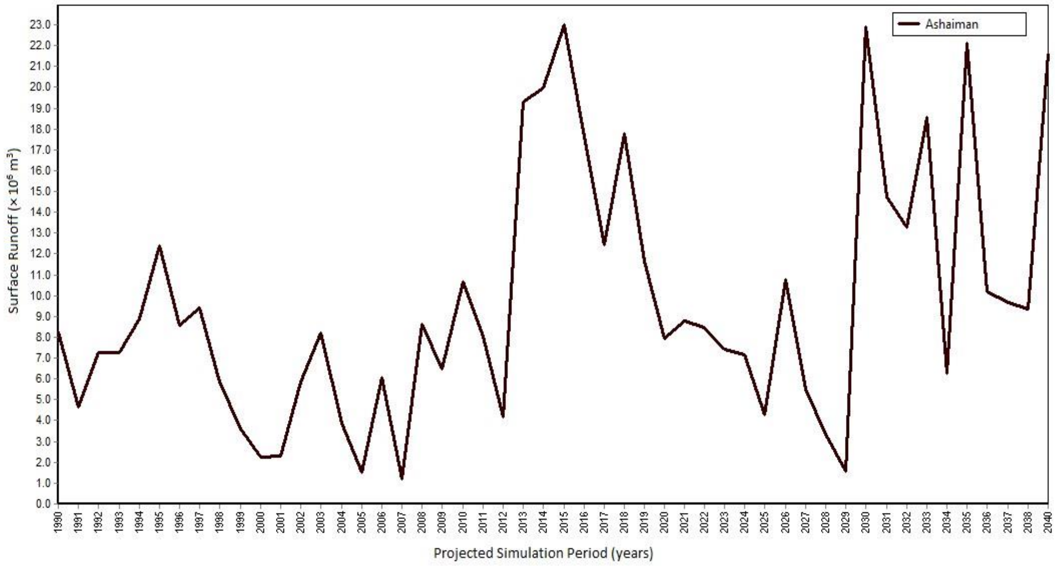
In general, the model predicted an annual average runoff of 9.62 $\times 10^6$ m^3 with the maximum annual volume being 23.02 $\times 10^6$ m^3 and the minimum being 1.22 $\times 10^6$ m^3. The total surface runoffs simulated for the basin is 481.13 $\times 10^6$ m^3 throughout the fifty year period of simulation. The trend of smaller basins generating low surface runoffs has reoccurred in this basin. There are other physiological factors which contributes to the generation of runoff in a basin aside the surface area. Considering the drainage density



and the developed nature of the Densu Delta basin, runoff volumes shown in figure 4.26 may be problematic and have the tendency of causing floods if not controlled properly.

Figure 4.24: The surface runoff simulated for Ashaiman Basin

The annual surface runoff estimated for the basin is within the range of about 1.22×10^6 m^3 and 23.02×10^6 m^3 for the minimum and maximum runoffs respectively as shown on figure 4.25. The differences between the maximum and minimum generated surface runoff in the basin implies that, runoffs could be greater than the current carrying capacities of the drains due to the low drainage density represented on table 3.2. Areas with high drainage densities have smaller chances of experiencing floods. The relatively small nature of the land enclosed within the basin, has made it susceptible to flood in the case of increase rainfall especially during the rainy seasons.



4.4 Comparison of Standardized rainfall to flood history

The rainfall from January 1990 to December 2015 was analyzed and the standardized deviations were computed. The normal range for a normal rainfall pattern as shown in table 2.2 is within -0.99 and +0.99. Rainfalls whose standard deviations fall outside the range could be a potential cause of flooding or drought in such areas. The greater the Figure 4.25: Annual total surface runoff simulated for Ashaiman Basin deviation, the higher the likelihood for floods to occur and when the anomaly is less than -1, there is a higher chance of drought occurring. The estimated Standardization Precipitation Index were compared to the flood events presented in table 2.1.

