CLIMATE CHANGE AND ITS IMPACTS ON FLOODING IN ACCRA-GREATER ACCRA METROPOLITAN ASSEMBLY

BY

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SEPTEMBER 2013

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BSc. Physics (Hons.)

A Thesis submitted to the School of Graduate studies, Kwame Nkrumah University of Science and Technology in Partial fulfillment of the requirement for the degree of

MASTER OF SCIENCE
in
Water Resources Engineering and Management

Department of Civil Engineering
College of Engineering

September 2013

Certification

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

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DEDICATION

To my parents and siblings

ABSTRACT

Climate change resulting in high precipitation is of utmost importance as it yields floods of varied amounts. Such floods result in loss of lives and properties worth billions of Ghana Cedis (BGH₵). Accra, the capital city of Ghana, has experienced various levels of floods with the July 1995 incidence recorded as the highest floods over the basin. This research work seeks to investigate the impacts of floods over Accra basin as the future experiences changes in the climate system. Aptitude to predict future precipitations depends on established climate scenarios. Landuse characteristics and atmospheric parameters define the changes in the hydrologic cycle hence the resultant precipitations. This affects the variations in the precipitation pattern as the years proceed. Known precipitation values are used to develop flood vulnerability maps and their impacts due to changes in the precipitations assessed under each of the scenarios in an ARCGIS model for this work. Six main scenarios are developed based on the landuse characteristics of the basin. These are HISTORICAL_1995, SDAN_2020, SDOK_2040, SDIK_2060, SDIOL_2080 and SDIOK_2100 yielding precipitation values of 249.30mm, 234.09mm, 149.58mm, 24.93mm, 124.65mm and 398.88mm respectively. These precipitation values are integrated into the HYDROCAD software to generate runoff depths or flood levels, flood volumes and hydrographs for each of the sub basins within GAMA. Vulnerability assessment depends on known precipitation data; hence the historical_1995 precipitation used to develop the flood vulnerability map of Accra as the reference point for impact assessment. Climate change impacts on floods are then assessed based on the obtained precipitation values under each of the generated scenarios. Therefore, the developed climate scenarios helped to forecast precipitation values over the GAMA basin and assess their future impacts on floods. This will serve as an urban planning tool for the Government of Ghana (GoG) and other flood disaster management agencies.

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List of Abbreviations

BBC	British Broadcasting Cooperation
BGH₵	Billion Ghana Cedis
CN	Curve Number
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
GAMA	Greater Accra Metropolitan Assembly
GCM	General Circulation Models
GIS	Geographical Information System
GoG	Government of Ghana
GPS	Global Positioning System
GSD	Geological Survey Department
HSD	Hydrological Service Department
HSG	Hydrological Soil Group
IPCC	Intergovernmental Panel on Climate Change
MLG	Ministry of Local Government
MLGRD	Ministry of Local Government and Rural Development
MSD	Meteorological Service Department
MRH	Ministry of Roads and Highways
MWRWH	Ministry of Water Resources, Works and Housing
NADMO	National Disaster Management Organization
NRCS	National Resources Conservation Services
RCM	Regional Circulation Model
RCSNDIPOA	Regional Circulation Single Distribution Precipitation over Accra
UNFCCC	United Nation Framework Convention of Climate Change
WRC	Water Resources Commission

Acknowledgment

I thank the Almighty God for granting me the wisdom, strength and ability to complete this thesis successfully.

I would like to extend my profound gratitude to my supervisor Prof. S. N. Odai for his time and contribution to this project in seeing it through to a successful end. I am grateful to Dr. G. K. Anornu, Dr. Kwaku Adjei and Mr. Frank Ohene Annor for their insightful contributions and encouragement.

A special appreciation to Prof. S. N. Odai for sponsoring this research work through the award he received as the National Best Research Scientist in Water, Sanitation and Environment from Vodafone Ghana in 2011.

My special acknowledgement geos to Dr. Antwi Bosiakor of Soil Research Institute, Mr. Wise Ametefeh of Hydrological Services Department and Mr. George Owusu of CERSGIS-Legon who helped in diverse ways especially in the areas of data collection, real time field observations, explanations and sharing of ideas throughout the research period.

I extend my deepest appreciation and heartfelt gratitude to my parents and siblings who shared their precious times and counseled me during the difficult times.

Finally my special thanks goes to all those whom I have encountered for one help or another towards the completion of this thesis work, I am grateful.

CHAPTER ONE

1 INTRODUCTION

1.1 Background

The Intergovernmental Panel on Climate Change (IPCC), Fourth Assessment Report, in its summary projections of climate change impacts for Africa, deemed the continent one of the most vulnerable in the world (IPCC, 2005). Poor urban planning in southern cities are experiencing the negative impacts of changing weather patterns associated with climate change and climate variability with future projections suggesting that these impacts will get worse. Simulation models have been utilized as powerful tools either for generating stream flow or determining how runoffs respond to changes in climate due to landuse, landscape and soil-water saturation.

Considering all natural hazards, floods are by far the most hazardous, frequent and widespread throughout the world (Dhar and Nandargi, 2001). This makes flooding an important subject to study particularly in a third world country city like Accra. Flooding is a hydrological phenomenon characterized by both precipitation and soil-water contribution. Precipitation and temperature are the key climatic response factors influencing flood events in Accra. Flood management using storage structures have become the best alternative to society and a city like Accra is no exception. With technological development, flood modeling is now seen as an integral part of flood management.

Lack of appropriate and continuous research into floods management in Accra results in the dreadful events. 2012 has been an exception and we ask why? Has flooding in Accra come to an end? Flooding is the most common environmental hazard worldwide, after disease and transport accidents. Afeku (2005) attributed it to the widespread geographical distribution of river flood plains and low-lying coastal areas and their long-standing attractions for human settlement. Health concerns like cold symptoms, fevers, vomiting, catarrh and various water borne diseases resulted from the floods in Alajo (Afeku, 2005). The most severe flood experienced in recent history in Accra is the July 1995, 249.3mm precipitation over the region. This caused considerable floods in the Sakumo basin which submerged the Tema treatment plant and flooded different areas within GAMA.

The future trend in the climate system leading to extreme hydrological events gives no cause for comfort. As a result of the greenhouse effect which is being heightened by anthropogenic factors, it is expected that in future the meteorological conditions that favor extreme hydrological events (floods) in Accra will occur more frequently (Bismuth et al., 2004). Ground based study, calibration and verification results show that climate change resulting in heavy precipitation play a vital role in floods generation in the catchment. This study investigates flooding solely caused by precipitation due to changes in the climate system likely to be experienced in the future.

Between 1955 and 1997, properties worth billions of Ghana cedis (BGH₵) have been destroyed; over 100 lives lost during or after flood periods and 10,000 people displaced from their homes leading to monetary losses due to government intervention through financial support to the affected people (Gyau-Boakye, 1997; Adinku, 1994). In June 2001, five hours of rain caused flash floods that killed 6 people and drove tens of thousands from their homes in Accra (Neighborhood plans for Alajo, 2003). 148.4mm magnitude rainfall record in July 2002 due to four hours heavy down pour displaced 2000 people in Accra and some communities in Accra (Hydrological Services Department, 2002).

Chan (1997) attributed floods in Accra to improper land use practices that lead to drain siltation, building on or across water ways, eroding of soils as a result of construction works and decrease in drain capacity. IPCC set up a committee to draft a Framework Convention of Climate Change upon recognizing how the global climate is being affected. Article 4.1 and 4.8 of the UN Framework Convention of Climate Change (UNFCCC), indicate that all parties have the requirement to assess their national vulnerability to climate change and to submit national communications.

Vulnerability assessments are informed by estimating climate change impacts which is often based on scenarios of past climate information. Projections of climate change undertaken by Global Circulation Models (GCM) generate such scenarios. GCM's are adequate to a few hundreds of kilometers but in order to obtain detailed global projections, the Regional Climate Model (RCM) is used (Jones et al., 2000). The use of high resolution atmospheric global models and statistical techniques linking climate information at GCM resolution with that at higher resolution or at point locations are some of the techniques used for scenario generation.

It is very important to note that RCMs do not replace GCMs, but it is a powerful tool used together with the GCMs in order to add fine-scale details to their broad-scale projections. Historical climate scenario is the most appropriate tool for vulnerability assessment whiles future scenarios generation are effective for flood predictions and management.

1.2 Problem Statement

Human lives and properties worth several cedis are lost each year due to floods. Governments employ the services of agencies such as NADMO, fire service, the military, private agencies etc. to save lives and properties. During such periods, Accra the study area almost comes to a halt affecting various sectors of the economy. To identify incidence of floods and appropriate mitigation measures, data are of paramount importance. The MSD lacks such quality data and where existing there are discrepancies for change impact studies.

As a result it is difficult to obtain information on previous floods therefore making flood investigation a useful research area to work. When flooding occurs the economic losses in terms of time and resources in saving lives and properties is huge. The question one will ask is “do people know the causes of flooding, its impacts and how they are mitigated?” Most people know but continue to live in flood prone areas. Afeku (2005) researched into urbanization and flooding in Accra and attributed it to absence of drainage and sanitation services.

Identified preventive measures have not helped curtail the problem of floods as people, reserves and wildlife’s are inundated each year in Accra; the year 2012 being an exceptional one. Accra will continue to experience changes in the climate as landuse is on the rise hence floods; until appropriate mitigation measures are identified and implemented. Appropriate models become the best option to assess potential changes in the climate in order to predict future floods likely to occur in GAMA. Future climate scenarios generation coupled with suitable models is an appropriate tool for flood management within a city like Accra-GAMA. With suitable models, floods likely to occur as a result of climate changes in the future i.e. (next 20 years, 40 years, 60 years, 80 years and 100 years) can be predicted for likely impacts.

1.3 Justification

This research work on the potential impacts of climate changes on flooding in Accra is to serve as an urban planning tool for development by the various agencies working on flood management within the city. With the appropriate climate change scenarios, floods have been modeled for future years in order to know their impacts on various sectors and areas in Accra so that appropriate mitigation measures can be established. Flood vulnerability maps and flood prone findings is to oblige sectors like the Meteorological Service Department, NADMO, donor agencies and other private sectors in Accra to meet flood contingencies.

Future precipitations obtained from the developed future climate scenarios are used to estimate flood volumes, flood levels or runoff depths and discharges from the various sub basins within Accra. Generated flood vulnerability maps and flood prone maps is to help decision making bodies such as the Government of Ghana (GoG) and other interested bodies.

The flood impacts assessed based on the generated scenarios will activate decision making minds and institutions interested in floods for further research works. Findings will aid drainage engineers in their future designs of drainage systems for Accra. Flood prediction for control using appropriate scenarios is therefore a great tool for flood management in a city like Accra. It will be used as a planning tool for private estate developers who are continually erecting concrete structures in areas that experience periodic floods.

1.4 Objectives of Study

The main objective of this research work is to assess the potential impact of climate change on flooding in Accra, Ghana.

1.4.1 Specific Objectives

In order to accomplish the main objective, the following specific objectives were met;

- Develop future climate scenarios.
- Estimate flood volumes and flood levels from the climate scenarios data.

- Generate flood vulnerability area map.
- Assess climate change impacts on flooding in Accra.

1.5 Challenges

Data acquisition from government agencies is a big problem when it comes to dealing with critical issues like floods. Data acquired for this research work is solely from the private agencies as some are not ready to give out such data.

Scenarios generation using landuse characteristics is about 95% accurate with the remaining 5% being accounted by other atmospheric paramters. Scenarios can be generated by using general circulation model (GCM's) but do not give fine details data for research hence the use of regional circulation model (RCM). Research use satellite based data but this does not give ground based real time data as some of these data are lumped.

CHAPTER TWO

2 Literature Review

This chapter reviews literature on climate changes, how their variations lead to precipitations and to floods. Floods across the world, Africa, Ghana and its impacts are also discussed in this section. Prediction of changes in climate for impacts assessment requires climate scenarios generation using appropriate models and this is dealt with in this chapter. The section again looks at runoffs generation and discharge computations for flood investigations.

2.1 Climate Change

The IPCC Third Assessment Report (TAR) identified aerosols as potentially significant contributors to climate change with radiative forcing of the same magnitude as methane, nitrous oxide or halocarbons (IPCC, 2005). Climate change is a great worldwide menace causing hazards (droughts or floods) each year. The biggest challenge about climate change is that there is no one single answer, no one single solution (Lee, 2009). Climate change simply refers to increase or decrease in the average precipitation caused by landuse changes and the anthropogenic increase in the concentrations of greenhouse gases, particularly carbon dioxide (CO_2) in the earth's atmosphere.

2.1.1 Climate Change and Climate variability

The Intergovernmental Panel on Climate Change (IPCC) has concluded that warming of the climate system is indisputable, evident from observed increase in global average air temperature, ocean temperatures and other observations. There is no doubt this climate change is going to have an impact on the hydrological cycle which is sensitive to wind and temperature. Ghana and Accra has registered a strange climate variability this year as precipitation pattern has changed drastically. Proper understanding of basic aspects of climate change and how it impacts extreme events reflected in the hydrological cycle is important. African's climate scientists face a further challenge in that the role of land cover changes in this continent-some natural and some human related is modifying the regional climates (Xue, 1998).

2.1.2 Climate Changes in Ghana

Climate change in Ghana has become a peril to livelihoods and nature. Droughts and extensive flooding in Accra is a yearly worry to the people and the government. Residents of flood plains and flood prone areas are constantly rendered homeless and ousted during such periods. The impacts of climate change in the southern part of Ghana, especially Accra results in droughts in the dry season, severe floods in the rainy season, high temperatures, influx of pest and diseases taking away human lives and properties worth several billions of Ghana cedis (GH₵).

The enormous loss of farm produce due to climate changes is predicted to lead to famine if adaptive measures are not put in place. This is experienced in the northern part of Ghana where drought is the problem of the day. Afeku (2005) mentioned that the government of Ghana contracts engineers to come out with ways to solve the problems of floods in Accra. The government is also in consultation with Burkina Faso to solve the flooding problem in the north collectively. This has not resulted in any useful outcome as the country especially Accra continues to be flooded each year. The year 2012, did not record a drastic change in the climate system leading to changes in the precipitation pattern hence no devastating flood recorded.

2.1.2.1 Effects of Climate Changes on water resources

From urban and agricultural water supplies to flood management and aquatic ecosystem protection, global warming is affecting all aspects of water resources management. Climate changes affect most of the water bodies within the Greater Accra Metropolitan Assembly. Lagoons, streams and rivers within the basin increase in volume whenever there is torrential precipitation. Some of the lagoons within GAMA include the Sakumo west lagoon, Chemu west lagoon, the Korle lagoon, Kpeshie lagoon, Songo lagoon, Mokwe lagoon and Gao lagoon. These lagoons increase or decrease in volume in proportion to changes in the climate system. Rising temperatures, frequent flood events and rising sea levels are some of the impacts of climate change having broad implications for the management of water resources (Kankam-Yeboah et al., 2000). Reducing the emissions that causes climate change and its impacts is a critical step needed to be commenced. Water resources managers and decision makers must act now to adapt to the effects of the warning that has already occurred and develop appropriate steps to avoid future occurrences (Monty, 2010). Studies and predictions by experts on Accra basin reveal that global warming will increase the frequency and intensity of floods or drought events on water resources. Changes in precipitation pattern and temperature associated with global warming have exacerbated water quality complications on most of the water bodies within the study area. The 2012 warming climate will nevertheless place additional stresses on water resources, whether or not future precipitation is significantly altered.

2.1.3 Climate Change Scenarios in Africa

Published works on future climate change scenarios for Africa have been relatively few. Tyson (1991) published on the first scenario analysis specifically on the African Region. Conway et al., (1996) studied the impact of climate change on the Nile Basin. Zinyowera et al. (1998) in the IPCC assessment of regional impacts of climate change (IPCC, 1998) reported on some GCM studies that relate to the African continent.

2.2 Climate Scenarios

Climate scenario depicts future climate that has been constructed for explicit use in investigating the potential impacts of anthropogenic climate change. Climate scenarios make use of climate projection description of the modeled response of the climate system to changes in landuse and atmospheric characteristics. It is difficult to generate scenarios of complex events, such as tropical cyclones and ice storms which may require specialized techniques.

Scenarios are neither predictions nor forecasts of future conditions. Rather they describe alternative plausible futures that conform to sets of circumstances or constraints within which they occur (Hammond, 1996). The true purpose of scenarios is to illuminate uncertainty as they help to determine the possible ramifications of an issue (here climate change) along one or more plausible paths (Fisher, 1996).

2.2.1 Climate scenario construction for impact assessment

Scenarios for future climate changes are required when individual countries are assessing climate change impacts. To assess flood impacts in Accra, precipitation data is of great importance. The basis for all climate scenarios for use in adaptation assessments is by projecting climate change from Global Climate Models (GCMs) or Regional Circulation Models (RCM's). The generalized stages needed to provide climate change scenarios for climate change impact assessment is presented in **Figure 2-1** below;

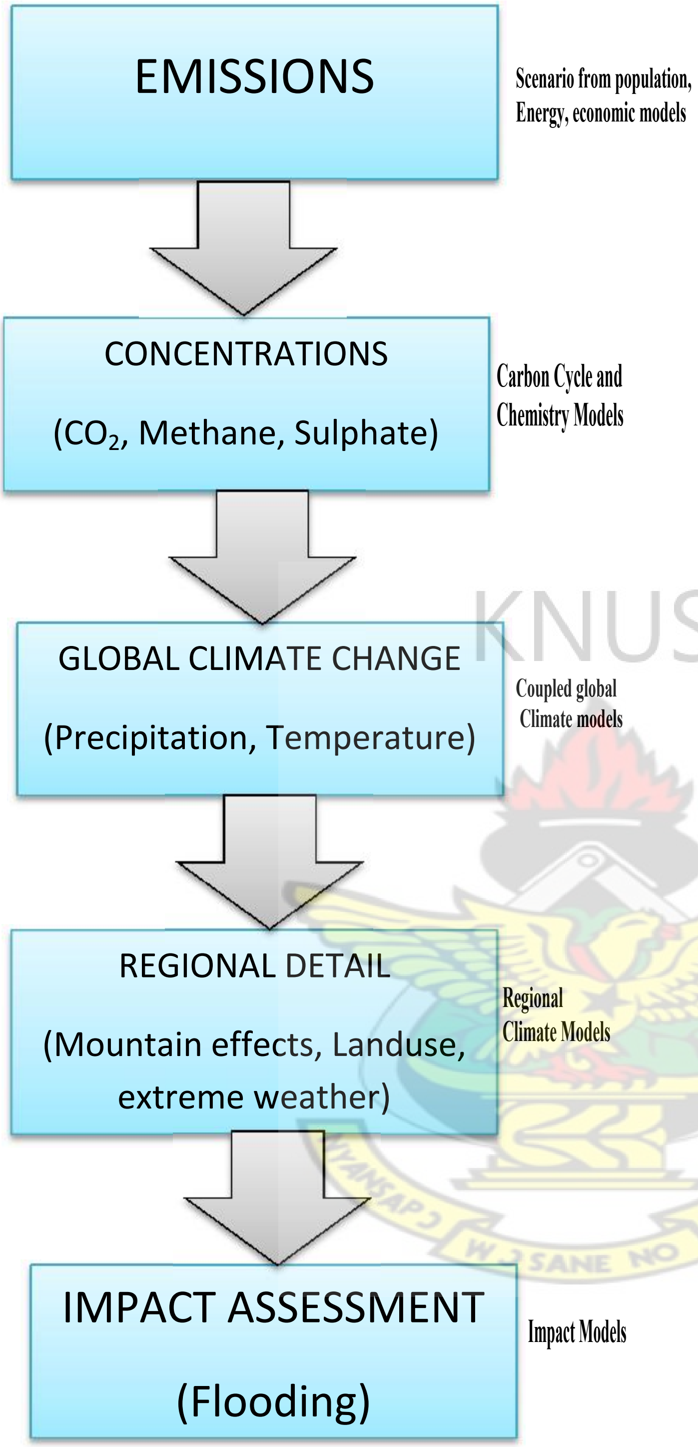

Figure 2-1: The general stages required to provide climate change scenarios for climate change impacts assessment.

