ENVIRONMENTAL FLOOD RISK ASSESSMENT AND URBAN RESILIENCE BUILDING: THE CASE OF FLOODING IN TEMA, GHANA

By

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Abstract

ABSTRACT OF THESIS submitted by:

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Economic and social livelihoods in the past few decades have been greatly affected by flooding. This is mainly attributed to high-intensity rainfall as a result of climate change factors. However other studies have also pointed out that the incidence of flooding is greatly influenced by several human and environmental factors such as poor waste management, lack of coordination leading to poor development planning, poor drainage design problems, building of illegal structures in water courses and flood plains and rapid urbanization resulting from uninformed changes in land use patterns. In this study a catchment area close to the Sakumonor Ramsar site in the city of Tema was used as a case study as a result of its frequent flooding nature during high intensity rainfall. The aim of this study is to identify the environmental impact of flooding and help build flood resilience by performing an environmental flood risk assessment, make use of GIS data and Jacobs Flood Modeller 2021 software to predict future flood events. The results obtained shows a devastating impact of flooding on livelihoods and environment also future flood simulations indicates intense flooding event due to high rainfall and the inability of the Sakumono Ramsar site to contain much rainfall and channeling it to the sea. Based on these findings, it is suggested that, in order to find a long-term solution to flooding issues, the Government of Ghana must implement a more sustainable urban flood plain management system to be more resilient against future flooding events.

Keywords: Ramsar, Jacobs Flood Modellar, Flood plains

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Chapter 1: Introduction

1.2 Background

Flooding remains one of the natural hazards which impacts the immediate natural and built environment and destroys vegetation, anthropological and ecological habitats (Hague, 2017). Scientific studies for Ghana have shown that the phenomenon of flooding is projected to increase largely due to factors such as changing climatic conditions leading to higher precipitation, hence a corresponding devastating effect on the environment (Ahadzie and Proverbs, 2011). Other critical circumstances that affect the consequence and vulnerability to flooding include urbanization as a result of increasing population growth and demographic dynamics, poor town and housing planning, poorly engineered drainage systems and the menace of solid waste management (Asumadu-Sarkodie et al., 2015). Since the 1800s urbanization and associated negative impact as listed above is a common characteristic in many regions of the world (Ritchie & Roser, 2018).

Currently the UN estimates that more than half the world's population live in urban areas, and it is projected to be about 60% by 2030 and 68% by 2050 with mostly the developing and low-and-mid income countries located in Sub-Saharan Africa (SSA) being the highest contributor (UN,2018). It is also estimated that about 72% of Africa's urban population liven slums (UN-Habitat,2003). The rate of growth of the urban poor in the world's poorest countries is faster than the rate of population growth. Ghana experiences seasonal rainfall patterns in late spring and early summer just like most of the countries in SSA whose capital city, Accra has experienced devastating floods caused by high rainfall(pluvial) and fluvial flooding leading to high surface runoff (Okyere, Yacouba and Gilgenbach, 2013; Amoako and Frimpong Boamah, 2015). Flooding problems in Accra is prevalent in the rainy season for several reasons. Accompanying the climatic extremes such as heavy rainfall that leads to constant flooding in

Accra is its low-lying nature, inadequate and poorly planned drainage systems, silting of water channels as a result of surface runoff School of Earth and Environmental Sciences and indiscriminate dumping of solid waste into drainage systems as well as the surrounding environment which end up choking the water ways during rainfall (UNEP/OCHA, 2011).

The significance of this study stems out of the fact that Ghana is recognized as one of the SSA countries which could be seriously impacted by climate change as a result of its geographic location (Appiah, Asante and Nketiah, 2019). This therefore suggests that with uncontrolled urban growth, poor solid waste management systems and practices, poor flood prevention and emergency systems coupled with the extreme climatic conditions perennial flooding in Accra is likely to get worse in the future. Thousands of occupants in the growing city of Accra continue to suffer the impacts of flooding because responses to flooding have been missing or inadequate due to weak institutions, lack of capacity and political will.