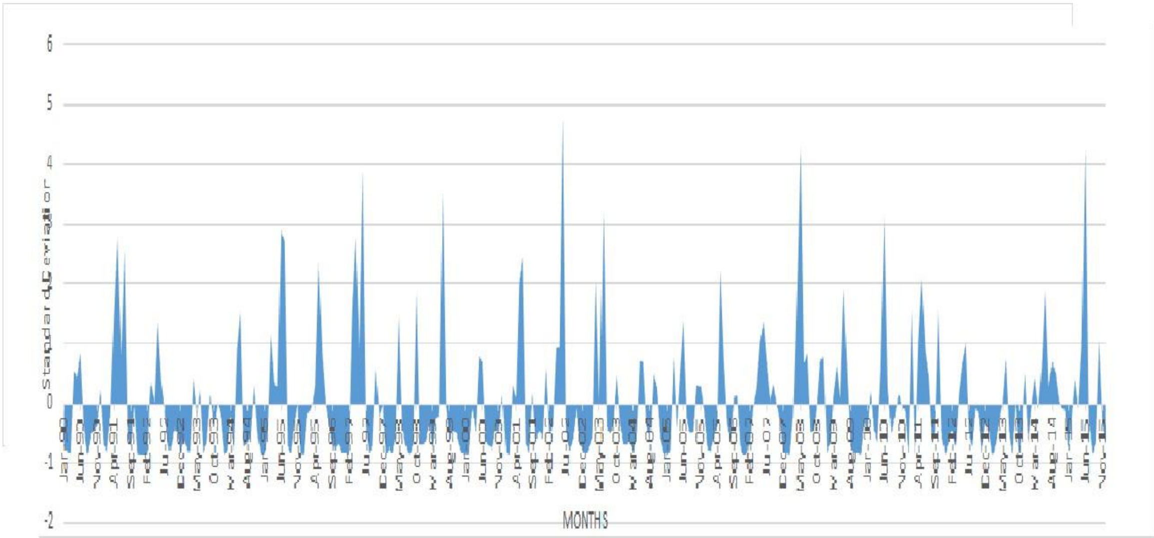


Figure 4.26: A plot of the standardized precipitation anomaly of rainfalls for Accra

For the purpose of this scenario, the following assumptions were made;

1. Rain events leading to floods were assumed to start and end on the same day.
2. Two rain events recorded on the same day were computed as one.
3. Gauge station records were considered for the entire basin. errors in rainfall gaugeequipments were not considered.

From figure 4.26, points that lie high above the +1 value implies that there were high rainfall within the month under consideration. On normal terms, there should be the occurrence of flood if the deviation is greater than 1 standard deviation above normal but this may not be actually accurate due to the fact that there are other factors that contributes to flooding. Higher rainfall values would imply higher deviation but not necessarily a month in which flood may occur.

The history of flood events in Accra and its environs were obtained from various institutions and also from journals. The history of flooding was compared to the standardized anomaly of the rainfall data and the possible outliers were verified to know if there was any flood events.

In July, 1991, rainfall of 157.2 mm was able to caused floods in Accra on the 14th, a standardized anomaly of about 1.6 standard deviation above normal was obtained. The high and positive value of deviation shows that the rainfall for the day was high and could be the possible cause of the flood. Preceding this day, there was a rainfall activity which recorded rain of about just 2 mm and this implies that the rain of that very day in which flood was observed may be the cause of the flood. The rainfall recorded a standardized anomaly of 2.6 which represent extreme wet event based on table 2.2.

Also, in July 4 1995,there was a flood event that affected a lot of business activities within Accra and its sub towns. A total rainfall of 243 mm was recorded with a standardized deviation of 2.7. The normal range for rainfall is within -1 to +1, hence, with a standardized anomaly of 1.7. This implies that the rainfall for the day in July is 1.7 standard deviations above normal. The greater value implies that there was lot of rainfall and it could be a possible reason for the occurrence of flood within the sub-basins.

On the 28 day of April and the 12 day of June in 1997, there were floods in Accra and they claimed a lot of lives as well as properties. Rainfalls recorded on these days were 124.1 mm and 113.7 mm respectively. These rainfall events were found to have SPI of 2.4 and 2.3 respectively which implies that they were about 1.4 and 1.3 standardized anomalies above the normal and were extremely wet periods. The flood observed in June was preceded by a rainfall activity of about 38.7 mm and this could also be a major contribution to the occurrence of flood since not all the water may have been able to drain from the basins.

The volume of rainfall is a great contributor to the possibility of flooding to be observed in an area. On 27 June 2001, the rainfall recorded was 81.1 mm and yet there was flash floods in Accra. The incident was a little surprising but judging from the rainfall recorded for the preceding day, thus rainfall of 27.3 mm, the flood event could be attributed to the collective actions of these rainfall events. Calculating the standardized anomaly, it was realized that the rainfall was about 1.2 standardized deviations above normal. The actual value of anomaly that was obtained is 2.2, which shows a major shift in the standard deviation value for normal rainfall events.

The rainfall recorded for June 9, 2002 is 123.3 mm. Analysis of the deviation data revealed a 1.4 standardized deviations above normal. This is in correlation with the flood event that were experienced and it is evident from the damages that were caused. The rainfall showed a standardized anomaly of about 2.4. It can be observed that, the greater the volume of rainfall, the higher the anomaly and the more possible it is for flood to happen. Rainfalls preceding flood events may also contribute to the intensity of flooding that may occur but in this case, no rainfall was recorded for the preceding day and therefore the flood event may be attributed solely to the day’s rainfall.

Rainfall of 89.2 mm which was recorded for Accra on June 10, 2003 was observed to have caused floods and as a results created a lot of menace. The flood event followed a rainfall activitity that produced rain of about 1.6 mm on the preceding day. The volume of rain was found to have a standardized anomaly of 1.2 above normal with actual standard deviation of 2.2. The flood event lasted for a long time and as such, halted a lot of productive activities within the basins.