2.2.2 Global Circulation Models (GCM) and Regional Circulation Models (RCM)

GCM's are the most appropriate tools for addressing future climate changes (Hudson et al., 2002). General circulation models also known as Global Climate Models (GCMs) representing physical processes in the atmosphere, ocean and land surface are the most advanced tools currently available for simulating the response of the global climate system to increasing greenhouse gas concentration.

According to IPCC (1994) only GCMs in conjunction with nested regional models or other downscaling methods such as Regional Circulation Models (RCM) have the potential to provide geographically and physically consistent estimates of regional climate change which are needed in flood analysis.

Dependable climate change information is usually required at finer spatial scales than that of a typical GCM grid-cell in order to formulate adaptation policies in response to climate change impacts. GCM's do not capture the details required for regional and national assessments. This happens to be true for Accra where variations in topography, vegetation, soils and coastlines have a significant effect on the climate system.

To address this issue, we use Regional Circulation Models (RCM) which provides finer and temporal details than GCM. RCM represent important components of the climate system. Higher resolution exists for RCM within the study area than GCM since land coverage is to a limited region of the country.

The RCM is 'nested' within a GCM. There exists a high degree of compatibility between GCM and RCM in terms of their physics and dynamic schemes (Hudson et al., 2002). The GCM and RCM make use of the same grid scale dynamics and sub-grid scale physics except for certain parameterization constants which require different scaling in the RCM to account for higher resolutions (Jones et al., 2001). The typical resolution of a RCM is about 50km in the horizontal. It covers an area usually of 5000km×5000km, located over a particular region of interest.

2.2.3 Creating regional climate change scenarios for use in impact models

Climate change impacts assessment models require climate information for the periods between which the change is being estimated. Information for such assessment is obtained in two ways; the first is the use of current climate information-historical data. The use of observed climate as an input rather than model-simulated climate gives better impact models to produce the current or past situations.

To create the required future climate information, combination of changes derived from the model simulations of present and future climate with the observed 'baseline' climate is done. Other simple approaches such as adding an average spatial pattern of change derived from the model onto the observed data, though even for a basic variable such as precipitation, it is not clear whether absolute or percentage increments are absolute (Arnell et al,. 2003).

The second approach is using climate model data for both periods (current and future) and the impact of climate change in that sector estimated based on the generated future data. Improved models have resulted in improvement in control simulations making this approach increasingly attractive and competitive. Knowledge of performance of the climate model and an assessment of the projected climate changes is invaluable when selecting a method to provide climate information (Arnell et al,. 2003). It is desirable to develop from the coarse-scale driving model when developing scenarios from RCM experiment for use in impacts models.

2.2.4 Limitations of Climate Change Scenarios

Developing future climate change scenarios is difficult because of some limitations. For Accra to be precise some of the limitations include;

- The problem of small signal-to-noise ratios in some scenarios for precipitation and other variables,
- The inability of climate model predictions to account for the influence of land cover changes on future climate, and
- The relatively poor representation in many models of some aspects of climate variability that is important for Africa.

Some of these limitations have been revealed works and analysis done on African climate change (Hulme et al., 2000). A number of methods have emerged to assist with the quantification and communication of uncertainty in climate scenarios generations. These include pattern-scaling technique to interpolate/extrapolate between results of model experiments, climate scenario generators, risk assessment frameworks and the use of expert judgment (Carter et al., 1996).

2.3 Flooding

Floods which occur as natural phenomenon across the world in most cases are appreciated by people living in affected areas. One major issue and source of uncertainty highlighted in flood modeling is accurately defining and targeting appropriate mitigation measures for the relief of extreme flood events and pollution "hotspots" within urban development areas. Flood management through predictions and flood control measures are incorporated in many sectors to prevent the negative consequences of flooding.

2.3.1 History of Floods across the World

History of floods dates back to the time of Noah when God told him how He was going to cover the earth with a flood that will destroy every living thing that breath (Genesis chapters 6-9). In all only 8 people were saved and God covenanted with Noah never to destroy the earth with such floods that will destroy *all life* again. This covenant still holds,*'not all life'* and hence the lessor floods experienced each year worldwide and the associated damages and loses. Studies shows that Shanghai is the most vulnerable major city in the world to serious flooding. Although it has a great economic wealth, the Chinese city is considered to be more exposed to the risk of flooding than much poorer cities in the world (BBC, 2012). Every year floods claim around 20,000 lives and adversely affect at least 20 million people worldwide mostly through homelessness (Smith, 2004).

2.3.2 Flood history in Accra

Ghana's experience with floods in recent years dates back to 1955 in Accra. Floods occurring between 1955 and 1997 led to the loss of billions of Ghana cedis (BGH₵) worth of properties, hundred lives during or after the floods and thousands of people rendered homeless (Gyau-Boakye, 1997).

The following basins; Sisan, Sakumo basin, Volta basin, Akora basin have recorded floods leading to destruction in diverse ways. Remarkable historical floods include;

- On July 3rd 1995, Accra experienced a severe flood that caused untold damage to lives and properties. The city experienced the highest intensity in 49 years with a death toll as high as 30 and several properties loses costing 50 billion Ghana cedis (BGH₵).
- Flood that occurred on 27th June 2001 was described as the worst to hit Accra since the 1995 event. 11 people died with several properties damaged. Accra is vulnerable to anticipated sea level rises over the next century with extensive flooding and inundation of coastal regions expected especially in the low-lying sandy areas (Black et al,. 2008).

2.3.3 Why Flooding or Floods

Flooding occurs when the volume of water resulting from precipitation enters a given basin/sub-basin area and it's unable to be discharged quickly enough through a particular outlet. Hence, the water level rises until peak stage is reached and flooding occurs. Most importantly are the elements of area and time of concentration. The enormous masses of water producing flooding cannot be decreased. Aquifers cannot accept such water within a short time period and evaporation will not occur overnight. This has led to vast areas of lands inundated each time floods occur in Accra (Duivendijk, 1999).

Flooding has been widespread and severe because of the absence of drainage and sanitation services which the government is expected to provide (Konadu-Agyeman, 2001). Overtopping or breaching of embankments or storage structures such as dams also generates floods of high magnitudes.

2.3.4 Urbanization and Flooding

Poor planning and management during urbanization processes leads to flooding (Diop, 2000). The result of urbanization is increase in paved surfaces replacing vegetative covers (Aboagye and Nai, 1996) with decrease in natural storage capacity of the soil because the vegetation is replaced by impervious surfaces (Andjelkovic, 2001). Increase in storm water runoff rates is directly proportional to total volume of runoff due to increase in impervious surface.

Irresponsible practices in urban areas such as lack of sanitation services, improper drainage systems, garbage dumping and uncontrolled artificial development all contributes to flooding (Chan, 1997). Floods in urban areas are flashy and occur in small urban rivers and on urban surfaces such as on streets, parking lots, yards and parks. Improper uses of lands, building on water ways all generate urban floods. Surcharge due to blockage of drains, street inlets and inadequate street cleaning practices all causes urban floods (Kolsky and Butler, 2002).

2.4 Rainfall record sources

There are many organizations within Ghana that record rainfall data for a variety of purposes. Water managers require rainfall data for resources estimation and allocation. Water Resources Commission (WRC) and the Environmental Protection Agency (EPA) require rainfall data for water resources assessment and management. Meteorological Service department require rainfall data to assess numerical weather prediction models and for flood warnings as well as in research institutions etc.

There is one major source of freely available raw archived rainfall data for research within Ghana. This is obtained from the Meteorological Services Department (MSD). They have facilities for extracting raw time series rainfall data and the results are considerable but not 100% correct.

For researchers, scientists and engineers interested in analysis using country –wide rainfall data, the use of raw meteorological data requires careful consideration. Hence significant amounts of data date checking and assessment for quality is required before use.

2.5 Lumped Models

Lumped models are attractive as compared to the more complex detailed physically based distributed models because they are easier to operated and require less and usually easily accessible data. The lumped models have been developed for and are very good at describing runoff generation and overall water balances. They however fail to provide fine subarea details of water flows and soil moisture storages. Lumped models are important hydrological tools that can capture dominant basin dynamics while remaining parsimonious and computationally efficient. An important feature of this model is that their parameters are not directly measured and must be inferred or calibrated from observed historical data.

2.6 Hydrological Modeling of Peak Flow

For the purpose of this research, models and papers that contribute significantly to the field of peak flow modeling were considered importantly. This research work is primary concerned with potential climate change and impacts on floods hence the rational model and soil conservation services (SCS) method the most appropriate. Therefore, this section of literature focuses on methods suited to estimating runoffs from precipitation.

2.6.1 Review of Runoff Models: Rational and SCS Curve Number Models

2.6.1.1 Rational Method

Peak flow prediction is vital in any hydrologic studies and the rational method is one of the simplest rainfall-runoff methods used. The rational method which is traced back to the middle 19^{th} century is still probably the most widely used method for designs of storm water drains and other large conveyance systems.

The Irish Engineer, Mulvaney (1850) was the first to publish principles on which the rational method works, although Americans tend to credit Kuichling (1889) and the British crediting it to Lloyd-Davies (1906). Mihalik (2007) indicates valid criticisms have been raised about the adequacy of the rational method. However, it still continues to be used as the most appropriate for storm water discharge estimation because of its simplicity.

The product of rainfall intensity, *I*, and watershed area, *A*, is the inflow rate for the basins or sub basins, *IA*, and the ratio of peak discharge, *Q* (which occurs at time t_c), to this rate *IA* is termed runoff coefficient *C* ($0 < C < 1$). A storage coefficient, C_s, is included to account for a recession time larger than the time the hydrograph takes to rise. This is expressed in the rational formula as;

$$Q = KCC_S IA \qquad (2.1)$$

Where Q = peak flow (m^3/s), C = runoff coefficient (dimensionless), C_s = Storage coefficient (dimensionless), I = rainfall intensity (mm/hr.), A = Catchment Area (km^2), K = conversion factor = 0.00278. For Q in litres/sec, the conversion factor K = 2.78.

The idea behind the rational method is that a rainfall of intensity, *I*, begins instantaneously and continues indefinitely. The rate of runoff will increase until the time of concentration, t_c, when all of the basins or sub basins are contributing to flow at the outfall/outlet. The duration used for the determination of the design storm intensity is the time of concentration, t_c, of the basins or sub basins.

The rational method can be analyzed compositely. In urban areas like Accra, the drainage system usually consists of sub basin areas of different surface characteristics. In such cases, the rational formula becomes;

$$Q = KI \sum_{j=1}^{m} C_{S_j} C_j A_j \qquad (2.2)$$

where m is the number of sub-basins within the basin.

2.6.1.1.1 Assumptions for the Rational Method

- Rainfall intensity is constant throughout the basin and within the storm duration.
- The time of concentration, t_c, employed is the time for the runoff to become established and flow from the most remote part of the sub basins to the outlet.
- The computed peak rate of runoff at the outlet point is a function of the average rainfall rate during the time of concentration, that is, the peak discharge does not result from a more intense storm of shorter duration, during which only a portion of the watershed is contributing to runoff at the outlet.

2.6.1.1.2 Limitations of the Rational Method

Important factors that determine the magnitude of flood such as antecedent moisture conditions, spatial and temporal rainfall variations are not covered by the rational method. The rational method assumes homogeneous characteristics for the watershed area. Therefore another method is most appropriate when inhomogeneity exists in the watershed or catchment under consideration. The rational method is adequate for peak runoff estimation as a result not concerned with other parts of the hydrograph after peak is reached for a particular design storm.

2.6.1.2 SCS Curve Number Model

The model developed by the National Resources Conservation Services (NRCS, 1957) within the US department of Agriculture is used for computing abstractions from precipitations. Soil Conservation Service (1964) did a further work on the method of runoff estimates which assumes a relationship between total precipitation, runoff, infiltration and abstractions.

A precipitation of depth P produces a depth of excess rain or direct runoff P_e. There is some amount of rainfall I_a (initial abstraction before ponding) for which no runoff will occur, the potential runoff is $P-I_a$ $(P_e < P-I_a)$. The initial abstraction consists mainly of interception, infiltration and surface storage. After runoff begins, the depth of water retained within the watershed, F_a, is less than or equal to some potential maximum retention S ($F_a < S$).

The hypothesis of the SCS method is that the ratios of the two actual to the two potential quantities are equal.

That is $$\frac{F_a}{S} = \frac{P_e}{P - I_a} \qquad (2.3)$$

From the continuity principle; $$F_a = (P - I_a) - P_e \qquad (2.4)$$

Combining equation 2.3 and 2.4 to solve for direct runoff P_e gives,

$$P_e = \frac{(P - I_a)^2}{P - I_a + S} \qquad (2.5)$$

Results from many small experimental sub basins shows;

$$I_a = 0.2S$$

$$P_e = \frac{(P - 0.2S)^2}{P + 0.8S}, P > 0.2S \qquad (2.6)$$

The value of the maximum potential retention, S, is defined as;

$$S(inch) = \frac{1000}{CN} - 10 \qquad (2.7a)$$

$$S(mm) = \frac{25400}{CN} - 254 \qquad (2.7b)$$

The Curve Number method considers the landuse and landcover type, the antecedent moisture condition of the sub basins and the soil hydrology for computing direct runoffs.

A weighted CN for each sub basin is computed as a result of different soil groups and land covers within the basin. This is given by;

$$CN_w = \frac{\sum_{i=1}^{n} CN_i A_i}{\sum_{i=1}^{n} A_i} \qquad (2.8)$$

Where CN_w is the weighted curve number, CN_i is the curve number for the land cover type; A_i is the area with curve number CN_i and $\sum_{i=1}^{n} A_i$ is the total area of the basin. The Curve numbers have been tabulated by the SCS on the basis of soil group and land use. Four hydrologic soil groups are defined;

- Group A: Deep sand, deep loess and aggregated silts.
- Group B: Shallow loess, sandy loam.
- Group C: Clay loam, shallow sandy loam, soils low in organic content and soils usually in clay.
- Group D: Soils that swell significantly when wet, heavy plastic clays and certain saline soils.

The antecedent moisture condition (AMC) is an index of basins wetness (Silveira et al., 2000). The formula for AMC II is given by the equations;

$$CN(II) = \frac{2540}{25.4 + S} \qquad (2.9a)$$

where S is in cm.

For dry conditions (AMC I) and wet conditions (AMC III) of the soil under consideration in the basin, equivalent curve numbers can be computed by;

$$CN(I) = \frac{4.2\,CN(II)}{10 - 0.05\,CN(II)} \qquad (2.9b)$$

$$CN(II) = \frac{23\,CN(II)}{10 + 0.13\,CN(II)} \qquad (2.9c)$$

(Odai, 2012)

The SCS method has some weakness as seen in Capece et al. (1984), although the method is widely used in engineering analysis. The various antecedent moisture conditions cannot handle accurately the problem of matching measured hydrographs in areas with high water tables.

Table 1-1: A table showing AMC with seasons for a 5 day antecedent rainfall

AMC GROUP	Total 5-day antecedent rainfall (cm)	
	Dormant Season	**Growing Season**
I	Less than 1.3	Less than 3.6
II	1.3 – 2.8	3.6 – 5.4
III	Over 2.8	Over 5.4

Adapted from Chow et al. (1988)

2.6.1.3 Hydrograph Analysis

A discharge hydrograph is a graph or table showing the flow rate as a function of time at a given location on overland or sub basin. Hydrographs are categorized as annual hydrographs and storm hydrographs. This study focused on hydrographs generated by storm water over the sub basins from the highest precipitation over a period. Hydrograph is composed of the overland flow, groundwater flow and the sub surface flow. Hydrographs for the sub basins are generated based on the area, slope, curve number, precipitation and the storage capacity of the soil. Climate factors form the inhibitors when considering hydrographs generation and these include precipitation intensity pattern, sub basin area distribution, precipitation type and duration.

2.7 Computer Models

Development of computers for use in various fields of studies and research has led to its usage in watershed hydrologic studies. This has given way for development of computer based urban runoff models that have been calibrated and validated through comparisons with observed field data. Urban flow simulations are recorded by the development of the Road Research Laboratory Model by using hydrologic models in the United Kingdom and the Chicago model in the U.S. (Watkins, 1983).

Computer based models for precipitation runoff investigation, storm water collection and conveyance has increased tremendously due to software development (Bedient and Huber, 1988). Development of softwares in the early mid 1970's by several agencies in the USA led to computer modeling becoming integral part of hydrologic and hydraulic designs and analysis.

2.7.1 HydroCAD

HydroCAD is a **C**omputer **A**ided **D**esign system for modelling the hydrology and hydraulics of storm water runoff. It is based largely on the hydrology techniques developed by the Soil Conservation Service (SCS/NRCS), combined with other hydrology and hydraulics calculations. For a given rainfall event, these techniques are used to generate hydrographs throughout the basin/sub basins. This allows the engineer to verify that a given drainage system is adequate for the area under consideration, or to predict where flooding or erosion is likely to occur.

HydroCAD has the capability of maintaining a complete database for the sub basins and drainage system. With available data, HydroCAD becomes a working model for the entire drainage system where changes can easily be made and their effects viewed. HydroCAD takes just minutes, not hours in generating results, so the engineer can interact with the watershed model in a way not previously possible. This gives the engineer the opportunity to evaluate numerous possible designs and choose the one most suitable for analysis and judgement, not just from a safety and environmental standpoint, but based on cost and other considerations as well (Hydrocad, 2012).

2.7.1 Geographic Information System (GIS)

Geographic information system (GIS) is a system of hardware, software and procedures designed to support the capture, management, manipulation, analysis, modeling and display of spatially referenced data for solving complex planning and management problems (Rhind, 1989). GIS uses advanced analytical tools to explore at a scientific level the spatial relationships, patterns and processes of cultural, biological, demographic, economic, geographic and physical phenomena. GIS functions include; capturing of data, storing data, data analysis, query, data visualization and output of information.

2.7.1.1 Why Use Geographic Information System

Using GIS helps to integrate spatial and other kinds of information into a single system. It offers a consistent framework for analyzing geographical data. By putting maps and other kinds of spatial information into digital form, GIS allows the manipulation and display of geographical knowledge in new and exciting ways. GIS makes connections between activities based on geographic proximity. Looking at data geographically often suggest new insights and explanations to results. For example, we can link human waste records with university locations through geographic proximity.

2.8 Model Selection, Calibration and Validation

The main model used for this research work is the RCSNDIPOA (Regional Circulation Single Distribution Precipitation over Accra) model. Scenarios generation is based specifically on land use characteristics (CN) which tend to affect the climate system through the hydrologic processes. The various landuse factors considered includes; grass cover, pavement lots, gravel roads, gravels surfaces, forests, urban and commercial business areas, newly graded areas, fallow lands, pastures, reserves, urbanization, drainage systems, water bodies and the sea etc. A weight of 0-1 is placed on the landuse parameter based on evaporation, transpiration processes that contribute to rainfall formation through the hydrologic cycle.

Future impact assessment projections are solely based on the highest historical rainfall record. The obtained historical hydrographs for the sub basins are based on the July 1995 highest rainfall. Rainfall of established return periods derived from Intensity Duration Frequency Curves (IDF) by Dankwa, 1974 is used to validate incongruities arising from the lack of data. Precipitation data observed from synoptic stations have been compiled to obtain the IDF data with significant long records extending up to 34 years. The precipitation values used gave a fair representation of the precipitation pattern for Accra as all hydrologic modelings are based on a 30 years minimum historical data.