The justification for choosing the Tema Metropolitan area is the fact it is one of Accra's fast and booming growing towns which houses Ghana's biggest seaports (Tema Harbor) with a fast-growing urban population. Also, very close to the catchment area is the Sakumono Ramsar site, also known as the Sakumono Lagoon which covers about 1,340 hectares. A Ramsar site is a wetlands site designated to be of international importance under the Ramsar convention. It is the governments only totally owned wetland, and it is used to safeguard Sakumono, Tema, and their environs from flooding and pollution, as well as fish breeding for the Sakumono Lagoon and recreational activities. On August 14, 1992, it was recognized as a Ramsar wetland site of international significance(MatheusATHEUS, 1993). It is of interest because flooding of the catchment area if not assessed will derail the economic gains that have been achieved over the years as well hampering the economic and future growth of Tema also known as the Harbor

City and Ghana as whole. The Port of Tema is not only important to the economic fortunes of Ghana but also the gateway to landlocked neighbors i.e., Burkina Faso, Mali, and Niger.

1.3 Aims

The frequent flooding of the capital city of Ghana, Accra and for that matter Tema Metropolitan area needs a comprehensive and pragmatic approach to forestall or reduce future impact of flooding in Tema which has the potential of hampering the basic wellbeing of its inhabitants. The main aim of this study is to perform an environmental risk assessment with respect to flooding that will contribute to making the Tema Metropolitan area a flood resilient city in the future. The study also aims to use the Jacobs Flood Modeller Software (2020) to simulate the extent and impact of flooding of both current and future scenarios. The output of the simulated scenarios will be used to compliment emergency planning to improve response time and prevent extensive damage to life and property in the event of an unpreventable flood situation in the future.

1.4 Objectives

This study will use quantitative, qualitative approaches, Environmental Risk Assessment processes and flood modelling software to achieve below objectives:

1. To understand the changes in rainfall patterns in Accra (Tema Metropolitan area) and its impact on the extent of flooding.

   a) This will be achieved by reviewing annual, monthly, and daily rainfall intensity data, (ratio of the total amount of rain (rainfall depth) falling during a given period to the duration of the period) from the Meteorological Department office in Accra.

b) By reviewing literature, news reportage and articles on flooding incidents in Accra (Tema Metropolitan area) in past and the extent of devastation caused to both life and property, cost to the nation and cost of recovery.

2. To know how vulnerable Accra and the Tema Metropolitan Area is to flood and the efforts that have been made to mitigate the impacts of flooding.

a) By reviewing literature and documents form the Ghana Meteorological Agency.

3. Using the Jacobs Flood Modeller Software (2020) to simulate current and future of the extent flooding and its possible impact the Tema Metropolitan area.

a) This can be achieved simulating different current and future rainfall volumes through the software to see the extent of flooding and which critical infrastructures will be impacted.

4. Performing an Environmental Risk Assessment with respect to flooding for the Tema Metropolitan area to ascertain the extent of possible impact of flooding on the environment as well as the mitigation and control measures to put in place.

a) This can be achieved by interviewing and taking responses from locals with regards to the extent to which their livelihoods and economic activities are impacted by flooding in the past and current occurrences.
b) Interview and document responses from locals to know their views concerning the contributing factors to the extent of flooding and their vulnerability.
c) By researching and reviewing available documentations with respect to flood emergency response planning at the local assembly level in the Tema Metropolitan Assembly.

1.4 Scope

This research study's the environmental impact of flooding due to changing rainfall patterns in the context of climate change in the Tema Metropolitan Area. The catchment includes areas within Tema community's 3,5,6,11 and 12 located close to the Sakumono Ramsar lagoon site. These sites were chosen because they are the most affected during floods in the Tema Metropolitan Assembly area. The area lies along the coastal savannah zone and near the Tema Harbour, it has a flat topography and is part of the coastal lowlands, rendering it vulnerable to flooding(Ghana Statistical Service (GSS), 2014).

The study further uses the Jacobs Flood Modeller Software (2020) to simulate current and future extent of flooding using changing rainfall patterns and its possible impact on the activities and livelihood of communities within the catchment area.