The smallest volume of rainfall to have caused floods within the basins that were considered was recorded on the 26 day of March, 2007. With rainfall volume of 59.2 mm without any rain on the previous day, a standardized anomaly of 1.5 was obtained, which is 0.5 standardized anomalies above normal. This flood event redefined a lot of conceptions about the volumes of rainfall that could cause flooding in the sub-basins. It was therefore realized that, rainfalls with standardized anomalies above the normal have the potentials to cause flooding.

On May 18, 2008, Accra recorded a rainfall of 151 mm and this led to flooding of many communities. The rainfall resulted in a standardized anomaly of about 2.6 which is 1.6 standardized anomalies above normal. The rainfall was not preceded by any rains since records show that, there was no rainfall activities on the 17th of May. In view of this, the flood events that were observed may be attributed solely to the rainfall that occured on the 18th of May, 2008.

A rainfall of 97.7 mm was recorded on October 25, 2011 as well as flood event that resulted in a lot of damages and took lots of lives. The rainfall recorded a standardized anomaly of about 0.6 above normal which depicts that there were a lot of rain which could be attributed to the flood event that was observed. A day before the flood event, rainfall of 58.3 mm was recorded and have also been attributed to be a contributor to the flood event.

On June 5, 2014, a rainfall of 80.3 mm resulted in a standardized anomaly of 0.9 standard deviations above normal. The standardized anomaly value obtained for the rainfall event is 1.9. The rainfall did not produce any huge anomalies but was able to cause flooding in some parts of Accra as it was observed. This is to prove that not only does rainfall cause flooding also, other natural and artificial factors like landcover, sea level rise and others.

In June 3, 2015, a flood event occurred and caused a lot of havoc to the nation. The rainfall value recorded for the day is 212.8 mm. This rainfall value showed a standard deviation value of 2.7. The anomaly obtained for the standard deviation was estimated to be 1.7 above normal. The high variation in the anomaly describes to large extent on the intensity of floods which occurred throughout the month. Rainfall of 12.5 mm was recorded on the day before the flood and it really contributed to the floods since not all the water was able to drain from the basins.

Chapter 5

Summary, Conclusions and

Recommendations

5.1 Summary

The WEAP hydrological tool was used to develop a hydrological model for some selected water basins in the Greater Accra region of Ghana. The basins were selected based on their spatial proximity to the nation's capital and the activities that are observed within the basins. The basins were created using the ArcGIS 10.3 tool and named as; Upper Densu, Lower Densu, Densu Delta, Odaw, Kpeshie, Sakomo. Mokwe and Ashaiman based on the major streams and towns that exist within that basin.

The study was basically geared towards generating hydrological model for the selected water basins in other to help in the assessment of flood situations. It further sought to compare floods that have been observed over the period between 1990 and 2015 to standardized rainfall data that were recorded during the flood events in other to know the impacts of rainfall in the occurrence of floods within the sub-basins. The surface runoffs generated within each of the individual sub-basins were also determined.

The research began with the desk study and planning in order to know the data needed for the work. Hydro meteorological data were obtained from the Ghana Meteorology Agency (GMA), Stream flow and other data relating to the basins were obtained from the

Hydrological Service Department (HSD) and Geological Service Department (GSD) of Ghana. Further data were acquired from some cited literature and the USGS platform on

the Internet.

The basic thematic maps like the Digital Elevation Model, TIN, watersheds and geological maps were created using the ArcGIS 10.3 tool. The WEAP hydrological model was set up as shown in figure 3.4 and the input parameters fed into the model. The time step was taken to be on the monthly basis and scenarios were created. The standardization of the rainfall data was done and compared to flood history in Accra to know the volume of monthly rainfall that led to flooding.

5.2 Conclusions

The minimum rainfall activity that have been recorded to have caused flood across the basin is about 60 mm. From this observation, it could be inferred that rainfall above this value have the tendency to cause floods in each of the eight sub-basins (Okyere et al., 2013). The standardization of the rainfall showed that, any rainfall volume that gave a standardized anomaly of 0.5 above normal or more is capable of causing flooding in the basin in which it occurred.

From the research, it was realized that, months that fall within the major raining seasons of the area generated high surface runoffs monthly and annually within the range of 4 $\times 10^6$ m^3 to 50 $\times 10^6$ m^3 for monthly basis and 25.5 $\times 10^6$ m^3 to 385 $\times 10^6$ m^3 on annual basis. The month of June was found to produce the highest volumes of surface runoff with December generating the least, and with average runoffs of 2.4 $\times 10^6$ m^3 and 1.0 $\times 10^6$ m^3

respectively.

5.3 Recommendation

5.3.1 Further studies

1. Further studies should be conducted on the basins by considering the soil factorsthat may be contributing to flooding.
2. Land cover changes must be considered in in further studies to know its impacts onthe basins.

5.3.2 Policy making

1. Weather forecasters must warn people of expected rainfall that would exceed thenormal standard anomaly value since it has the ability to cause flooding.
2. Areas that are yet to be developed must take the drainage system into considerationin the planning and land allocation process to prevent and reduce the risk of the area being flood prone.
3. Laws must be enacted to control the encroachment of wetlands.
4. Relocation or demolishing of structures that impede the flow of water especially inthe paths of drains.

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