Various commercial and free software packages are available for urban storm water runoff modeling. Few standard ones well established for research work and for other uses are analyzed for this work. These include HEC-RAS, WIN-TR 55 and ERPD. Several models were examined for the purpose of this work and the SCS model selected on the bases of data availability, acceptance and simplicity of computations in the HydroCAD software.

CHAPTER THREE

3 Study Area

3.1 Area under study

The study area falls within the Greater Accra Metropolitan Assembly (GAMA) covering a total land area of 1550.37km^2. GAMA is divided into ten main basins and these are the Densu, Lafa, Chemu west, Odaw, Osu Klottey, Kpeshie, Songo, Mokwe, Sakumo and Chemu basins. Densu basin covering an area of 568.32Km^2 is the largest and the lowest which is Osu Klottey basin covers an area of 13.85Km^2. GAMA harbors all the ethnic groups like Gas, Akwapim's, Akan's, Fantes, Ewes, Dangmes and all the northern tribes. The map below shows the various basins within the study area.

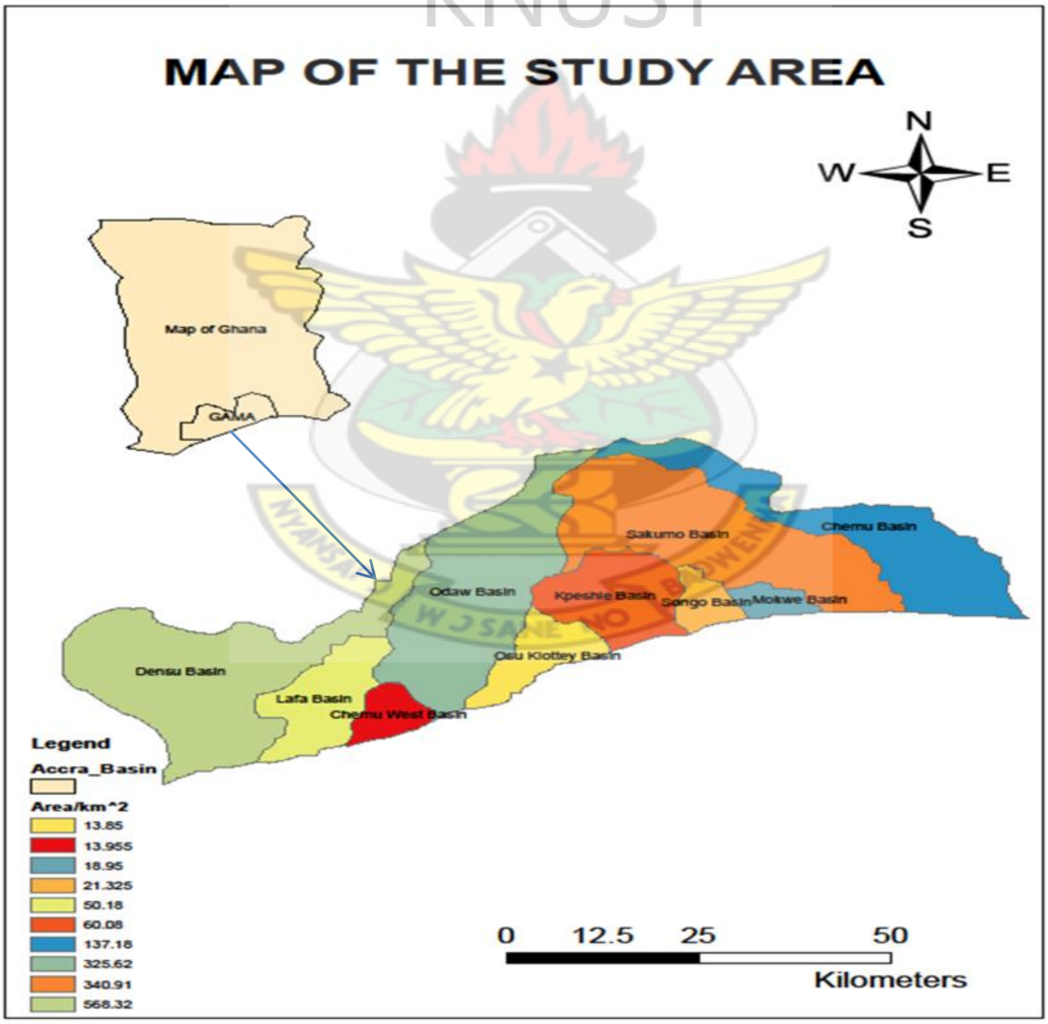

Figure 3-1: Map of the study Area

3.2 Geomorphology of Accra

Geological base knowledge of the rock formations is very important in order to make proper environmental and engineering decisions in various sub basins with regards to runoff generation. Some areas of applications are mineral resources potential assessments, flooding studies, erosion, rock fall and mass movement, ground water supply investigations and land use zoning. The underlying geology consists of four broad terrains namely the western lowlands, Akwapim Range, Eastern Lowlands, Coastal lowlands and Lagoons.

The terrain for the Western Lowlands is low-lying with gentle rolling hills. The drainage system has a dendritic pattern and the rivers are perennial in nature following SE, SW, and S to SSW and east west directions. Zones of weakness exist in the rocks due to the joint or shears, steeply dipping faults and dikes intrusions. The base level height for this terrain is 70 meters above sea level in the northern part of the study area and slopes gently towards the coast. The geology of the ridges rises to approximately 200m from the low-lying terrain towards the North West.

Forming eye-catching hills is the Akwapim Range and mostly includes the Weija Mountains. The Akwapim Range is made up of stratified rocks which dip to the South East and East-South-East. The range rises to a height of 365 meters above sea level with a width of 3km to 6km. The uneven pattern of slope exhibited by the Akwapim Range is caused by erosions which are deflected down slope as it encounters resistant layers during downward erosions. The drainage system is controlled by ridges and valley pattern of the topography. Deviating significantly from the normal North-East trend is a chain of North-South running valleys in the Ofankor-Taifa Kwabenya area within the Odaw basin to the north of Accra (Muff et al., 2006).

Because of disturbances along the North-South running faults which rotate the strata has caused a deviation in the strike direction of the strata in these valleys from their normal regional North-East direction.

The Eastern Lowlands which is recognized as pediment surfaces (BURKE, 1969) occupy the Akwapim Range and the Weija Mountains. It is a low-lying terrain with slope valleys ranging from 0 to 5%. It has a very gentle gradient from the streams towards the ocean with a dendritic pattern forming the drainage system. Forming the Coastal lowlands and lagoons are several sandy platforms with inlets and river deltas. These are usually flat unconsolidated sands having occasional interlayers of silt and clay. Their surface is approximately 4 to 6m above sea level (Muff et al., 2006).

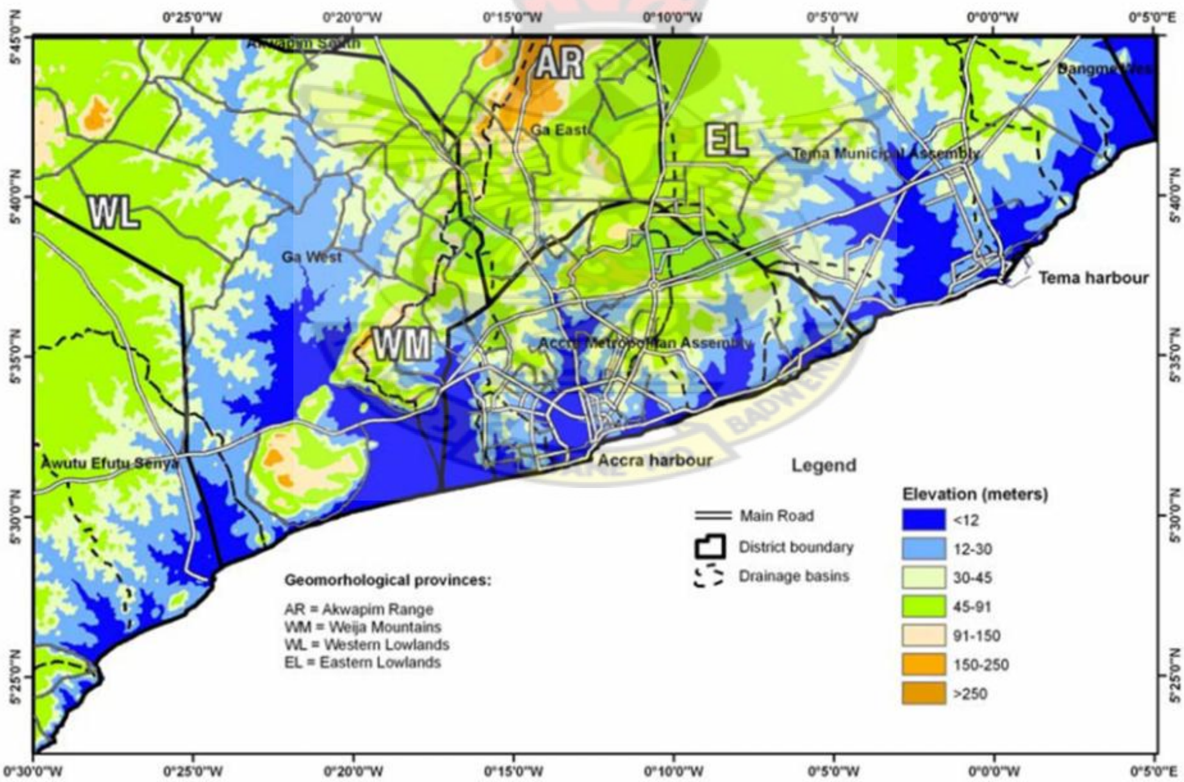

Figure 3-2: Geomorphological Formation of the study area, *Source: GSD, Ghana-2012.*

3.3 Soil Formation of Accra

The soil formation of the basins can be divided into five main groups. Shallow rocky soils are deposited at places where erosions are greater than soil formations. They contain rock fragments and occur predominantly in the Akwapim Range and Weija mountains within the Densu basin. The soil conservation service classifies such soils as group A.

Red earths are made up of laterite gravels mostly less than 1m deep and often mined for fillings during road constructions and estate developments. Hard thick layers up to several meters occur over large areas within the Odaw and Chemu basins usually falling within group A, C and D classifications. Mature clay loam and plastic clays which are often soft and friable classified as group B are located within the upper Sakumo and parts of Odaw basins.

Pale coloured, coarse-grained sandy soils forming the pallid sands often contain pebbly gravel of vein quartz material. These are the areas where initial infiltrations are high. This soil falls in all the lower basins; Songo, Mokwe and the Chemu west basin. Such soil falls within the classified soil group A, B and C (Bosiakor, 2012).

Forming the grey earths classified as soil group B are the various clay loam and heavy plastic clay soils. They are low in organic content and usually occur along the rivers and lagoons (Sakumo, Kpeshie, Mokwe and Songo). They are impermeable and contain saline which are harmful to soil fertility and ground water quality. They form hard and mud-cracked surfaces during the dry seasons and hence classified by SCS as soil group C and D.

3.4 Climate

Accra is located in the Dahomeyan Gap, where the coast runs parallel to the prevailing moist monsoonal winds. Accra features a tropical savanna climate that borders on a semi-arid climate. Accra experiences two rainy seasons; April to June and September to October with the first being the heaviest. The year 2012 recorded a change in the precipitation pattern as compared to the previous seasons as land use and urbanization continues increase within GAMA. The average annual rainfall is about 730mm which falls primarily during Ghana's two rainy seasons (MLG, 1992). Rainfall is usually intensive and short and gives rise to local flooding where drainage channels are obstructed or impervious surfaces causing sheet floods which cannot be handled by the natural river systems (Muff et al., 2006).

Variation in temperature throughout the year is recorded to be nominal. The mean monthly temperature ranges from 24.7°C (76.5°F) in August (the coolest) to 28°C (82.4°F) in March (the hottest) with an annual average of 26.8°C (80.2°F). The cooler months tend to be more humid than the warmer months. Accra experiences a breezy dry heat during windy harmattan seasons that feels less warm than the cooler but becomes more humid during the rainy seasons.

Due to the closeness of Accra to the equator, the daylight hours are practically uniform during the year. Relative humidity is generally high, varying from 65% in the mid afternoon to 95% at night (Muff et al., 2006). The predominant wind direction in Accra is from the West-South-West (WSW) to North-North-East (NNE) sectors. Wind speeds normally range between 8 to 16km/hr. High wind gusts occurs with thunderstorms which generally pass in squall along the coast often causing damage to properties by removing roofing materials. Along the Akwapim Hills, the wind velocity increases and this gives rise to slightly cooler temperatures along the foothills.

3.5 Vegetation

The Accra vegetation is of the typical Savannah-type. There is evidence to suggest the vegetation of the basin has been altered in the more recent past century by climate and other anthropogenic factors. Accra metropolis is believed to have been covered by dense forest of which only a few remnant trees survive. Climate changes combined with gradient of plains and cultivation has imposed vegetation structures similar to those of the southern shale, Sudan and Guinea Savannahs all of which lie north of the Accra plains.

Accra is characterized by three broad vegetation zones; shrub land, grassland and coastal lands. Occurring more commonly in the western outskirts and in the north towards the Aburi hills is the shrub land. It is made up of dense clusters of small trees and shrubs, which grow to an average height of 5m. The grasses are mixtures of species found in the undergrowth forests. They rarely grow beyond 1m and mostly short. Ground herbs are found on the edge of the shrub and include species which normally flourish after fire. Along the coast, wetlands and dune vegetation's are found dense grass, palms and coconuts trees.

The coastal zone comprises two vegetation types; wetlands and dunes. The coastal wetland zone is highly productive and forms an important marine and terrestrial habitat. Mangroves comprising two dominant species are found in the tidal zones of all estuaries sand lagoons. Salt tolerant grass species cover substantial low-lying areas surrounding the lagoons. These grasslands provide nutrients for prawns and juvenile fish in the lagoon systems. Protection of the coastal wetland zones is very important to the long-term sustainability of the fish industry which the population of Accra highly depends on.

Agriculture within the metropolis is practiced in various basins with irrigated urban vegetable production being the most important type. Urban agriculture plays a very important role in supplying food to the metropolitan population but as the agricultural plots are situated along heavily polluted urban streams and drainage channels, the vegetable farming is with health hazards. Urbanization and expansion of the metropolis areas has led to land use pressure and this will in the future reduce the space used for agricultural purposes in the urban and peri-urban areas.

3.6 Population

With an estimated population of about 2,291,352 at the 2012 census, Accra is one of the largest and fastest growing cities in Africa with an annual growth rate of 3.36%.

The period between 1960 and 1970 saw rapid industrialization and expansion in Accra's manufacturing and commercial sectors. This contributed to high rural-urban migration and illegal immigration from West Africa nationals to the city and consequently a high population growth rate. The primacy of GAMA as Ghana's administrative, educational, industrial and commercial center continues to be the major force for its rapid population growth, with immigration contributing to over 35% of the city's population growth.

The gross density of population for the Accra metropolitan area in 2000 was 10.03 per/h compared to 6.23per/h in 1970. The highest densities recorded averaged 69.3per/h. Densities exceeding 250per/h occur mostly in the immigrant and depressed areas in the oldest parts of Accra such as Accra New Town, Nima, James Town and Usher Town. In high income earning areas, densities ranged between 17.5 and 40 persons per hectare.

CHAPTER FOUR

4 METHODOLOGY

This chapter looks at climate scenario generation, types and sources of data, methods used for data collection. Detailed explanation of the process and tools used for analysis in order to meet the set objectives is developed in this section.

4.1 Desk studies and Reconnaissance Survey

The research work involved assembling materials which included literature review of floods in Accra, their impacts and the appropriate modeling method used. Obtained information for the study in order to achieve results includes;

- Data type identification and sources.
- Landuse characteristics and atmospheric parameters.
- Basin/Sub basins areas determination (Shapefile of Accra), (HSD, 2002).
- Field topography survey of the study area.
- Input of soil and Landuse data (DEM).

The institutions liaised with for the needed information are; Ghana Meteorological Agency (GMA), Hydrological Service Department, Soil Research Institute, Geological Service Department, Town and Country Planning Department in Accra, GAMA, Sambus Ltd, CERSGIS-Legon (Owusu, 2012).

4.2 Climate Scenario Generation

Regional Circulation Models do not replace General Circulation Models, but they are powerful tools used together with the GCM's in order to add fine-scale details to their broad-scale projections. Scenarios are derived from projections of climate change undertaken by the Global Climate Models (GCM's). GCM's projections are usually adequate to a few hundreds of kilometers hence not able to give details needed for impact assessment at regional or city levels. For detail climate scenario generation, we make use of the Regional Circulation Models (RCM's). Historically, GCM's have been the primary source of information for constructing climate scenarios and will always provide the basis for comprehensive assessments of climate change at all levels from local to global (Mearns et al., 2001).

For the purpose of this work, scenario generation is based specifically on land use characteristics (CN) which tend to affect the climate system through hydrologic processes. The various landuse factors considered includes; grass cover, pavement lots, paved roads, gravel roads, gravels surfaces, forests, urban and commercial business areas, newly graded areas, fallow lands, pastures, reserves, urbanization, drainage systems, water surfaces etc.

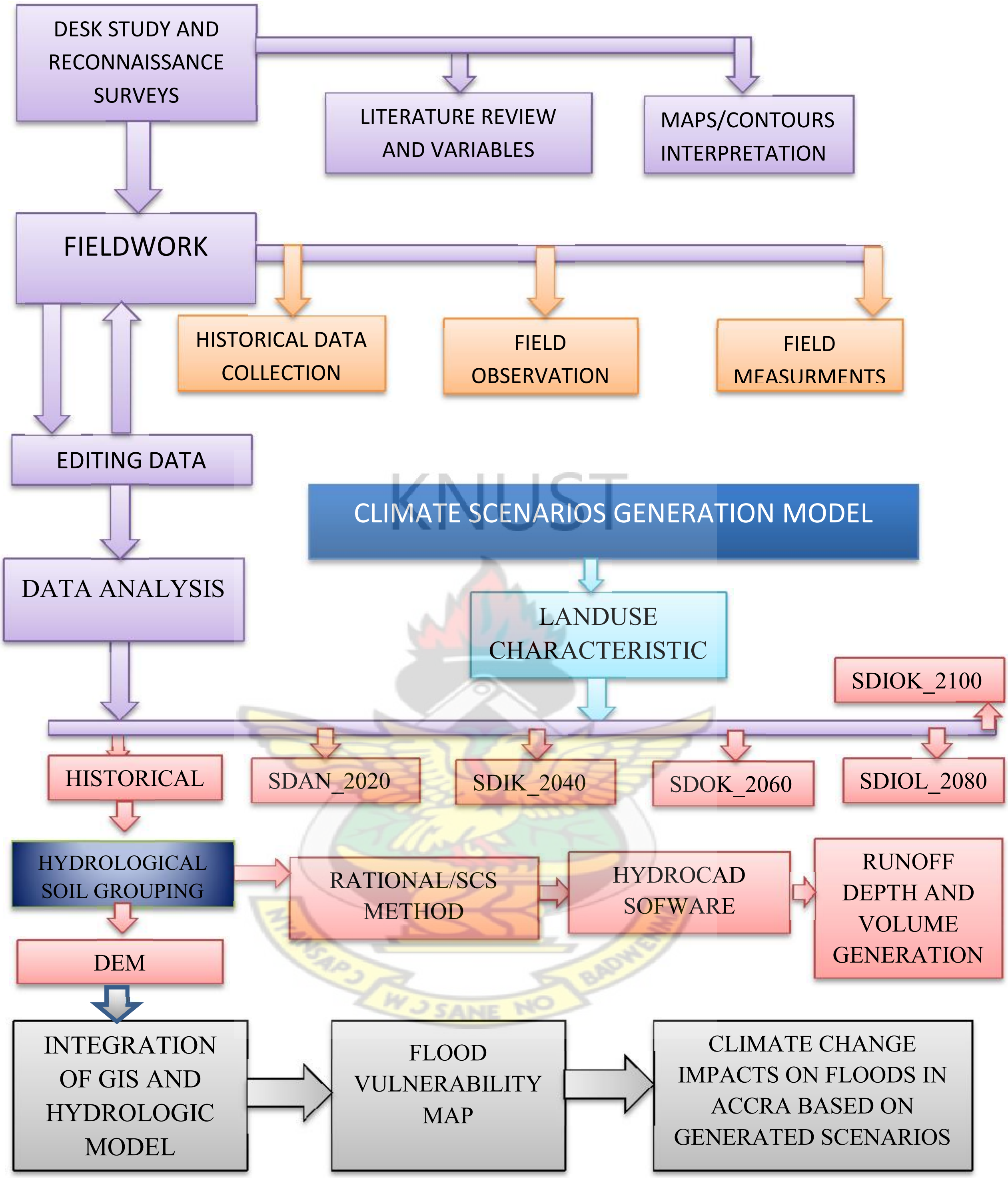

Figure 4-1: Flow chart for the research methodology (*Source: Authors Context, 2012*).