1.5 Organization of the study

The following sections make up the study's structure:

- Chapter 1- Provides an introductory background on flood risks and includes the aims, objectives and scope of this research.
- Chapter 2- This consist of the literature review with overview of flood risk at global level, Flood risk in Ghana and the Tema Metropolitan Area. It also discusses the environmental effects of flooding within a catchment, current and future rainfall patterns as a result of climate change, and 2D Direct Rainfall Modelling (DRM) utilizing Jacobs Flood Modeller Software (2020). Another subchapter is dedicated to the detailed application of the flood modelling software.

- Chapter 3- This chapter describes the research methodology describing the process of identifying the catchment area, data collection and data analysis. It also covers the step-by-step processes of the environmental flood risk assessment and the 2D Direct Rainfall Modelling (DRM) input data, the modelling approach and justification.
- Chapter 4- Results and discussion of field survey and flood simulation.
- Chapter 5- Limitations
- Chapter 6- Summary and Conclusions
- Chapter 7- Recommendations

Chapter 2: Literature Review

2.1 Flooding

Flooding occurs when water oversaturates the ground as a result of precipitation, overflows from water bodies, or high tidal waves along coastal zones (Kusimi & Yeboah, 2019). Floods are the natural hazard with the greatest frequency and geographical spread on the planet. Although most floods are minor, monster floods do occur on occasion (Chandrappa et al., 2011). Localized flooding due to insufficient drainage, flooding from small streams within the built-up area, flooding from major rivers, and coastal flooding are the four types of flooding in urban environments (Kusimi & Yeboah, 2019). Flooding can have disastrous consequences, causing substantial disruptions in electricity, water, communication, transportation, interfering with public services, having a huge impact on the environment, cultural heritage, causing pollution, changing habitats, and causing migration (Asumadu-Sarkodie et al., 2015).

2.1.1. Causes of Flooding

Flooding is most often caused by heavy rains when natural watercourses are unable to transport excess water. It can also be caused by other occurrences, such as a storm surge linked with a tropical cyclone, a tsunami, or a high tide, particularly in coastal locations (Chandrappa et al., 2011). Flooding can occur when the amount of precipitation in a given area exceeds the soil's evaporation rate and infiltration capacity. The majority of flood damage is caused by extreme, intense, and long-lasting floods caused by meteorological phenomena such as prolonged and intense rainfall/precipitation, cyclones, storms, tidal surges, and drainage alterations when paired with heavy rain (Braimah et al., 2014).

2.2 Flooding as a global risk

Floods are the most common natural disasters in the world, affecting both rural and urban areas (Kusimi & Yeboah, 2019). Floods have a de facto catastrophic effect on the global level. Flooding in Cumbria in 2005 and 2009, as well as severe flooding in England in summer 2007, resulted in fatalities and had a significant impact on the health and well-being of people living and working in the affected areas. The floods in July 2007 cost more over £3.2 billion, with the floods in Cumbria in 2005 incurring £450 million in damage (Asumadu-Sarkodie et al., 2015). Approximately one-fifth of Pakistan's territory was flooded in 2010, affecting 20 million people and claiming nearly 2,000 lives. The economic damages were anticipated to be in the billions of dollars. A year later, another massive flood wreaked havoc throughout Southeast Asia. The floods hit sections of Thailand, Cambodia, Myanmar, and Vietnam, and a few smaller flood occurrences damaged areas of the same countries: Thailand, Cambodia, Myanmar, and Vietnam. In the meantime, the Lao People's Democratic Republic was flooded, with a death toll of about 3,000 people (Chandrappa et al., 2011).