4.3 Data type identification, source and mode of collection

Data for this study is collected from various sources. Data is characterized as primary, secondary and tertiary. Obtaining primary data involved field observations, measurements, map interpretation, information related to Landuse, soil characteristics and classifications, drainage size and runoff determination, flood levels and flood volumes estimations.

Secondary data includes rainfall data, basin/sub-basins characteristics, landuse planning (industrial estate, settlement zones, flood prone areas, government buildings, business centers, parking lots etc.) of the study area. Published information on flood generation factors such as rainfall, various drains sizes and the 2000 landuse map is obtained from the hydrological service department (Ametefeh, 2012).

Tertiary data used involved all kinds of net surfing and downloads from the internet. This includes precipitation shapefiles downloads, the use of Google earth for elevation verifications, obtaining and downloading the required softwares, Landuse and Digital Elevation Models (DEM's).

Study area observation is done where quick assessments and interpretations is achieved (Mitchell, 1973) in order to obtain observation data. Landuse, drainage characteristics, perviousness and imperviousness, storage facilities data were obtained. This helped to attain a level of generality by locating common factors (De Van, 1993; Molenaar, 1998).

Hydrological factors that could not be obtained by direct observations on the field are measured through DEM analysis and cross checked with derived values from model (UNESCO, 1971). Field measurement of hydrological parameters such as CN and cross sectional areas of selected drains is done. Measurements/ observed variables obtained from the field include;

- Basin Area/Characteristics/Storage Coefficients
- Landuse (CN)
- Precipitation

- Slope/Elevation Characteristics
- Flood prone areas

4.3.1 Data Calibration and Validation

Raw data obtained for this research are not 100% and some level of inconsistency. Google earth and other softwares are used to ensure that outliers do not exist in the data set. A technique for detecting and correcting inconsistency in precipitation data is used before they are used for analysis. Elevation data is cross checked using DEM's and the Google earth software.

4.4 Basins/ Sub basins areas and elevation determination

Basins and sub basins area delineation helped to determine the runoff rate with a given input of rainfall event. The extent of variations in basins and sub basins shape, CN's, flow length, slope and area produces hydrographs of different nature and shapes. Using topographical map, basin/sub basins areas within GAMA is obtained. This is integrated into ArcGIS to obtain the Shapefile of the study area which improved the modeling process. Google earth software and DEMS are used to obtain elevations at various points.

Various drainage channels within the study area are identified. Measurements of some selected drains and drainage areas within the basin/sub basins are accomplished. The runoff coefficient is obtained to assess the rate at which water quickly flows through the basins for both paved and unpaved areas. Topographic sheet of GAMA is obtained and basin/ sub basins areas delineated to determine the extent to which drainage system contributes to flooding in the city.

4.4.1 Topographic Survey of the Study Area

It is difficult to make all measurements for hydrological modeling in a study area like GAMA hence the need for the use of a topographic sheet. The topographic sheet of GAMA helped in basins/ sub basins delineation, determination of drainage areas and perimeters, determination of channel longitudinal and cross sectional profiles. Global Position System (GPS) equipment is used for this research work to obtain coordinates of flood prone areas within GAMA. The topography of GAMA varies in slope and elevation due to urbanization and other landuse factors. A Digital Elevation Model (DEM) obtained form CERSGIS-Legon gave a clear indication of heights at various levels. Elevation heights are justified by the use of the Google earth software and real time field measurements. With the help of the topographic sheets, flow directions are determined. Slopes and flow lengths gave a clear indication of the direction of a precipitation event to an outfall.

The nature of the soil has a greater influence on the topography of the study area. Climate changes, parent rock formation and urbanization all influence the soil distribution. Soil samples within the study area are analyzed for clay, loam, sand, silt and gravel identification for hydrologic groupings as indicated on **page 22**.

4.5 Estimation of flood volumes, F_V and flood levels, F_L using generated data

Various precipitation data are analyzed as the historical rainfall and a given selected maximum years-days rainfall recurrence interval chosen. Scenarios based on landuse characteristics are used to generate the subsequent precipitation starting from 2020 to 2100. Precipitation depth is a noteworthy event in the basin as an input for runoff generation. Precipitation generates runoff after hydrological abstractions such as interceptions, surface storage, evapotranspiration and infiltration. Therefore, precipitation minus abstractions gives the effective runoff overland.

Landuse, soil characteristics, antecedent moisture conditions (AMC) and landuse areas are the conditions on which the Curve Number (CN) depends. The average antecedent moisture condition II (CN-II) is used for SCS-CN model. The dry conditions (AMC-I) and wet conditions (AMC-III) depends on AMC-II. Reasoning being that some amount of moisture proceeds the wet season. The weighted curve number (CN-II) is given in equation 4.1.

$$CN_w = \frac{\sum_{i=1}^{n} CN_i A_i}{\sum_{i=1}^{n} A_i} \qquad (4.1)$$

Where CN_w is the weighted curve number, CN_i is the curve number for the land cover type; A_i is the area with curve number CN_i and $\sum_{i=1}^{n} A_i$ is the total area of the basin.

Historical rainfall is obtained based on the highest rainfall ever received to give the HISTORICAL_1995 scenario. A weight of 0-1 is placed on the landuse parameter based on evaporation, transpiration and evapotranspiration process that contribute to rainfall formation through the hydrologic cycle as shown in the appendix. The subsequent scenarios generated based on future landuse characteristics are SDAN_2020, SDIK_2040, SDOK_2060, SDIOL_2080 and SDIOK_2100. The obtained sub basins areas, CN's and precipitations are integrated into HYDROCAD software to obtain hydrographs, runoff volumes and runoff depths or levels for all the sub basins.

4.5.1 Soil classification

The soil is always at the lose end as man's activities on land surfaces continues to alter the topography of land. Urbanization and other activities like farming, road construction, mining, estates developments etc. will continue to affect the landuse within the basin and finally the nature of the soil. Various factors are considered with regards to soil classification for this project as reviewed in the literature (Bosiakor, 2012). In order to obtain the required scenarios, different areas within GAMA are identified and the nature and characteristics of the soil obtained. The identified nature of the soil helped to obtain the soil group and the curve number (CN) to be inputted into the HYDROCAD software. The plates below show some of the identified soils and their groupings.

Plate 1: Deep sand and aggregated silts, SG A

Plate 2: Sandy Loam, SG B

Plate 3: Clay Loam, HSG C

Plate 4: Heavy plastic clays, HSG D

4.6 Determination of runoff discharge of the study area

Runoff discharges are computed for all the sub basins for the entire study area. This generated the total discharges for each of the sub basins contributing to flow within the study area. Data and map of the basin/ sub basins is obtained from the Hydrological Services Department (HSD). Runoff discharges for each of the sub-basins are computed using the simple rational method as in **equation 4.2** below. Precipitation is the main parameter being considered here and floods within GAMA are attributed to landuse and land cover leading to changes in the climate. The SCS method is the most appropriate for runoff levels and volume determination since it takes into account landuse and land cover, soil and sub basins areas when integrated into the HYDROCAD software. Knowing the runoff coefficients (C), storage coefficients (C_s), rainfall Intensity (I), and areas (A) of each of the sub basins within the study area, the discharges (Q) for each sub basin likely to cause flooding is obtained. The storage coefficient is included to account for a recession time larger than the time the hydrograph takes to rise. This is done by considering the most severe daily rainfall (historical) ever experienced in Accra and the generated scenarios.

The product of rainfall intensity, *I*, and sub basin area, *A*, is the inflow rate for the system, *IA*, and the ratio of peak discharge, *Q* (which occurs at time t_c), to this rate *IA* is termed runoff coefficient *C* ($0 < C < 1$) and storage coefficient, *Cs*. This is expressed in the rational formula as;

$$Q = KCC_sIA \qquad (4.2)$$

Where Q = peak flow (m^3/s), C = runoff coefficient (dimensionless), C_s= storage coefficient (dimensionless), I = rainfall intensity (mm/hr.), A = Catchment Area (Km^2), K = conversion factor = 0.00278. For Q in litres/sec, the conversion factor K = 2.78.

Equation 4.2 gives the discharges for each of the sub basins for GAMA as shown in **page 46**. This is then integrated into ArcGIS model to obtain the discharge map of the study area.

4.7 Flood maps

4.7.1 Flood vulnerability map

Historical rainfall data gave the base scenario precipitation for this research work. Landuse characteristics determined the weighted storage coefficients for each of the sub basins and hence their discharges. This is integrated into ArcGIS software to obtain the discharge map for the study area. Discharge map plus the digital elevation model by overlay operation gives the flood vulnerability map for the study area in an ArcGIS model.

4.7.2 Flood prone areas zoning

Geographical positioning system (GPS) is used to obtain coordinates of flood prone areas within the study area. Flood marks and aerial photographs taken of previously occurred floods within GAMA are done. Flood prone location and coordinates are incorporated into ArcGIS platform to obtain the flood prone map of the study area.

4.8 Climate changes impact assessment

Precipitation resulting from direct effect of climate changes is the main parameter for this study. Varied landuse yields changes in the climate system leading to a decrease or increase in the precipitation pattern over the study area. Future changes in the climate system are as a result of changes in landuse and climate factors. The digital elevation model for Accra is used to obtain the elevations and slopes at various locations for the historical impact assessment. Real time field measurements of elevations of identified flood locations are validated with elevations and slopes from DEM measurements for the historical impact assessment. To assess the impacts, elevations are varied as a result of future landuse and changes to build a digital elevation model (DEM). Combining the DEM and the discharge maps at varied elevations in ArcGIS model will give the impacts experienced by GAMA under each of the generated scenarios.

CHAPTER FIVE

5 RESULTS AND DISCUSSIONS

5.1 Climate scenarios generation

The main model used for this research work is the RCSNDIPOA (Regional Circulation Single Distribution Precipitation over Accra) model. Climate change scenarios generation requires future landuse information with historical informations used as the referenced data. These are usually derived from model simulations of present and future landuse likely to affect the climate system. Scenarios generation for this study is basically based on landuse characteristics where parameters like grass covers, parking lots, paved/unpaved roads, business centers, pastures, fallow grounds, reserves, urbanization, water bodies etc. are used. These are the factors that affects the hydrological cycle as there is transpiration, evaporation, base flows, stream flows, infiltrations, evapotranspiration and overland flows. This is what results in condensation and advection forming clouds to precipitate over a catchment. These parameters through the hydrologic cycle will affect the climate system as the years go by hence future changes in the climate system.

The 1995 land cover system is used as the baseline to give the Historical_1995 scenario. Hence the use of the 1995, 249.3mm rainfall which produced the highest floods ever experienced by Accra in recent history as the baseline for the research work. Subsequent future scenarios are then based on changes in the landuse likely to be experienced by the city in the future.

A weight of 0-1 is placed on the landuse parameter based on evaporation, transpiration and evapotranspiration process to contribute to rainfall formation through the hydrologic cycle. The weightings are used to obtain an average weight over a basin and hence the percentage increase or decrease in rainfall based on the historical 1995 rainfall as shown in **Table 5-1**.

Detailed in **Appendix** is the weighting calculation process in order to obtain the percentage increase or decrease in precipitation.

The scenarios generated are HISTORICAL_1995, SDAN_2020, SDIK_2040, SDOK_2060, SDIOL_2080 and SDIOK_2100 with precipitation values 249.3mm, 324.09mm, 149.58mm, 24.39mm, 124.65mm and 398.88mm respectively. For consistency, comparisons and analysis, these precipitations are expected to be experienced for an hour hence the obtained intensities. Percentage increase or decrease in precipitation is based on the amount of water lost or gained during the hydrologic cycle through evapotranspiration, evaporation, transpiration and the greenhouse gases. This is highly based on the future landuse parameters of the basin as future urbanization, vegetation covers, road constructions and other developments are all subjected to these factors.

The **Table 5-1** below gives the summary of the generated scenarios and their precipitations likely to cause floods in Accra. Detailed explanation of the scenarios generation process, RCSNDIPOA model, is shown in the **Appendix 8.1**.

Table 5-1: Generated Scenarios and their precipitations

SCENARIOS	PRECIPITATION(mm)	Intensity (mm/hr)	Δ Precipitation (mm)
Historical_1995	249.3	249.3	
SDAN_2020	326.2	326.2	30%↑
SDIK_2040	149.6	149.6	40% ↓
SDOK_2060	24.9	24.9	90% ↓
SDIOL_2080	124.7	124.7	60% ↓
SDIOK_2100	398.9	398.9	40% ↑

5.2 Discharges Computations

The basic rational model is the best alternative for this study since the research is based on a conceptual lumped model. The 10 basins within GAMA are regrouped into sub basins based on the area of the basin. The general rational formula given as;

$$Q = KCC_S IA \qquad (5.1)$$

Where Q = peak flow (m^3/s), C = runoff coefficient (dimensionless), C_s = Storage coefficient, I = rainfall intensity (mm/hr.), A = Catchment Area (km^2), K = conversion factor = 0.00278. For Q in litres/sec, the conversion factor K = 2.78 is used to compute the *discharges* for each of the sub basins based on the historical rainfall. This is summarized in **Table 5-2** below.

Table 5-2: Sub basins Discharges based on historical_1995 scenario

Name of Basin	Area (Km^2)	Runoff Coefficient (C)	Storage Coefficient (C_s)	Rainfall (mm)	Rainfall Intensity (mm/hr)	Discharge (m^3/s)
Upper Densu	180.93	0.50	0.30	249.30	249.30	1894.446
Middle Densu	247.37	0.50	0.20	249.30	249.30	1726.742
Lower Densu	140.02	0.40	0.30	249.30	249.30	1172.875
Lafa	50.180	0.60	0.20	249.30	249.30	420.3318
Chemu West	13.960	0.70	0.30	249.30	249.30	204.5641
Upper Odaw	83.400	0.60	0.30	249.30	249.30	1047.898
Middle Odaw	117.98	0.70	0.40	249.30	249.30	2305.933
Lower Odaw	124.24	0.75	0.40	249.30	249.30	2601.735
Osu Klottey	13.850	0.70	0.30	249.30	249.30	203.0249
Upper Kpeshie	21.090	0.80	0.50	249.30	249.30	588.8665
Lower Kpeshie	38.990	0.60	0.40	249.30	249.30	653.1979
Songo	21.320	0.60	0.30	249.30	249.30	267.9427
Mokwe	18.950	0.60	0.30	249.30	249.30	238.1014
Upper Sakumo	142.65	0.60	0.30	249.30	249.30	1792.357
Middle Sakumo	101.67	0.70	0.40	249.30	249.30	1987.152
Lower Right Sakumo	59.560	0.70	0.40	249.30	249.30	1164.107
Lower Left Sakumo	37.030	0.80	0.40	249.30	249.30	827.1495
Upper Chemu	55.480	0.40	0.20	249.30	249.30	309.8181
Lower Chemu	81.700	0.60	0.30	249.30	249.30	1026.538

The obtained discharges for the sub basins are integrated into a GIS model to generate the discharge map for the study area as shown below. Lower Odaw generated the highest discharge of 2601.735m^3/s during the 1995 rainfall which is the base rainfall upon which all discharge analysis is based. This resulted in flooding areas like circle, New town causing loss of lives and properties worth BGH₵. Mokwe basin generated a discharge of 238.1014m^3/s and is the lowest during the floods. The map below shows the discharge map for the 1995 rainfall that caused devastating floods within the study area.

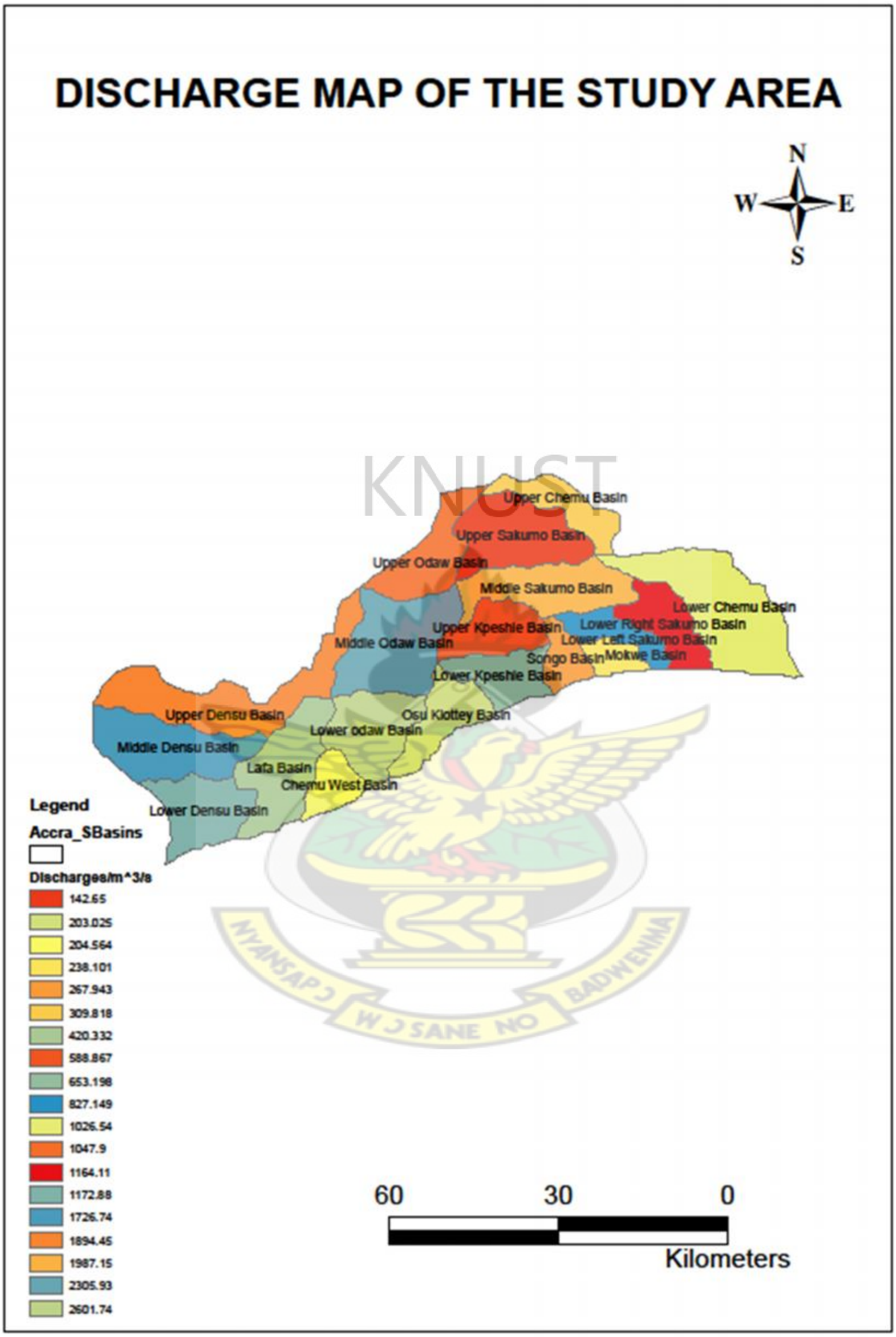

Figure 5-1: Discharge map of the study area

Analysis indicates that the Lower Odaw basin generates the highest runoff at a discharge rate of 2601.735m^3/s. This is attributed to the low lying topography of the sub region. Middle Sakumo basin generated a discharge of 1987.152m^3/s which resulted in high floods with areas like Madina getting flooded. This was seen as a result of poor drainage systems and maintenances. Middle Odaw and lower Odaw basins received discharges of 2305.933m^3/s and 2601.735m^3/s respectively and were recorded as areas that were severely hit during the 3rd July 1995 floods. Areas such as Circle, Newtown, Spintex Road, Christian Methodist, and Zongo Junction were part of the area's most severely hit. 238.1014m^3/s runoff discharge through the Mokwe basins flooded Nungua and other parts of the basin. Areas such as the Upper, Middle and Lower Densu basins generated discharges of 1894.446m^3/s, 1726.742m^3/s and 1172.875m 3/s respectively leading to rise in water levels in the Weija Lake and the Sakumo west lagoon. All the other lagoons received various rises in water levels but not to the extent of causing devastating floods as their outlets is the sea.

5.3 Flood levels, F_L and flood volumes, F_V generation

Modelling runoffs generated in a well-established city like Accra involved a lot of work especially where drainage systems exists. Because this research is a conceptually lumped model, the main paramters considered to generate runoffs are the area of the sub basins, the CN and the precipitation over the basin. Based on the historical data obtained, F_L and F_V are obtained by integrating these parameters in the HYDROCAD software. A 24-hr hydrograph is also obtained for each of the sub basins. **Table 5-3** and **Table 5-4** shows the F_L and F_V for all the scenarios generated.

From the historical scenario, middle Sakumo basin recorded the highest volume of runoff of 352098.220Mlitres at a depth of 124mm. This resulted in floods within the basin with areas like Madina recording high floods. Middle Densu basin recorded a runoff volume of 32292.284Mlitrs increasing the volume of water within the Weija lake hence downstream floods. Middle Odaw received the highest flood at a level of 196mm generating a runoff volume of 21170.5980Mlitrs over the basin. Areas like Accra New town, Circle, Asylum down, Christian Methodist which falls within this basin form the regions where high floods were experienced causing loss of lives and properties worth BGH₵. Lafa basin recorded the lowest flood volume of 9944.722Mlitrs rising to a level of 209mm causing floods but to a minimal extent.

Under the SDAN_2020 scenario generated, the highest flood volume of 743263.39Mlitrs over the Songo basin is recorded flooding to a level of 289mm. Landuse changes being experienced like the construction of the Teshie Nungua Estate is contributing to more impervious surfaces hence more runoff overland. Comparing the flood volume and flood level for the SDAN_2020 scenario with the HISTORICAL_1995, it's possible the 2020 highest rainfall of 324.09mm to be received over the basin will cause serious floods. This can be verified from **Table 5-3** below. Areas like Oyerfa and Frafraha are likely to experience floods in 2020 to a flood level of 214mm generating a flood volume of 145126.43Mlitrs over the upper Sakumo basin. This can be curtailed if proper drainage systems are established.

A precipitation value of 149.58mm in 2040 will result in minimal floods over the middle Odaw basin to a level of 132mm if nothing is done to drainage systems and other flood causing parameters such as building on water ways within the basin. Upper Kpeshie recorded the second highest runoff volume of 469901.34Mlitrs and is been attributed to first class development to be experienced by areas like East Legon and Accra Airport. Lower Densu is likely to receive the third highest runoff volume of 155757.56Mlitrs which will yield an increase in water levels for the Weija lake and the Sakumo west Lagoon. Runoffs around these locations are expected to build up to a level of 112mm under the SDIK_2040 scenario.

SDOK_2060 scenario generated the lowest precipitation of 24.93mm over the GAMA basin. Accra is expected to experience a drastic change in modernization and technology by 2060 therefore improvement in all ministries, resources, systems and levels. Flood levels and flood volumes generated under this scenario are very low hence no flood over the region.

124.65mm precipitation value generated by the SDIOL_2080 scenario resulted in a flood level rise of 225mm over the Lower Chemu basin. Middle and lower right Sakumo basins generated the highest runoff volumes of 629208.159Mlitrs and 603002.276Mlitrs respectively under this scenario. These are the locations where all the Tema communities are located and are seen as the areas with high urbanization rate with various forms of estate developments. Upper Densu recorded the lowest flood level of 20mm with a runoff volume of 3471.814Mlitrs with no flood impacts over the basin.

SDIOK_2100 scenario generated the highest precipitation to be experienced by GAMA over the 105years period. The highest runoff volume likely to cause floods during that period is 176353.89Mlitrs to be experienced over the Upper Odaw basin rising up to a level of 269mm. Accra will experience this precipitation in 2100 should the country continue to experience increase in urbanization and development with no improvement in the drainage sector. Variation in climate over the region will only occur when there is relocation of the city due to urbanization, development and other political factors like what happened in Nigeria. 2100 398.88mm precipitation is likely to result in high floods over the basin because of the high flood levels and flood volumes as depicted in **Table 5-4** and the flood map for the SDIOK_2100 scenario.

Table 5-3: Generated flood levels and flood volumes for the generated scenarios

		HISTORICAL_1995		SDAN_2020		SDIK_2040	
Sub Basin	**Area (Km^2)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**
Upper Densu	180.93	143	24351.1450	83	12408.211	60	10665.743
Middle Densu	247.37	137	32292.2840	192	39973.941	72	16491.614
Lower Densu	140.02	177	21868.0390	208	23001.132	112	155757.56
Lafa	50.180	209	9944.72200	277	13024.412	107	5124.7150
Chemu West	13.960	167	2213.69800	234	2985.5110	118	1547.0980
Upper Odaw	83.400	156	12022.9110	173	13496.209	60	4997.7210
Middle Odaw	117.98	196	21170.5980	277	63366.020	132	364163.22
Lower Odaw	124.24	180	20694.9250	217	23748.843	94	7836.2620
Osu Klottey	13.850	191	26104.2200	289	3852.6160	99	1312.0060
Upper Kpeshie	21.090	197	4045.07800	287	5463.0280	99	469901.34
Lower Kpeshie	38.990	175	6196.57300	284	10060.104	86	2953.0930
Songo	21.320	185	3512.80300	289	743263.39	96	1993.8500
Mokwe	18.950	187	3125.39900	231	4104.6830	69	28228.627
Upper Sakumo	142.65	140	111725.933	214	145126.43	101	94581.887
Middle Sakumo	101.67	124	352098.220	244	23605.691	85	8245.6010
Lower Right Sakumo	59.560	184	9619.89900	283	16427.029	126	294501.76
Lower Left Sakumo	37.030	170	5909.55800	283	10444.623	128	6813.7500
Upper Chemu	55.480	184	14354.6260	211	10872.926	85	3768.0580
Lower Chemu	81.700	168	12643.5940	257	20617.711	125	9732.8180

Table 5-4: Generated flood levels and flood volumes for the generated scenarios

		SDOK_2060		SDIOL_2080		SDIOK_2100	
Sub Basin	**Area (Km^2)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**	**Flood Level (mm)**	**Flood Volume (MLitrs)**
Upper Densu	180.93	7	7315.1440	20	3471.81400	343	59502.033
Middle Densu	247.37	11	20637.595	75	18574.3600	329	79693.325
Lower Densu	140.02	2	5335.8410	28	3812.65800	351	46952.524
Lafa	50.180	-	2354.7960	101	5045.58800	358	17090.071
Chemu West	13.960	4	8103.3410	109	1512.73600	381	5054.6090
Upper Odaw	83.400	2	21144.886	85	7070.30900	269	176353.89
Middle Odaw	117.98	10	1077.7670	67	7814.30900	322	35629.737
Lower Odaw	124.24	7	593.05700	77	9556.10900	337	41594.081
Osu Klottey	13.850	4	53.331000	74	1022.41900	316	4176.6880
Upper Kpeshie	21.090	3	12058.529	78	1586.44700	350	7093.3510
Lower Kpeshie	38.990	3	27630.327	78	2953.22800	327	26267.232
Songo	21.320	3	61.498000	77	1556.66000	321	6680.4470
Mokwe	18.950	7	125.43100	103	1925.53600	295	5454.5180
Upper Sakumo	142.65	3	11043.353	40	69433.0060	355	315163.64
Middle Sakumo	101.67	15	73688.986	82	629208.159	343	34110.824
Lower Right Sakumo	59.560	11	24984.915	84	603002.276	280	9932.9420
Lower Left Sakumo	37.030	15	83960.133	64	3770.33200	194	11313.791
Upper Chemu	55.480	14	21678.334	227	12517.8110	363	19639.837
Lower Chemu	81.700	6	76874.147	225	18373.1000	369	27904.400

5.3.1 Hydrographs Generation

Discharge hydrographs are obtained for each of the sub basins for a given input precipitation under the generated scenarios. This gives the graphical representation of the discharge through each of the sub basins with time. The time for each hydrograph changes as the time for runoff to peak and reach the nethermost level depends on sub basins characteristics and landuse. Obtained precipitation values under each of the scenarios, sub basins areas and CN's which depends on the landuse are input into the HYDROCAD software to generate the hydrographs. Hydrographs showing runoff development is obtained for all the precipitations under each of the scenarios and below is that generated for the upper Densu basin for the precipitation obtained under the HISTORICAL_1995 scenario. Hydrographs results gave the runoff's areas, runoff volumes, and runoff depth or flood levels. This gives a clear indication of runoffs overland liable to cause floods after all artificial and natural drainage systems are filled up.

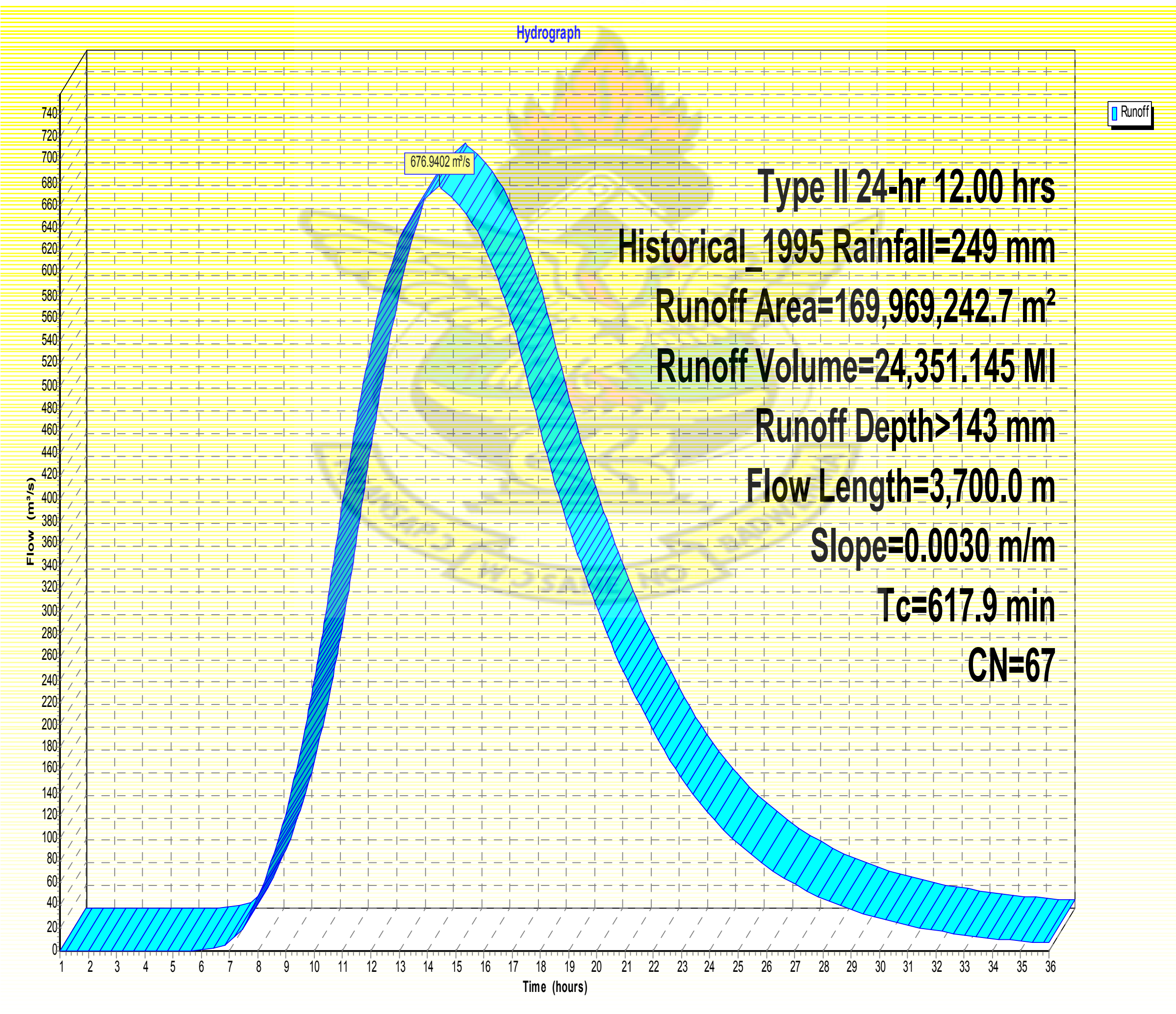

Figure 5-2: Hydrograph obtained for upper Densu basin under the HISTORICAL_1995 scenario.

5.4 Drainage system of Accra

Floods within a sub basin area will occur when all drains and other natural channels have been filled completely. This is the main assumption upon which floods within the study area was based. *That is, floods will only occur when all drains and other natural channels within a sub basin area are filled completely with total overland flow.* In order to assess conveyance structures within Accra, various drains of various sizes and shapes were measured. Most of the drains were underground based but had problems with cleaning and maintenance as most of such drains were filled with debris.

Drains such as the main circle drain have huge volumes of waste deposited in it as depicted in the **Plate 5** below. 1995 floods at Accra circle were attributed to this cause but it's still not rectified. It is now serving as a public toilet to residents around this area as field survey caught a man in the mood. This has reduced the designed capacity of the drain and hence any torrential precipitation that generates runoff up to 2/3 the capapcity of the drain will lead to flow overland. Drain capacity measurement is used to validate the model as in **Table 5-5**.

Most of the measured drains had varied levels of debris disposal hence reducing their design capacities. This is seen in areas like East Legon, Ministries, Kaneshie, Odorkor, Madina, Nima, Alajo just to mention a few. An area like Paloma Hotel has huge volumes of waste deposited in the drains behind the hotel. A washing bay had a huge volume of refuse deposits with its waste water draining into the nearby trapezoidal drain.

Sakama is pigeonholed as one of the most flood prone areas. A 2m×1.45m and a twice 2.45m×2m rectangular drains were under construction to help solve the problem of floods within the area. One major problem observed was the height of buildings. Most of the buildings were up to a height less than 1m with inadequate spacing and drainage networks as depicted in **Plate 7**. Some of the Kaneshie drainage systems are poorly constructed by contractors as some of the drains had their downstream blocked hence the flow directed to upstream.

Underground drains in Accra central needs to be reexamined by the drainage Engineers in Accra as most of the drains are filled with serious waste. Any heavy downpour will cause heavy gushing out of waste overland which will lead to serious health hazards. Drains around the Accra lorry station are not sightly at all as most of the drains have been filled with human waste with maggots feeding on them in the central part of the City.

As stated by the President, His Excellency John Mahama on the 56th Independence Day speech, '*we cannot throw plastic wastes into drains and expect no floods when it rains*' gives a clear indication of his interest in floods management in Accra. Drainage systems in Accra are of utmost importance when mitigating floods hence the need to maintain, upgrade and construct drains in order to manage floods in Accra.

Most of the drains have been nicely constructed but seems to be the ones that are not under constant maintenance with the other ones left unattended to. Various drains are under construction within the study area to manage possible floods likely to be experienced in the future. Such a drain is the 5.0m×2.5m rectangular drain under construction at Nima and some at Sakama. **Table 5-5** gives a clear indication of field based drain type measurements with their constructed capacities and current levels due to waste water or debris deposits.

Table 5-5: Measured drain Sizes within the study Area

Location		***Type of Drain***	***Drain Size***
Building opposite GRA	*A* *B*	*Rectangular* *Rectangular*	*1.4m×14m* *1.4m×0.9m*
Ghana Revenue Authority		*Rectangular*	*1.3m×1.1m*
GRA [Food Joint]		*Rectangular*	*0.65m×0.6m*
Silver Star Auto Ltd	*A* *B*	*U drain* *Rectangular*	*1.1m×0.9m* *1.5m×0.9m*
		Kosmos Energy House	
Kosmos Energy		*Rectangular*	*8.40m×1.90m*

	Kosmos Energy_A	*Rectangular*	*2.80m×1.90m*
	Kosmos Energy_B	*Rectangular*	*2.80m×1.90m*
	Kosmos Energy_C	*Rectangular*	*1.40m×1.50m*
	Kosmos Energy_D	*Rectangular*	*1.40m×1.50m*
	Kosmos Energy_E	*Circular*	*1.40m-D*
		Circle Main Drain	
CMD		*Trapezoidal*	*2.50m×1.80m×2.90m*
CMD with Debris		*Trapezoidal*	*2.45m×1.8m×0.75m*
Joining Drains	*A*	*Rectangular*	*2.90m×2.60m*
	B	*Rectangular*	*2.90m×2.60m*
	C	*Rectangular*	*2.90m×2.60m*
Paloma Hotel	*A* *B*	*Trapezoidal* *Trapezoidal*	*1.20m×4.20m×1.50m* *6.0m×2.40m×0.60m*
Behind Paloma		*Rectangular*	*6.40m×1.50m*
		Kaneshie	
Public Auto parts Front	*Without Debris* *With Debris*	*U Drain* *U Drain*	*1.10m×0.90m* *1.10m×0.750m*
Tertiary Drain		*U Drain*	*0.90m×0.75m*
		Drains with problems	
Kaneshie Fitting Area		*U Drain- No Inlet*	*0.90m×0.80m*
Zongo Junction Area	*A* *B* *C*	*U Drain* *U Drain* *U Drain*	*1.10m×0.70m* *0.85m×0.65m* *1.10m×0.90m*
Abosokai	*A* *B* *C*	*U Drain* *U Drain* *U Drain*	*1.0m×1.0m* *0.65m×0.65m* *0.85m×0.85m*
Total Life Management, Kaneshie		*Rectangular*	*3.30m×1.90m*
		East Legon Sambus Area	
Sambus Entrance A *Sambus Entrance B*	*With Debris* *Without*	*U Drain* *U Drain*	*0.45m×0.50m* *0.45m×0.36m*
Abidjan Street A		*U Drain*	*0.50m×0.45m*
Abidjan Street B		*U Drain*	*0.60m×0.60m*
Abidjan Street C		*U Drain*	*0.70m×0.70m*
Abidjan Street D		*U Drain*	*0.70m×0.60m*
Newmont A	*Without Debris* *With Waste*	*U Drain* *U Drain*	*0.90m×0.70m* *0.90m×0.46m*
Newmont B	*Without Debris* *With Debris*	*U Drain* *U Drain*	*0.60m×0.60m* *0.60m×0.40m*
Newmont C		*U Drain*	*0.70m×0.60m*
Pawpaw Avenue	*Without Debris* *With Debris*	*U Drain* *U Drain*	*0.90m×0.60m* *0.80m×0.60m*
Chris-Idle Infront A		*U Drain*	*0.60m×0.60m*
Chris-Idle Infront B		*U Drain*	*0.80m×0.60m*
Shell Filling Station A		*U Drain*	*0.60m×0.65m*
Shell Filling Station B	*Without Debris* *With Debris*	*U Drain* *U Drain*	*0.60m×0.60m* *0.60m×0.16m*
Ghana Network Link Server	*Without Debris* *With Debris*	*U Drain* *U Drain*	*0.80m×0.90m* *0.80m×0.80m*