2.3 Flood risk in Ghana

According to literature, Ghana, particularly Accra, has been swamped with flooding throughout the last decade, with the most recent instance occurring on June 10, 2016. Floods are Ghana's second most common natural disaster, claiming the lives of over 400 people on eighteen (18) occasions. In addition, an estimated total of 3.88 million people has been affected, with damages totaling more than one hundred and eight (108) million dollars. The 3rd June 2015 and 10th June 2016 floods are not included in these figures. As a result, urban flooding is unmistakably becoming a growing development issue in Ghana (Asumadu-sarkodie & Rufangura, 2016). The massive expansion of many cities in Ghana, along with lax adherence to development restrictions, has made cities exposed to a variety of natural disasters. Floods have become an ongoing issue in Ghana's major cities and low-lying towns. Low-lying locations, by definition, are prone to flooding (Dekongmen et al., 2021). However, there are other rural communities in Ghana (particularly in the Upper West Region, Northern Region, Upper East Region, and Afram Plains) that are not in low-lying areas but have been experiencing flooding as a result of overbank flooding caused by the spill of excess water from the Bagre and Kampainga dams (Dekongmen et al., 2021). Worryingly, the Accra Metropolis has been overwhelmed with flood disasters on a regular basis since 1968. Between 1968 and 2014, 415 individuals died as a result of flood disasters in the city, which has a population of about 3.86 million people (Dekongmen et al., 2021).

2.3.1 Causes of Flooding in Ghana

One of the major reasons of the June 3, 2015, flood was an obstruction of the Odaw river's mouth, which prevented water from flowing into the sea. Many lives and possessions were also lost as a result of the repeated floods that occurred between 2016 and 2019. Some researchers attribute the recurring floods in Accra to several contested factors, including the city's low-lying area, poor planning, drainage networks (choke drains, underside drains, etc.), massive city expansion, increased impervious surface area, mismanagement of surface water resources due to uncontrolled rapid urbanization, and the construction of residential and commercial structures on waterways. Other researchers attributed the city's developmental plan's poor flood management method, poverty, climate change variability, and the placement of residential and commercial structures along streams for the ongoing devastation (Dekongmen et al., 2021). Poor drainage, among other factors, has been blamed for the recent severe flooding in Accra. Even while some research has been done to map out flood-prone zones in Accra, nothing is known about the regularity with which such catastrophes occur (Kwaku & Duke, 2007).

Figure 1: Geographical location of Ghana

Source: www.mapsoftworld.com, 2022.

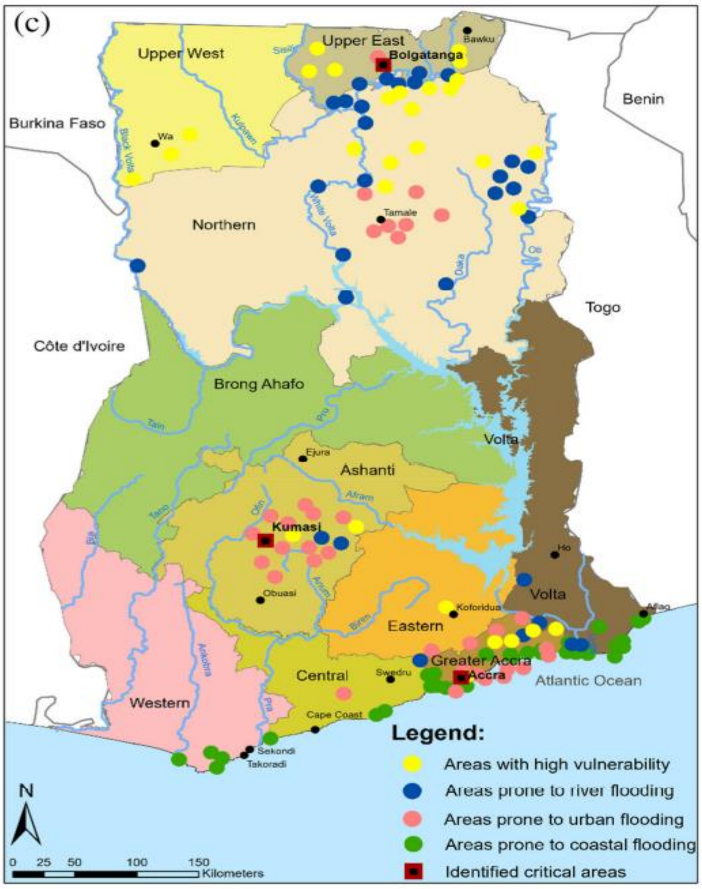


Figure 2: Flood Risk Map of Ghana
(Before the introduction of the six new administrative regions)