Ghana Network Link Server		*Rectangular*	*0.90m×0.80m*
Nima		*Rectangular*	*5.0m×2.5m*
Ministry of Finance A	*Without Debris* *With Debris*	*Rectangular* *Rectangular*	*0.45m×0.60m* *0.45m×0.40m*
Ministry of Finance	*B* *C*	*Rectangular* *U Drain*	*0.40m×0.60m* *0.70m×0.60m*
Geological Survey Department	*G1* *G2* *G3* *G4* *G5* *G6*	*U Drain* *U Drain* *U Drain* *U Drain* *U Drain* *U Drain*	*0.25m×0.20m* *0.4m×0.35m* *0.3m×0.3m* *0.6m×0.5m* *0.6m×0.6m* *0.5m×0.5m*
Electricity Company of Ghana	*A* *B* *C* *D*	*Trapezoidal* *Trapezoidal* *U Drain* *U Drain*	*1.40m×0.40m×0.70m* *2.20m×0.60m×0.90m* *0.75m×0.45m* *0.30m×0.30m*
Ghana Water Company Limited	*A* *B* *C*	*U Drain* *U Drain* *U Drain*	*1.10m×0.45m* *0.57m×0.75m* *0.80m×0.45m*
Statistical Service Department A	*Without Debris* *With Debris* *With Wastewater*	*U Drain* *U Drain* *U Drain*	*0.70m×0.50m* *0.70m×0.40m* *0.70m×0.45m*
Statistical Service Department B		*U Drain*	*0.60m×0.60m*
Statistical Service Department C	*Without Debris* *With Debris* *With Water*	*U Drain* *U Drain* *U Drain*	*0.60m×0.55m* *0.60m×0.50m* *0.60m×0.50m*
Statistical Service Department D	*With Water* *With Water*	*U Drain* *U Drain*	*0.35m×0.35m* *0.30m×0.30m* *0.35m×0.25m*
Ministry of Trade & Industry A	*Without Water* *With Debris*	*U Drain* *U Drain*	*0.50m×0.30m* *0.40m×0.30m*
Ministry of Trade & Industry	*B* *C*	*U Drain* *U Drain*	*0.50m×0.60m* *0.40m×0.40m*
Mateheko T to South Kaneshie		*Rectangular*	*3.0m×2.0m*
Odaw Drain		*Rectangular*	*4.5m×4.0m*
Sakama A1	*A1* *A2* *A3* *A4*	*Rectangular* *Rectangular* *Rectangular* *Rectangular*	*2.0m×1.45m* *2.6m×1.5m* *2.0m×1.6m* *2.5m×1.0m*
Under construction - Sakama		*Rectangular*	*2× [2.45m×2m]*
Sakama B		*U Drain*	*0.9m×0.9m*
Madina-Nsamanpom With Debris	*A1* *A2* *A3* *A4* *A5* *A6*	*U Drain* *U Drain* *U Drain* *U Drain* *U Drain* *U Drain*	*1.4m×0.9m* *1.2m×0.9m* *0.6m×0.6m* *0.65m×0.65m* *0.9m×0.6m* *1.4m×0.7m*

Madina Lorry Station	*B1*	*Rectangular*	*4.0m×1.9m*
	B2	*Rectangular*	*3.0m×1.35m*
	B3	*Rectangular*	*1.2m×0.8m*
	B4	*Trapezoidal*	*3m×1.2m×1.3m*
	B5	*U Drain*	*0.9m×0.6m*
	B6	*U Drain*	*0.65×0.6m*
Dansoman	*D1*	*U Drain*	*0.7m×0.6m*
	D2	*U Drain*	*1.8m×1.2m*
	D3	*Circular Drain*	*1.8m Diameter*
	D4	*U Drain*	*0.8m×0.8m*
	D5	*U Drain*	*0.65m×0.65m*
	D6	*U Drain*	*0.9m×0.9m*
	D7	*U Drain*	*0.6m×0.6m*
	D8	*U Drain*	*0.8m×0.7m*
	D9	*Rectangular*	*3.5m×1.5m*
	D10	*U Drain*	*1.2m×0.9m*
	D11	*Rectangular*	*1.0m×0.9m*
Accra	*A1*	*U Drain*	*0.7m×0.7m*
	A2	*U Drain*	*0.8m×0.7m*
	A3	*U Drain*	*0.7m×0.35m*
	A4	*U Drain*	*1.0m×0.6m*

Plate 5: Main Circle drain

Plate 6: Main Alajo drain

5.5 Flood Prone Areas

Accra is earmarked as the most flood prone city in Ghana. It receives various amounts of precipitation resulting in floods over the basin. Areas like new Weija, Aplaku, Gbawe, Awoshie, Nima, Asylum down, Kwabenya have been earmarked as flood prone areas. A visit to these locations was done and their geographical coordinates taken and input into the ArcGIS model as depicted below in the flood prone map. 2012 has been an exceptional year hence difficult to obtain real time flood marks at the study area as rainy season rains pattern have changed. This is attributed to low amount of water evaporation, transpiration and evapotranspiration process into the hydrologic cycle from water bodies, ocean, plants and stagnant drains, lagoons and the landcover (grass, lawns, pastures, reserves etc.)

Sakama has been identified as one of the areas that have experienced high floods recently and depicting in the plate below is the height of a building in the area. The building has a lot of flood marks and you can see the height of a store being built close to it. These are some of cases that GAMA needs to address to safeguard human lives and properties lost each year.

Plate 7: Flood marks at Sakama

Plate 8: Flood prone Area-Sakama

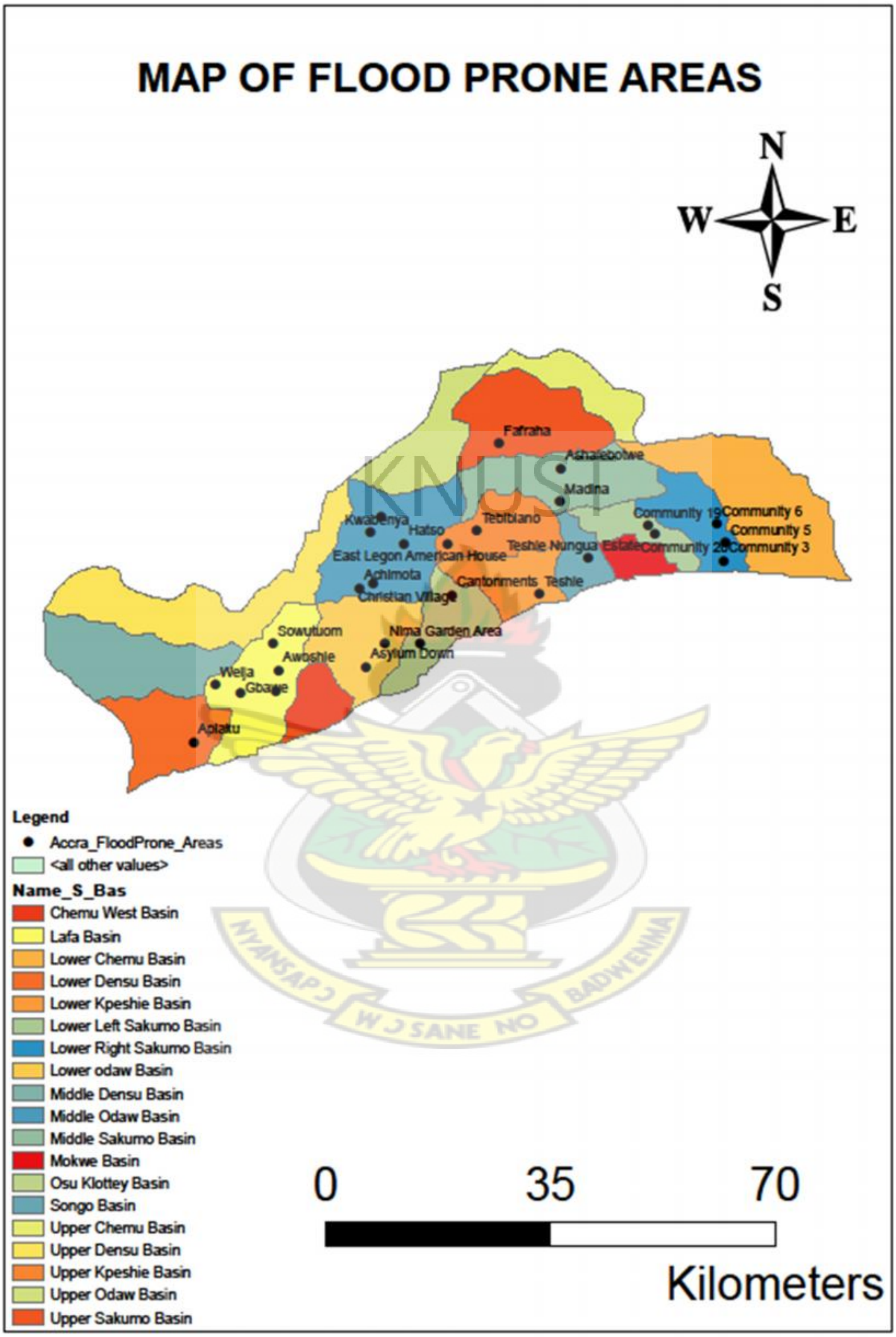

Figure 5-3: Map showing flood prone areas

5.6 Flood Vulnerability Map

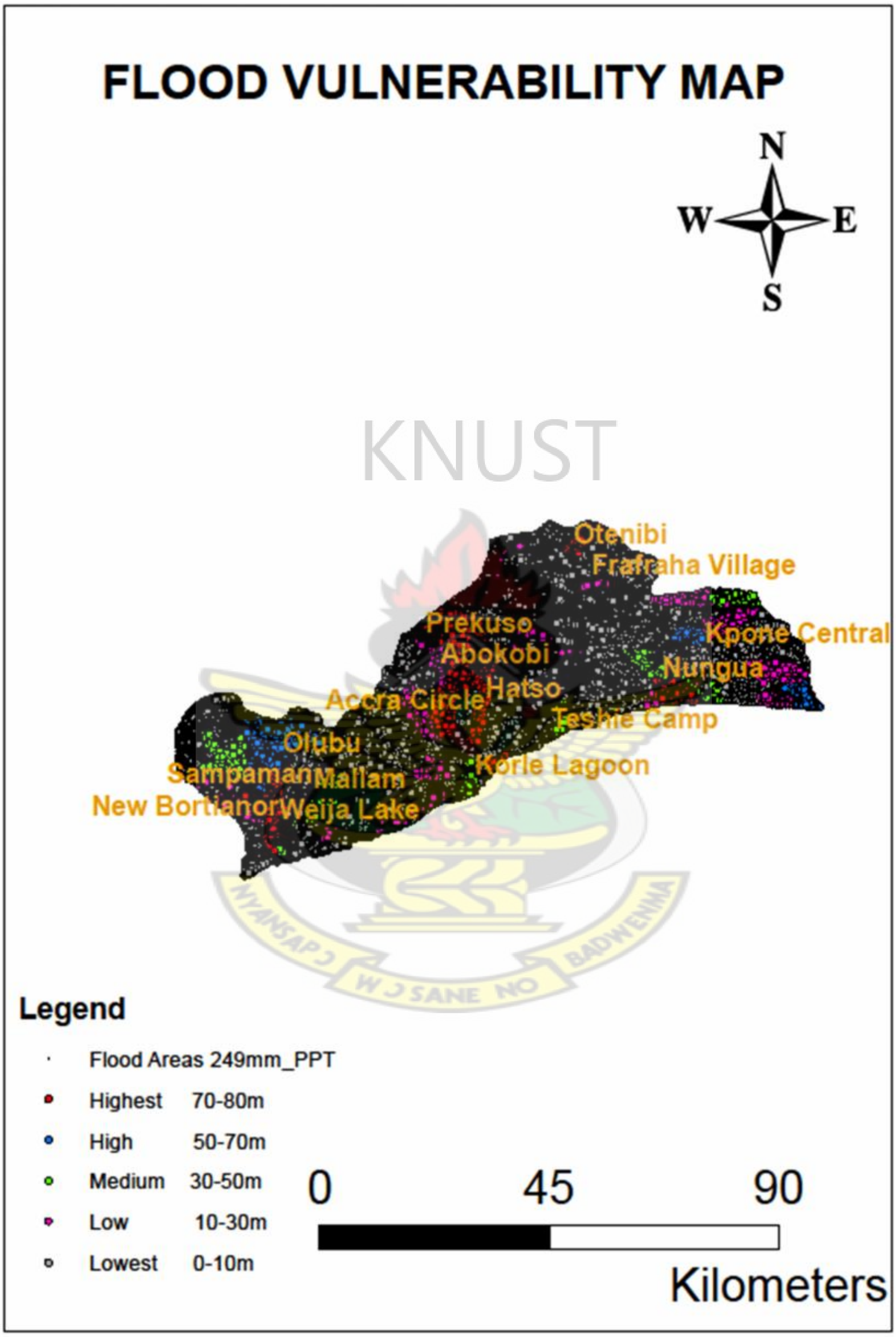

Figure 5-4: Flood vulnerability map

To generate the flood vulnerability map for the study area, highest historical precipitation impacts ever experienced by GAMA is of utmost importance. Vulnerability map generation is based on the highest precipitation recorded since 1968. This is obtained to be the July 1995 249.3mm precipitation that flooded Accra. Discharges, Q, generated by each of the sub basins are combined with a DEM to obtain the flood vulnerability map. This is shown in **Figure 5-4**. Flood impacts are classified into five main categories; highest, high, medium, low and lowest based on the level of harm experienced by the towns or areas.

Areas like Weija, Accra circle, New Town, Zongo Junction, Asylum down, Christian village, Adabraka, Nungua and Otenibi were the areas that experienced the highest floods. Most of the generated runoffs had their outlets as the lagoons toward the sea. Sakumo west, Mokwe, Songo and Kpeshie lagoons are the areas that experienced such floods falling within the high floods impact areas. Downstream towns to the Weija Lake were also impacted by high floods. Areas like Adenta, Kaneshie, Kwabenya and Osu were impacted with medium floods because of the landscape of such areas. Areas falling within elevation height of 10-30m like Achimota, Prekuso, Kissiman and most of the Tema communities experienced low floods. Areas with elevation height of 0-10m are characterized as the lowest flood impacts regions as depicted in the vulnerability map above.

Areas like upper and middle Densu, upper Sakumo and parts of middle Sakumo, upper Chemu and parts of lower Chemu were flooded to various degrees as shown on the vulnerability map. These areas are not urbanized so harms were solely to plants, organisms, vegetative cover, vegetable gardens and food stuffs.

Vulnerability map generated gives the suggestion of areas within the study area susceptible to floods and the extent of destruction. Assessment helped to explore the extent to which experts and Engineers have been able to respond and work to improve these areas. Large drains are under construction in areas like Nima and Sakama to carry high flood waters should there be any high intensity rainfall over the basin.

5.7 Flood Impact Assessment (FIA)

5.7.1 Flood impact assessment (FIA) for SDAN_2020 Scenario

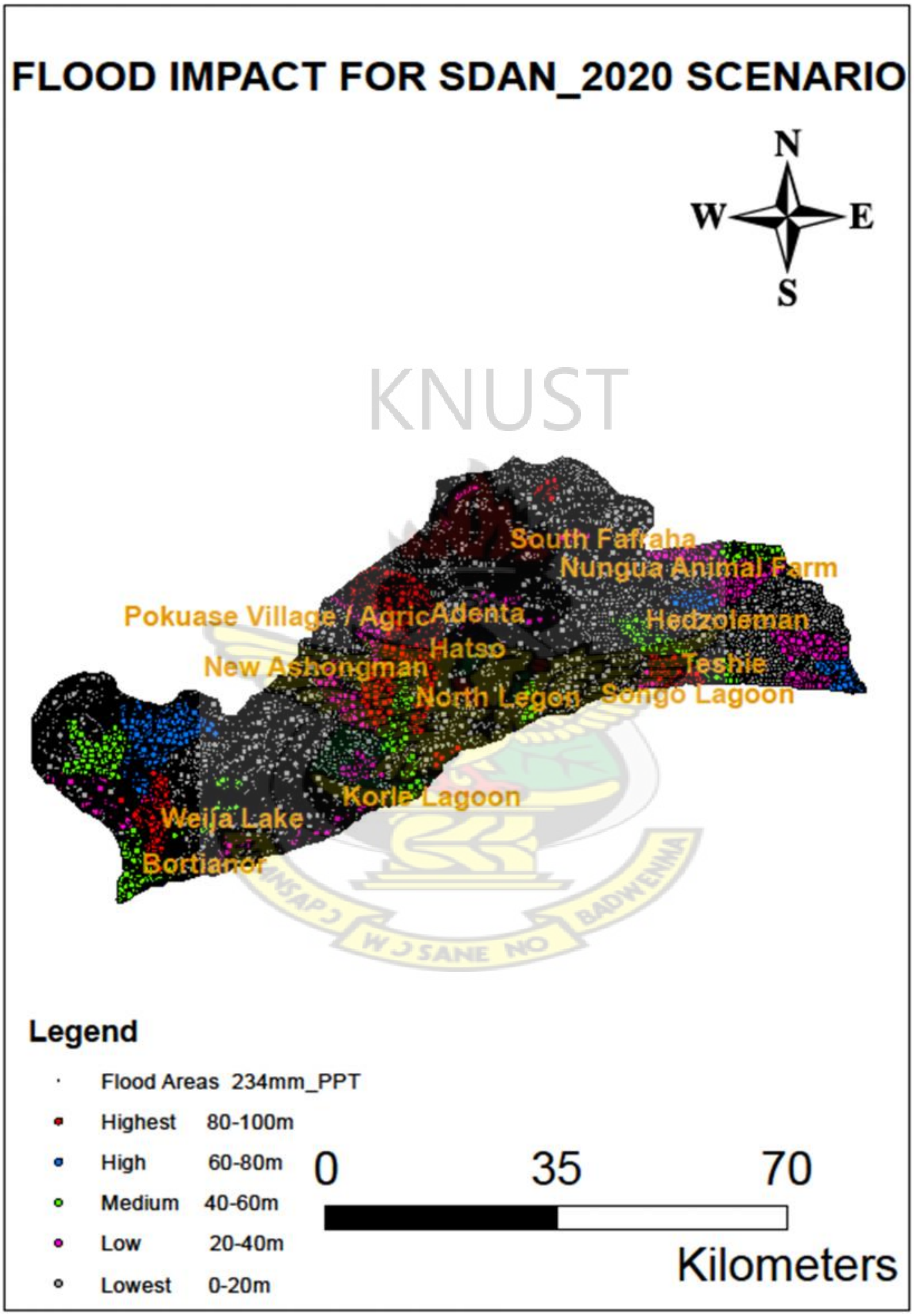

Figure 5-5: Map showing flood impact for SDAN_2020 scenario

The highest precipitation to cause floods under this scenario is recorded to be 234.09mm over the basin which is less than the 1995 precipitation. Projection gives the indication of good drainage system improvement in 2020. This can be compared to the floods that raided the Alajo Township within the metropolis leading to the construction of the new 2.7m×3m rectangular drain to carry storm water runoffs. This scenario resulted in the 2020 possible floods impacts ranging from lowest to medium as shown in the map above.