Source: (Almoradie et al., 2020)

2.4 Study of the Tema Metropolitan Area (TMA)

2.4.1 Location and Size

Tema Metropolitan Area is a Metropolis in the Greater Accra Region. Tema, the country's capital, lies 25 kilometers east of Accra, the country's capital. The region covers an area of roughly 365.78 km2 and is located between latitudes 5 3500N–55000N and longitudes 0 1000W–0 0500E. The Adenta and Leedzokuku Krowor municipalities border the metropolitan area on the west, the Ga East and Akuapim South municipalities on the north, the Dangbe West district on the east, and the Gulf of Guinea on the south. The newly formed Ashaiman municipality is located in the heart of the area. The Tema Metropolis is located in the coastal savannah vegetation zone, which receives low annual rainfall of 800 mm spread over 80 days (Ghana Statistical Service (GSS), 2014). The area's rainfall pattern is bimodal, with the main rainy season occurring between April and mid-July and a smaller wet season occurring around October. The average monthly temperature is 24.7 degrees Celsius, with an annual average of 26.8 degrees Celsius. Because of the region's proximity to the equator, daylight hours are nearly constant throughout the year. The relative humidity is high, ranging from 65 percent in the day to 95 percent at night. The metropolis' vegetation is mostly shrub and grassland, with scattered trees only found on the northern outskirts of the city, on the foothills of the Akuapem-Togo mountain range (Amenyo-Xa, 2017).

In the Ghanaian seas of the Gulf of Guinea, the Greenwich Meridian (i.e. Longitude 0^o) crosses through the Metropolis, which meets the equator or latitude 0°. The Metropolis' proximity to the sea, combined with its low-lying terrain that projects into the water, makes it an ideal location for a port. This influenced the decision to build the Tema Harbour in 1957, establishing the Metropolis as Ghana's "Eastern Gateway."

2.4.1 Topography

The Tema Metropolis has a flat topography and is situated on the coastal plains. The district's land only rises to 35 meters above sea level. The land's practically flat nature makes it flood-prone, but it also makes it ideal for agriculture and development. The only major constraint to this strength is the region's irregular rain fail pattern.

2.4.2 Climate

Because the Metropolis is in the coastal savannah zone, it has a dry equatorial climate. The rainy season lasts from April to July (main rainy season) and September to November (secondary rainy season) (minor rainy season). May, June, and early July are the months with the most rain. All year, temperatures are hot, with substantial daily and seasonal changes.

Because Tema is an industrial hub, some sections have been designated as greenbelts due to the lack of forest reserves (zones) to regulate the microclimate of the city (climatic condition in relatively small area). In recent years, the number of industries and waste produced generated in the Metropolis has increased without a proportional rise in afforestation to absorb extra carbon mono-oxide produced by the companies. Green belts are also being invaded. This has resulted in changes in weather, as well as consequences such as biodiversity loss and irregular rainfall patterns.

2.4.3 Vegetation Cover and Soil structure

The vegetation zones in the Metropolis are shrub land, grassland, and woodland. Sand, clay, humus, gravel, and stone make up the soil in Tema Metropolis. The sandy and humus nature of the soil supports vegetable cultivation, an aspect of clayey nature which impacts on general construction. The Metropolis also has some metamorphic rocks primarily composed of granite, gneiss, and schist were most likely produced from sedimentary layers. These stone formations are weathered or decomposed at the surface, and their thickness in the area does not exceed 12 meters.

2.4.3 Drainage and Sanitation

There are seasonal streams in the Metropolis. During the rainy season, most of the streams run into the sea through depressions. The Gynakorgyor (which flows into the Gao Lagoon between Manhean and Kpone) is one among them. The Chemu Lagoon, located between the port area and Tema Manhean, collects industrial liquid waste and water from the eastern side of Manhean Township. Pollutants, particularly those originating from industrial liquid waste, may be to blame for the lagoon's aquatic life's demise. The Sakumono Lagoon collects wastewater as well rainfall channeling it to the sea and performs a critical function of containing most of the surface runoff water during high intensity rainfall.

2.4.4 Administrative Land Management

In the Tema Metropolis, there are two district planning areas: the Tema "Acquisition Area," which is managed by Tema Development Corporation (TDC), and the Tema "No Acquisition Area," which is managed by the Tema Metropolitan Assembly's Town and Country Planning Department despite being owned by various traditional authorities (TMA). The Land Use Plan for this area was formed in 1960 and was based on community self-sufficiency and neighborhood planning. As a result of this situation, planning functions have started to overlap, resulting in numerous conflicts between the two planning authorities. Most people believe that TDC's development permits are frequently cancelled by TMA, and vice versa.

2.4.5 Economic Activities

The Tema Harbour, which was inaugurated in February 1962, is the epicentre of the Metropolis' economic operations. It is located on the Greenwich Meridian, 28.5 kilometres east of Accra, and has the necessary infrastructure to meet the country's planned growth in trade and industry. With approximately 500 companies producing chemicals, clothes, consumer electronics, electrical equipment, furniture, machinery, refined petroleum products, steel, and tools, the Metropolitan Area serves as Ghana's industrial hub. Tema is home to the country's largest port and harbour facilities. These contribute significantly to the state's revenue, but not much to the Tema Metropolitan Assembly. The Assembly is working with enterprises in the shipping industry to mobilize enough income from the Port to reverse this trend. A canoe beach is also available, where smaller boats and canoes can be moored. It has a fish market on the premises to facilitate sales.

2.4.5 Size, Structure, and Composition of the Population

Tema Metropolis has a population of 560,521, accounting for 10.1% of the region's total population. Males make up 48.3% of the population, while females make up 52%. Furthermore, the population is entirely concentrated in metropolitan areas (Ghana Statistical Service (2021).

2.5 Flood Risk in the Tema Metropolitan Area

The Tema Metropolitan Area, which is part of the larger Accra region, has been hit by flooding in several parts of the city, notably in low-lying neighbourhoods. According to a study conducted by the Greater Accra Metropolitan Area (GAMA), which includes Tema Metropolis, several locations of GAMA in the Very High flood risk zones have heights of less than 50 metres above sea level (for example part of Lashibi which is in the Tema Metropolitan Area). The survey also found that present flood zones are primarily in the Ashaiman, Ledzokuku-Krowor, Ga-East, and Ga-South districts, rather than the AMA, Ga-West District, Adentan Municipal, and Tema Metro districts (Kagblor, 2016).

2.6 Discussing the Impact of Flooding within the TMA

Flooding is regarded as one of the most dangerous natural risks to human societies. Floods have an impact on the economy, society, and most aspects of human life, particularly in metropolitan areas where the risk to people and property is greatest(Tsakiris, 2013).

Fluvial, pluvial, tidal/coastal, groundwater, and urban flooding all pose a threat to people's lives and property, as do other types of flooding, such as urban flooding. Urban areas face the greatest danger from pluvial flooding of any of these categories. It is common for rains of short length and high intensity to create surface water runoff, which in turn leads to pluvial floods. Ghana experiences both fluvial and pluvial types of flooding Studies on the causes and impact of the floods, notably in the nation's capital, abound in the literature. Accra's geography is naturally low-lying, and flooding will continue indefinitely unless otherwise well prepared. In most parts of Accra and several of its surrounding regions, a deluge wrecked devastation on property. Residents of Adabraka, Kisseman, Alajo Junction, A-Lang at Santa Maria, Oyarifa, Haatso, Adenta, and the Tema Timber Market had their property flooded or carried away. According to Ms Felicity Ahasianyo of the Meteorological Services Agency, the rainfall totaled 71.5 mm from 9.30 p.m. to approximately 3 a.m., which she described as "very heavy" (Asumadu-sarkodie & Rufangura, 2016).

In addition according to the final Technical Report of the IDRC Cities & Climate Change Project, TMA has had fewer than one flood incident in seven years, compared to AMA, which has had no flooding in that time period.The change from AMA to TMA discretely reduces the risk of a flood occurring once every seven years by 24%, all other variables being maintained constant. In other words, TMA experiences more floods than AMA does on a regular basis(Rips, 2020).