The Sampaman irrigation development project, Weija, Accra circle, new town and some lagoons are likely to experience medium floods. This will only occur if poor maintenance of drainage systems still exists as shown in the **Plates 11**. Low floods will be ascertained in towns like Bortianor, Hedzoleman, and South Frafraha village all to an elevation height of 40m. Most of the areas will experience low floods especially around upper and middle Sakumo basins. A change in the landuse of the soil will generate varied CN's (SCS method) in HYDROCAD henceforth the runoff overland leading to floods i.e. medium floods at an elevation of 60m.

Most of the lagoons like Korle lagoon, Mokwe lagoon and Chemu east lagoon recorded medium floods due to continual waste disposal into the lagoons. Ghana lacks proper maintenances to natural resources and government properties. These lagoons lack maintenance processes such as channelization and dredging to link the lagoons to the sea since the sea is one of the best natural self-cleansing resources when it comes to water resources. Many experts think flood management during a flood disaster calls for construction of larger drains in the future. This is never true because an old small or medium drain with good network to a large drain can control floods over a whole sub basin or a city. This reason is justified as flood experts and drainage engineers are much interested in building new large drains instead of maintaining the existing old drains.

5.7.2 Flood impact assessment (FIA) for SDIK_2040 Scenario

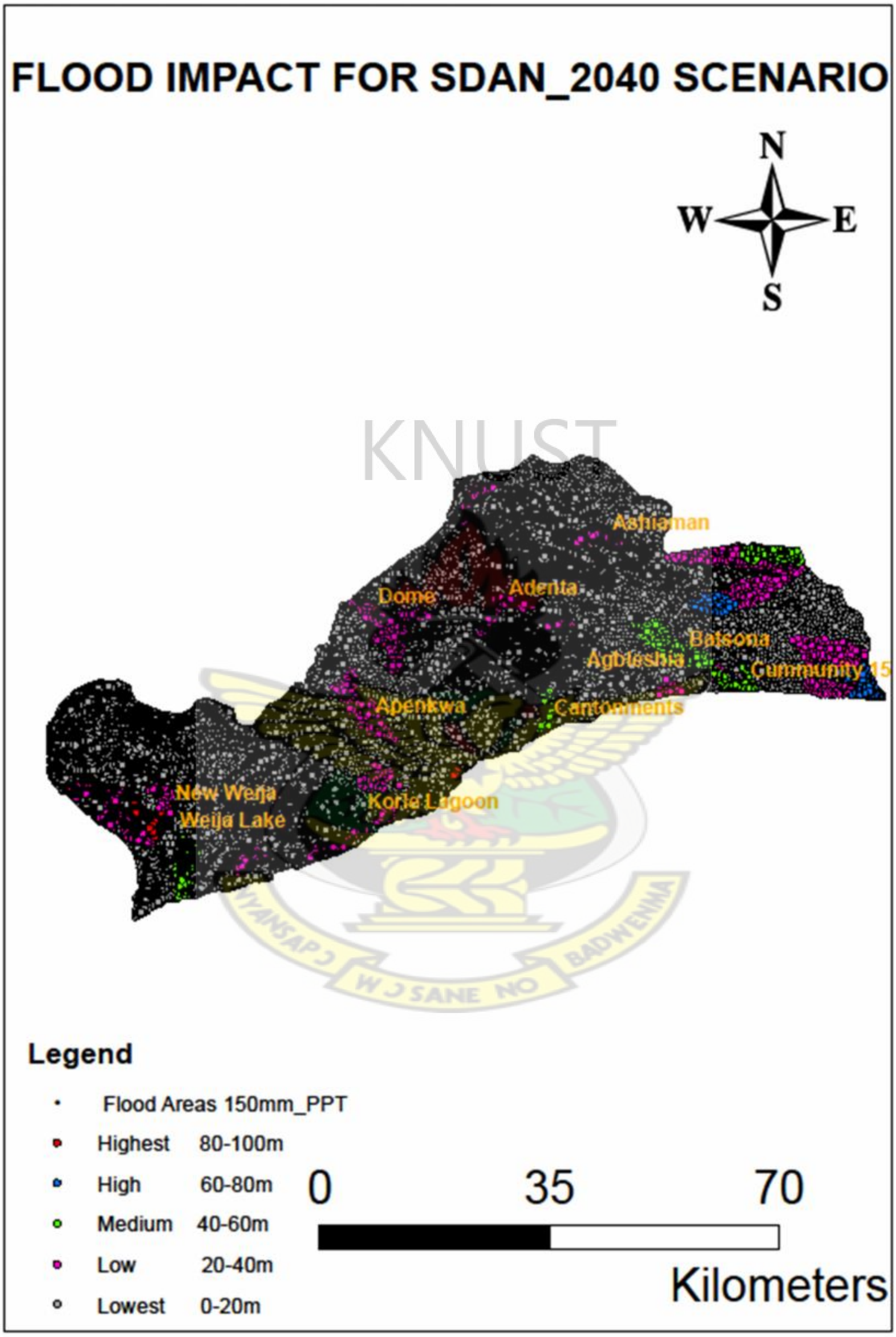

Figure 5-6: Map showing flood impact for SDIK_2040 scenario

Possible floods are expected to occur in 2040 should development within the metropolis cease which is not likely. As migration from the different regions to the capital city of the country continues, urbanization and all forms of city transformation will emerge. This will change the topography of Accra leading to different elevation heights within GAMA. These elevations are expected to cause different patterns of flooding over the study area in 2040. SDIK_2040 scenario projection indicates that Ashiaman is the only town within GAMA likely to experience medium floods at an elevation of 25m.

About 98% of floods expected in 2040 falls within the lowest to low category at an elevation of 20m maximum. Areas like Alajo, Hatso, Keneshie, Kwashieman, Pillar two, Cantonments, Osu are expected to be impacted with the lowest floods. These are floods expected not to cause harm to lives and properties. The Weija Lake, Korle lagoon, Chemu Lagoon, Batsonaa and Chemu east Lagoon is expected to be impacted with medium floods.

The Lagoons will be able to avoid banks overflows as dredging of the Lagoons to serve as touristic sites is a possibility. Parts of upper Densu basin is expected to receive medium floods by 2040. Low floods at maximum elevation of 10-20m are expected to be dominant as Accra is likely to be a well-built city in 2040 with good drainage network systems. Possible areas likely to experience such floods include ministries, community 15 and 20, Ashiaman, Papoa, Dome and Adenta.

Areas around the sea like ministries for instance are being subjected to serious impervious surfaces as inhabitants and workers are afraid of sea intrusion into the arena. This is a real case of landuse change which is going to have a tremendous impact on the climate system. The loose soils containing water have being compacted which reduces infiltration and increasing runoff hence decreasing the water gain during the hydrologic cycle and the precipitation resulting in the anticipated 150mm precipitation as shown in **Plate 9**.

Plate 9: Impervious surface around the sea banks under construction at ministries

5.7.3 Flood impact assessment (FIA) for SDOK_2060 Scenario

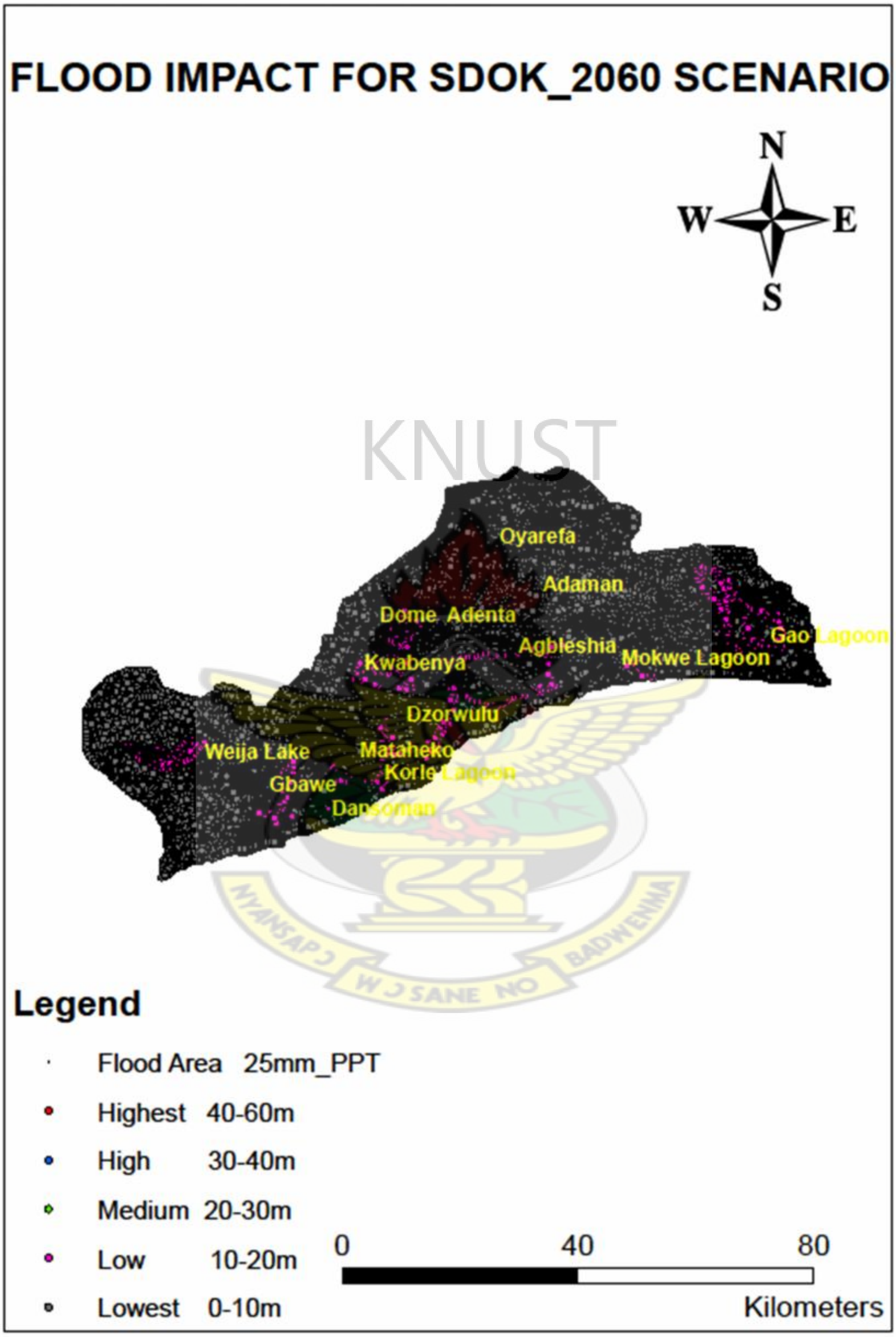

Figure 5-7: Map showing flood impact for SDOK_2060 scenario

SDOK_2060 scenario generated the lowest precipitation value of 25mm as the possible highest precipitation over the basin. Potential floods likely to be experienced are within the lowest to low range. Low floods are expected to flood to a land elevation of 20m over areas like Kwabenya, Mateheko, Agbleshsia, Weija Lake, Adaman and other areas. The lowest floods will be felt over areas like Accra central, Kaneshie, Madina, Achimota, Frafraha, Hatso and Sakumo west Lagoon. These floods will cause small lagoons level rise with no banks overflow.

Flood experts and ground based analysis indicates that 2060 precipitation is of no value in flooding the city of Accra. Interview with the Regional Director of Hydrological Service Department, Mr. W. Ametefeh, indicates that good large drains such as the drains at circle, Sakama, Alajo and Nima are under construction to carry generated storm runoffs within Accra in order to save lives and properties as depicted in the **Plates 10**.

Plate 10: Sakama Drain under construction

Plate 11: Main Circle Drain with waste

Sanitation is expected to play an important role as Accra is anticipated to be a more hygienic city by the year 2060. Education will also play a role as people's attitude towards waste disposal into drainage systems will be abrogated through national laws and other systems.

Data collection phase met one man deficating inside the main circle drain on a broad day light and you can even predict the health implications thereof.

Education and technology is changing the minds of Ghanaians hence better technology is expected to be adopted by Ministries like MWRWH towards good city planning. This will motivate Engineers and estate developers to build estates with good drainage systems to carry storm water runoffs to safe outlets.

5.7.4 Flood impact assessment (FIA) for SDIOL_2080 Scenario

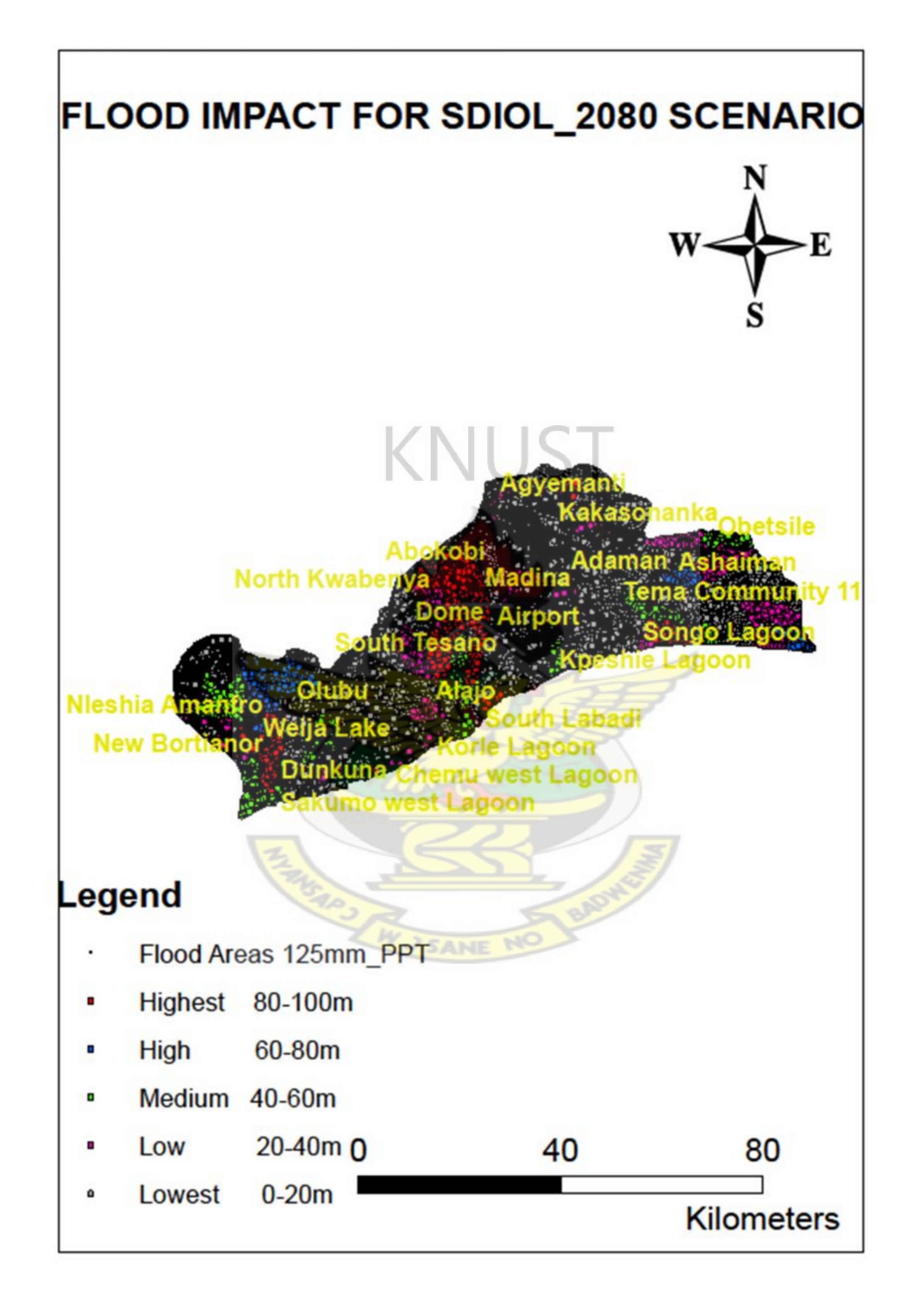

Figure 5-8: Map showing flood impact for SDIOL_2080 scenario

Detailed geological and soil map of the study area are studied in its highest esteem to establish real time soil groups as the underlying rock formation plays a major role in the soil formation. The physical and chemical characteristics of the rocks in most of the basins will change as the year proceeds hence affecting the soil and the hydrological soil groups. This affects the infiltration rate of the soil hence the generated runoffs overland to cause floods. Abstractions play a major function in runoffs generation since CN is directly proportional to how impervious the surface of the soil is.

SDIOL_2080 scenario generated a total precipitation of 125mm with areas like the Weija Lake experiencing the highest floods. Locations around the Weija experiences greater floods because of the rocky nature of the arena as high runoffs find the lake as their outlet. High floods are generated around Ashiaman and Chemu east lagoon. The lagoon is on high floods as it is subjected to high siltation without proper maintenance and dredging. Bortianor and Dunkuna are impacted with high floods up to 40m maximum elevation as the region is a highly natural impervious region.

Cultivation results in decrease in overland runoff due to increase in infiltration and transpiration and interception losses. This is what is expected in some of the basins as green vegetative environment and good drainage systems to carry runoffs in 2080 will be attained. This scenario gives the indication of less vegetative areas like parts of upper and middle Densu, upper Odaw, upper and parts of middle Sakumo being impacted with the lowest floods.

Various factors are predicted to have serious effects on the landuse of Accra influencing the topography of the basins. Factors like electricity systems, drainage system, water system, road construction, telecommunication system and possible natural resources like oil discoveries will affect the water holding capacity of the soil, abstractions and overland runoffs resulting in floods. Most of these systems unbind or compact the soils resulting in an indirect proportion between infiltration and runoff. That is infiltration I_F is inversely proportional to runoff, R_F. Mathematically, $I_F = K / R_F$ where K is the constant of proportionality under the defined factors discussed.

Field data and observations did not meet expert's explanations on drainage designs and maintenances. Huge volumes of waste have been dumped into large drainage systems with various piping's through drains. Drain capacities have been decreased considerably as shown in **Plate 12 and 13**. This decreases the time for drains to be full increasing the rate of floods development. This was experienced around areas like Alajo, Dome, circle and Madina as depicted in the plates below. Can you guess what is happening in **plate 15** on a broad day light? This is what the Engineers and experts need to address to save human lives and government properties.