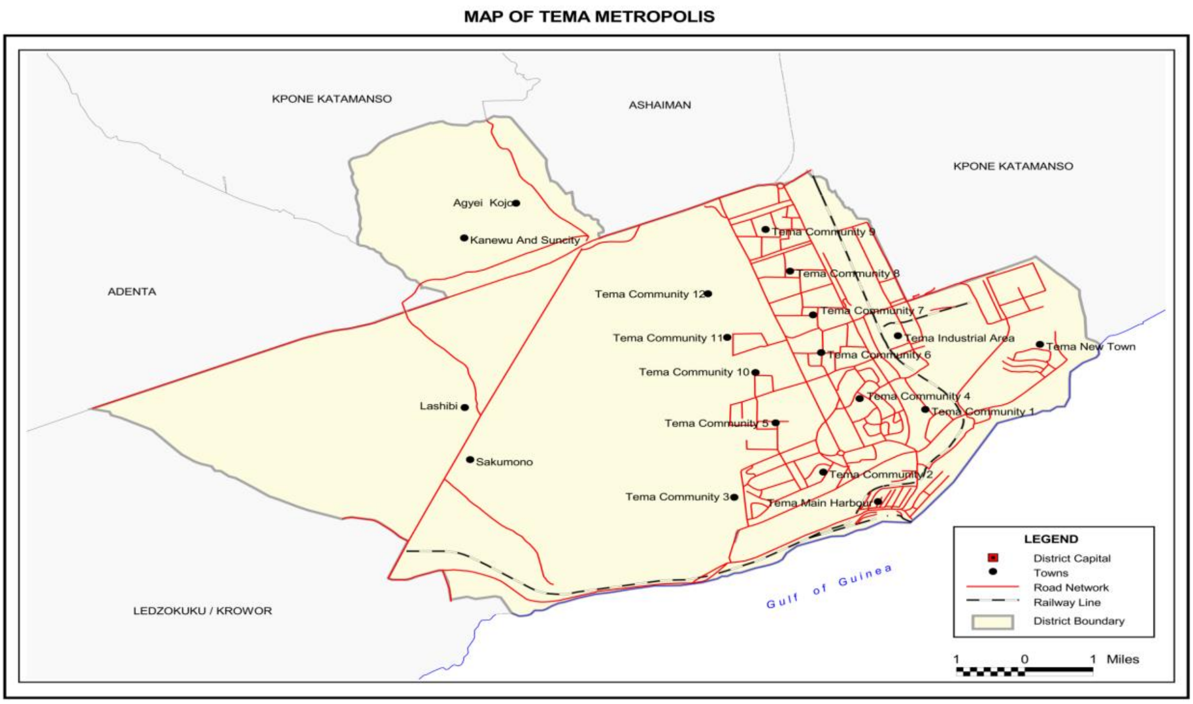


Figure 3: Map of Tema Metropolis

Source: Ghana Statistical Services (GIS)

2.7 Techniques for Flood Modeling

The rapid reduction in computational cost over the previous few years has enabled academics to simulate flood risk in real-world case studies using 2D models(Bellos & Tsakiris, 2015).

There are numerous sorts of flood modelling approaches to choose from; the choice of modelling techniques is determined by time scale, financial constraints, and necessary outputs. Direct rainfall 2D model (DRM) has been increasingly appealing to modellers over the last decade owing to its advantages, while it does have certain drawbacks. Direct rainfall can be applied to all the catchment's 2D grid cells using DRM. LiDAR tiles that simulate varied digital landscape elevations are then used to establish the preferred paths for the rainwater to follow. Surface runoff is additionally linked to Manning's roughness values and soil infiltration modules in order to improve the simulation's accuracy (Caddis et al, 2008).

For urban flooding models, it is evident that the most significant element is how buildings or other structures are represented in the model. For example, Bellos, 2012 reports that the most common representations for simulating water flow between structures include blocking out solid areas (which depends on the numerical method or numerical scheme used), elevating the solid area locally (and thus converting the digital terrain model (DTM) to a digital elevation model (DEM)), and increasing the roughness of the solid area either through the Manning coefficient increase which was used in this study or by the addition of other friction terms at the momentum equations(Schubert and Sanders, 2012).