Plate 12: Piping through drains at Dome

Plate 13: Drain destroyed by high floods

Plate 14: Drain filled with waste & soil

Plate 15: Main circle drain filled with waste

5.7.5 Flood impact assessment (FIA) for SDIOK_2100 Scenario

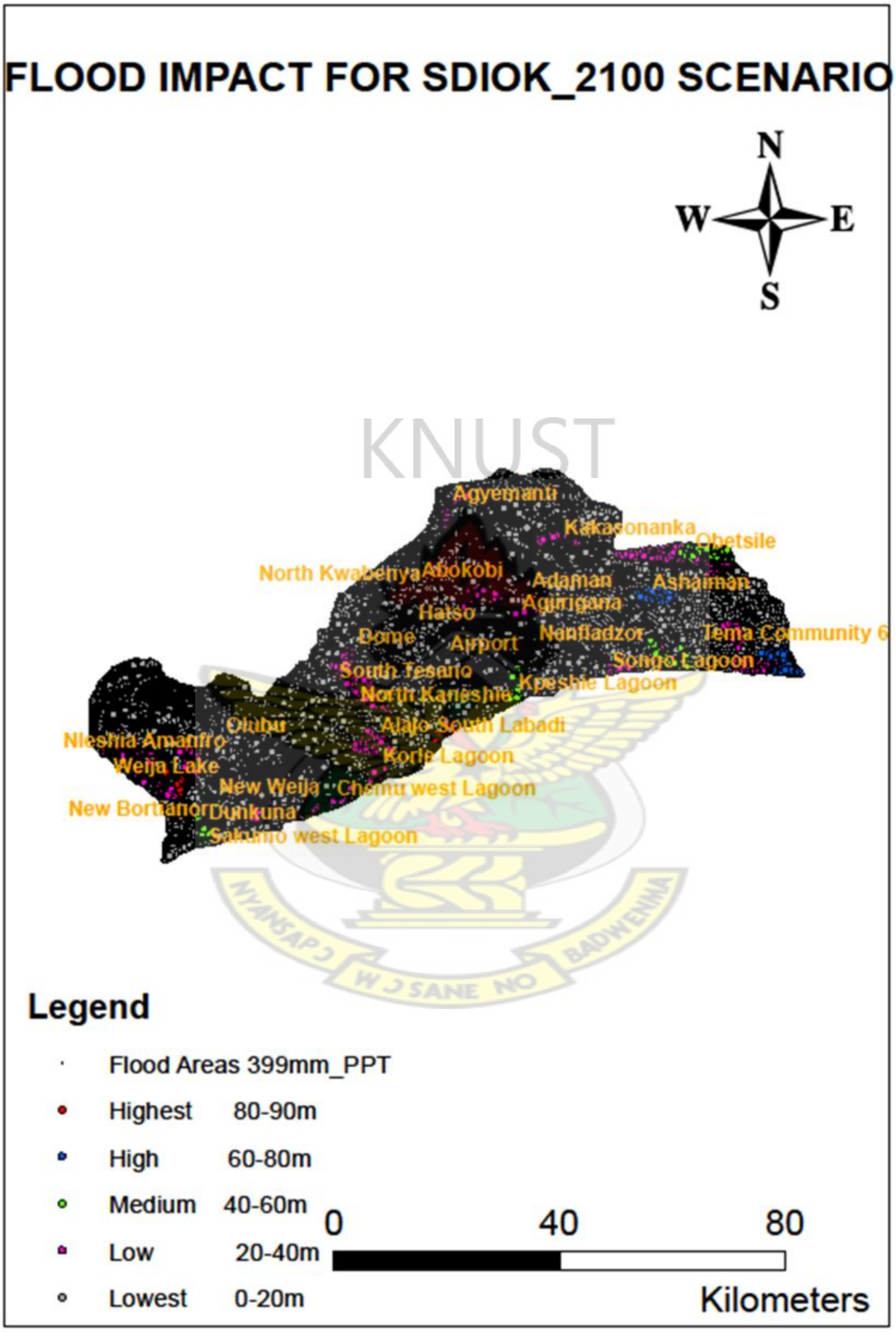

Figure 5-9: Map showing flood impact for SDIOK_2100 scenario

Probabilistic projection of possible precipitation in 2100 is of great value as it gives possible impacts within the study area up to a high level of certainty. In inputting this maximum precipitation into the HYDROCAD and ARCGIS model, flood impacts of different degrees are generated to obtain the 2100 flood impacts map. 87 years from now is a long period hence the likely possible changes in the climate system to be experienced. Not only landuse but atmospheric factors also affect the climate system. Scenarios generation are solely based on landuse characteristics within the study area without atmospheric considerations and neighboring landuse characteristics and the effect of the sea. But then if all these factors are contributing let's say 5% of the total precipitation, then impact effects assessment will be 95% resolved as mitigation measures will be determined based on the determined 399mm.

Urbanization is the main parameter likely to change the topography of the study area and hence the possible impacts over the study area. If a flood expert had predicted in 1980 that Accra will receive its highest precipitation to be 500mm in 2012, various mitigation measures would have been established by experts to mitigate the flood and save flood victims. All drainage systems within the study area and flood prone areas will be identified and precautions established to its highest level. But what has been the precipitation pattern in 2012? Almost 98% dry season. Have we experienced floods? No! This makes scenarios generation for flood predictions and impact assessments an ideal model as people would prepare for such eventualities.

Experts predicted the day and time for a total solar eclipse on 29^{th} March 2006 which lasted three minutes and became a reality then. Ghanaians were able to put in place all forms of precautious strategies to meet this natural phenomenon. Vehicles parked, all activities halted for this effect hence saving lives and properties.

Therefore, if this maximum generated precipitation is predicted up to 95% accuracy, human lives and flood victims will be managed to this level of percentage. This will alert flood experts, NADMO, floods management bodies and people living in flood prone areas to prepare for such eventualities. Depicting on the flood impacts map for 2100 are the various elevations and areas at which floods are likely to occur within the study area.

A general circulation model will yield one precipitation value over the entire country but different values even between neighboring countries. This is when regional circulation models play important roles as precipitation values are obtained from changes in landuse resulting in geographical disorientations. The southern part of the county is constituted to be full of forest with the northern part being savanna desert. This results in floods over the southern part due to high precipitation percentages in the hydrologic cycle over the south and droughts over the northern part. The high percentage in the hydrologic cycle is as result of evaporations, transpirations, evapotranspiration's from sources like large forest zones, streams and rivers, lakes, lagoons and sea rises and the greenhouse gases effects.

CHAPTER SIX

6 CONCLUSSION, RECCOMMENDATIONS

6.1 Conclusion

Scenarios generation for flood prediction and impact assessments depends on landuse characteristics and other atmospheric parameters. Predicting changes in the climate system through scenarios generation based on landuse characteristics is good for conceptual lump flood modeling.

Climate change scenarios generation model is good for flood prediction and can serve as an urban tool for flood management. Estimating likely precipitation in the future (20, 40, 60, 80, 100 years) is very necessary for flood forecasting and management.

HYDROCAD software is good for urban runoff research works for flood level, F_L and flood Volume, F_V computations. This generated F_L and F_V for each of the sub basins within the Greater Accra Metropolitan Assembly. Hydrographs resulting from these runoffs in each of the sub basins are generated to give a clear indication of the rate of peak flows development and hence floods. Integrating discharge maps and DEM's in ArcGIS model through overlay operation helps to obtain flood vulnerability maps and hence assess future impacts based on increase or decrease in precipitations over the GAMA basin.

Landuse characteristics and other atmospheric parameters were identified as the variables upon which the scenarios were developed. Other unidentified natural paramters still exist contributing to total precipitation formation. Predictions' using these characteristics and parameters in precipitation estimation helps to meet the naturally developed precipitation to a higher degree of accuracy for floods impacts assessments.

6.2 Recommendations

In generating climate scenarios, a percentage should be obtained to account for other climate suggestion factors such as ocean or sea paramters, forest zones around the study area (boundary conditions) and wind.

Engineers should work on good drainage designs and maintenances as storm runoffs generated from scenarios precipitations may exceed the obtained values by some minimal amount.

GoG, national policy on city development and other estate developers should work together and if possible have long term drainage design system for Accra so that whoever comes into power continues city planning and flood management from where they reached. This will serve as a platform for all governmental development as changes in the climate is in response to landuse.

Agencies like the HSD should make available important information like flood prone areas and new built up areas to departments like military, NADMO, fire service, town and country planning among others in order to save flood victims in times of contingencies.

Institutions like universities should establish flood research teams composed of students who will focus on serious scenarios generation models and floods assessment methods to manage floods within the Greater Accra Metropolitan Assembly.

GoG should establish laws to address waste disposals and defecations into drainage systems. GAMA regional engineers should work on the huge volumes of silts, soils and wastes deposited in drains reducing the designed size hence decreasing the rate at which runoffs goes overland.

GoG should work with foreign experts in addressing the issue of floods within the city-GAMA as modeling floods on distributed basis requires fine detailed work.

This research considered destruction to lives and properties by floods. Flooding the city can be in other forms such as volcanic eruption, heavy sea rise and ice falls resulting from future changes in the climate. This is an interesting research field which experts needs to take into consideration in order to avoid any form of disaster in Accra. Prediction on lump sum basis is appropriate for large basin areas modeling for climate change impact assessment.

Research areas did not cover upstream contributions such as upstream of Densu. These areas have huge influence on runoff generation downstream hence contributing to floods in Accra. Further research should be done to look at such contributions.

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APPENDIX 8

8.1 SCENARIOS GENERATION (RCSNDIPOA Model)

Table 8-1: Scenarios Generation Process 1

SDAN_2020 SCENARIO					
Basin	**Urbanization**	**Grass Covers/ Gardens**	**Unpaved Surfaces**	**Drainage Systems**	**Road Constructions**
Upper Densu	0.1	0.1	0.1	0.0	0.1
Middle Densu	0.2	0.1	0.2	0.1	0.2
Lower Densu	0.1	0.2	0.1	0.3	0.2
Lafa	0.5	0.1	0.2	0.2	0.3
Chemu West	0.6	0.1	0.2	0.2	0.3
Upper Odaw	0.4	0.2	0.2	0.1	0.2
Middle Odaw	0.7	0.3	0.4	0.3	0.5
Lower Odaw	0.6	0.2	0.3	0.3	0.4
Osu Klottey	0.4	0.2	0.2	0.2	0.2
Upper Kpeshie	0.5	0.2	0.4	0.2	0.3
Lower Kpeshie	0.3	0.1	0.3	0.2	0.3
Songo Basin	0.4	0.2	0.2	0.2	0.2
Mokwe Basin	0.4	0.2	0.2	0.2	0.2
Upper Sakumo	0.3	0.1	0.2	0.1	0.1
Middle Sakumo	0.5	0.2	0.3	0.2	0.3
Lower Right Sakumo	0.4	0.1	0.3	0.2	0.3
Lower Left Sakumo	0.5	0.1	0.4	0.2	0.2
Upper Chemu	0.1	0.1	0.1	0.0	0.1
Lower Chemu	0.3	0.2	0.2	0.2	0.3

Table 8-2: Scenarios Generation process 2

SDAN_2020 SCENARIO								
BASIN	**Farms/pastures**	**Vegetation**	**Reserves**	**Gravel Surfaces**	**Water Bodies**	**Weighted SG**	**P(mm)**	**P_{2020} (mm)**
Upper Densu	0.1	0.5	0.7	0.1	0.2	0.20	249.3	326.18
Middle Densu	0.2	0.2	0.5	0.1	0.2	0.20	249.3	326.18
Lower Densu	0.4	0.2	0.4	0.3	0.8	0.30	249.3	326.18
Lafa	0.3	0.3	0.1	0.2	0.2	0.24	249.3	326.18
Chemu West	0.3	0.3	0.1	0.3	0.4	0.28	249.3	326.18
Upper Odaw	0.3	0.3	0.2	0.3	0.3	0.25	249.3	326.18
Middle Odaw	0.6	0.5	0.2	0.7	0.3	0.45	249.3	326.18
Lower Odaw	0.5	0.5	0.2	0.6	0.5	0.41	249.3	326.18
Osu Klottey	0.3	0.4	0.2	0.5	0.3	0.29	249.3	326.18
Upper Kpeshie	0.4	0.4	0.2	0.5	0.3	0.34	249.3	326.18
Lower Kpeshie	0.3	0.3	0.2	0.4	0.5	0.29	249.3	326.18
Songo Basin	0.3	0.2	0.2	0.5	0.1	0.25	249.3	326.18
Mokwe Basin	0.3	0.2	0.2	0.4	0.4	0.27	249.3	326.18
Upper Sakumo	0.2	0.2	0.5	0.7	0.3	0.27	249.3	326.18
Middle Sakumo	0.4	0.4	0.4	0.5	0.3	0.35	249.3	326.18
Lower Right Sakumo	0.4	0.3	0.2	0.4	0.5	0.31	249.3	326.18
Lower Left Sakumo	0.4	0.3	0.2	0.4	0.5	0.32	249.3	326.18
Upper Chemu	0.1	0.6	0.6	0.1	0.2	0.20	249.3	326.18
Lower Chemu	0.4	0.3	0.4	0.4	0.6	0.33	249.3	326.18
						5.55		

8.1.1 Weightings

A weight of 0-1 is placed on the landuse parameter based on evaporation, transpiration and evapotranspiration process that contribute to rainfall formation through the hydrologic cycle.

Weighted SG = Averaged landuse paramters = Landuse parameter/18

Average Weight over the basin =WSG/18 Average Weight = 5.5/18 Average Weight = 0.3083 = 30.83%

Change in Precipitation due to climate change = 0.3083 * 249.3mm Change in Precipitation due to climate change = 76.8675mm

P_{2020} (mm) = Reference Precipitation + Change in Precipitation due to climate change

P_{2020} (mm) = 249.3mm + 76.8675mm

P_{2020} (mm) = 326.18mm

Landuse parameters were based on various factors such as parking lots, grass covers and impervious areas and so on as depicted in the summary of sub catchments in order to obtain the percentage increase or decrease. This is repeated for the subsequent years to obtain the likely precipitations for the entire basin as shown in the **Table 8-4.** The **P_{1995}** value serves as the reference rainfall upon which all future increase or decrease in rainfall depends on as depicted in the computation above.

Table 8-3: Sub basins with their determined precipitations based on landuse parameters

Sub Basin	P_{1995} (mm)	P_{2020} [30% Increase]	P_{2040} [60% Decrease]	P_{2060} [90% Decrease]	P_{2080} [20% Increase]	P_{2100} [40% Increase]
Upper Densu	249.30	326.18	149.58	24.93	299.16	398.88
Middle Densu	249.30	326.18	149.58	24.93	299.16	398.88
Lower Densu	249.30	326.18	149.58	24.93	299.16	398.88
Lafa	249.30	326.18	149.58	24.93	299.16	398.88
Chemu West	249.30	326.18	149.58	24.93	299.16	398.88
Upper Odaw	249.30	326.18	149.58	24.93	299.16	398.88
Middle Odaw	249.30	326.18	149.58	24.93	299.16	398.88
Lower Odaw	249.30	326.18	149.58	24.93	299.16	398.88
Osu Klottey	249.30	326.18	149.58	24.93	299.16	398.88
Upper Kpeshie	249.30	326.18	149.58	24.93	299.16	398.88
Lower Kpeshie	249.30	326.18	149.58	24.93	299.16	398.88
Songo Basin	249.30	326.18	149.58	24.93	299.16	398.88
Mokwe Basin	249.30	326.18	149.58	24.93	299.16	398.88
Upper Sakumo	249.30	326.18	149.58	24.93	299.16	398.88
Middle Sakumo	249.30	326.18	149.58	24.93	299.16	398.88
Lower Right Sakumo	249.30	326.18	149.58	24.93	299.16	398.88
Lower Left Sakumo	249.30	326.18	149.58	24.93	299.16	398.88
Upper Chemu	249.30	326.18	149.58	24.93	299.16	398.88
Lower Chemu	249.30	326.18	149.58	24.93	299.16	398.88

Table 8-4: Generated scenarios and their precipitation intensities

SCENARIOS	PRECIPITATION(mm)	Intensity (mm/hr)
HISTORICAL_1995	249.30	249.30
SDAN_2020	326.18	326.18
SDIK_2040	149.58	149.58
SDOK_2060	24.930	24.930
SDIOL_2080	124.65	124.65
SDIOK_2100	398.88	398.88

Assumptions

Precipitation over the basin is for an hour duration.

8.2 Precipitation Data for Accra

Table 8-5: Precipitation (mm) data for Accra

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1968	27.2	19.1	10.4	46.2	38.1	80.0	148.3	30.7	73.1	46.2	12.5	3.8
1969	4.1	1.0	33.8	69.9	18.0	60.2	7.90	2.0	14.7	37.1	5.3	5.8
1970	70.9	82.8	17.5	47.0	52.6	40.9	10.9	2.8	15.0	56.4	13.5	19.1
1971	0.0	33.5	34.0	56.6	27.4	66.0	50.5	40.4	26.7	5.3	20.1	10.4
1972	0.3	26.4	31.0	95.5	34.0	64.8	18.0	0.8	20.3	37.9	20.1	2.0
1973	8.2	1.0	31.5	24.1	43.4	175.3	73.9	11.4	46.5	18.0	17.0	14.2
1974	7.9	15.0	42.4	22.9	48.8	86.9	45.0	5.6	34.5	2.8	45.0	16.8
1975	0.0	26.7	42.2	24.6	37.1	93.0	45.5	3.8	39.9	6.1	38.1	54.6

YEAR	JAN	FEB	MAR	APRIL	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1976	52.4	16.5	9.4	47.2	17.3	46.5	9.90	1.8	10.2	75.4	17.0	1.0
1977	2.5	8.9	24.7	63.5	51.8	16.0	0.80	12.5	18.3	62.1	7.4	12.9
1978	0.3	8.4	2.8	30.0	77.5	21.3	13.4	1.8	17.3	23.6	0.3	19.5
1979	0.0	22.7	18.5	32.6	107.7	49.2	24.3	20.7	21.8	79.9	20.1	0.0
1980	0.0	5.3	12.7	85.3	61.7	58.4	63.8	24.4	46.5	23.9	18.0	5.8
1981	2.0	6.3	16.5	13.5	29.0	44.7	60.8	30.9	56.1	29.0	7.1	0.3
1982	17.8	16.8	50.8	60.0	44.2	82.3	28.2	2.0	0.3	12.0	0.5	24.2
1983	0.0	0.0	4.6	16.6	22.3	46.3	1.00	5.1	36.4	2.0	3.5	13.5
1984	9.7	0.0	48.3	42.1	44.7	19.8	34.6	57.1	41.2	19.3	12.2	25.4
1985	4.8	6.6	17.0	33.0	69.5	47.8	17.8	6.9	17.3	23.6	40.1	7.9
1986	0.0	44.7	22.1	11.2	69.3	13.5	14.3	0.5	19.8	37.5	26.7	5.6
1987	3.8	3.3	18.6	17.8	18.8	6.60	16.5	14.0	84.6	44.0	9.1	31.5
1988	0.0	5.6	72.3	31.0	157.9	87.9	80.1	5.0	9.2	39.7	35.6	17.8
1989	0.0	4.1	18.5	59.7	25.7	37.1	62.7	8.6	25.7	27.2	2.3	23.6
1990	9.6	4.9	1.5	54.0	28.2	31.8	19.0	0.2	19.1	12.9	19.4	35.5
1991	13.1	5.5	35.1	87.8	67.1	39.8	157.2	8.1	3.0	43.7	0.4	0.0
1992	0.0	0.0	44.4	55.4	79.3	50.3	17.8	3.1	1.4	19.9	13.4	0.2
1993	20.6	2.7	2.4	51.0	14.9	46.7	4.10	14.0	25.2	16.8	22.6	28.5
1994	24.0	7.1	23.6	6.1	58.9	63.4	3.60	6.9	7.1	22.4	19.9	18.4
1995	0.0	25.9	47.2	36.3	43.7	87.2	**249.3**	4.2	2.1	35.1	54.3	1.3
1996	0.0	28.2	32.8	37.6	50.8	75.3	20.1	11.4	11.9	7.0	12.3	3.7
1997	2.8	0.0	50.4	124.1	28.8	113.7	15.3	2.2	7.8	58.6	40.6	32.3
1998	0.0	8.7	1.5	13.6	58.9	18.6	9.90	0.5	9.8	150.7	14.1	14.6
1999	11.5	21.3	2.6	22.7	40.0	92.8	22.4	14.1	14.3	13.2	8.4	2.4
2000	0.4	0.0	48.2	21.5	42.5	57.0	10.4	6.9	4.0	36.6	25.0	55.4
2001	2.6	28.3	22.1	27.1	51.0	81.1	51.7	10.2	23.2	28.3	26.6	17.8