However, there are certain disadvantages to this strategy, such as the need for high-quality digital landscape information that has been updated by relevant infrastructures, and the effects of grid cells. To overcome these drawbacks, model calibration must be sufficiently close to reality, and the quality of input data must be evaluated prior to simulation. The goal of this research is to replicate surface water floods in future return periods (Joel, 2015).

2.8 Literature Review Summary

In view of the increasing trend in urbanization, industrial growth and land-use changes in the face of climate change, the industrial harbour city of Ghana will undoubtedly experience more frequent, higher magnitude extreme rainfall events and subsequent flooding in the future which will lead to pluvial flooding leading to enormous disruption and damage to the economic wellbeing (Nile et al., 2019);

Hence the justification for the inclusion of the urban 2D modelling as an aspect of this studies is very critical because it will provide information on the possible environmental impact, the most vulnerable locations, properties and critical infrastructure within the study area. This study combines 2D Direct Rainfall Modelling (DRM), field survey (interviewing correspondents) which will go a long way to help unearth the environmental impacts and the proposal of appropriate mitigation measures to tackle the impact of future flooding caused by land-use changes, human activities and climate change.

Chapter 3: Methodology

3.1 Methodology

In order to efficiently attain the study's objectives, successful research relies on an adequate design and control. This study project was completed using a variety of research approaches that were carefully combined to meet the goal, hence the qualitative and quantitative design methods featured prominently in this research. This chapter's content is centered on samples of various research approaches that were effectively used to complete this study assignment. It will also demonstrate the project's methodology, research design, study population, sampling techniques, sample size, Research instruments, data collection procedure and data processing and analysis and ethical considerations. Finally, the chapter also includes some challenges encountered on the filed during data gathering.

3.1.1 Field Survey

3.1.2 Research Design

The data for analysis was gathered using a descriptive and quantitative survey design, which shaped the study's core. Surveys are defined as techniques of gathering information (data) using oral or written interviews and a structured, more formal, or a combination of approaches. Consistency is critical, according to the survey design provided by Sarantakos (1998) and Fraenkel (2012), to decreasing or preventing errors as much as possible. Also, according to Creswell (2013), a descriptive study can collect background information and difficult-to-find data, whilst the researcher does not have the ability to encourage or influence respondents' responses. According to Newman(2013), different aspects required for a comprehensive comprehension of previous behaviors, experiences, or qualities are routinely inquired on participants in an identical inquiry on a situation/condition of the program. In a survey like the one used in this thesis, the cost in terms of finances required is rather minimal. In addition, the time and people required for a successful analysis are moderate and manageable. The descriptive survey design was also deemed appropriate since it allows the researcher to apply or generalize findings from the sample to the entire population. That is, the sample's varied features and other elements can be extrapolated to the entire population.

3.1.3 Population

Residents in the catchment study region, Tema communities 2,3,5 and 12, which are partly surrounding the Sakumono Ramsar Lagoon site, are referred to as the population in this study. Adult inhabitants over the age of 18 who resided near the lagoon, where flooding occurs most often, were the target group. Key opinion groups and leaders from many communities of interest were present, including Tema Metropolitan Area assembly members and officials, officers from the National Disaster Management Organization (NADMO), and the Department of Town and Country Planning.

3.1.4 Sample Size and Sampling Technique

Sampling is the process of selecting a subset of a population to examine or perform research on. These samples are usually chosen in such a way that the findings or inferences gained from the study can be applied to the full population. Creswell and Clark (2007) describe sampling as the process of selecting pieces from a much larger population, a group about which a generalized statement is made, so that the full group is represented. Sampling is not a technique for gathering information in and of itself, but it assures that any technique used will aid in gathering data from a smaller group that appropriately represents the total population. The sample size is influenced by the target population. Due to a lack of resources, high cost, and insufficient equipment, it is preferred to examine only a subset of the population, which serves as the sample (Ahmadzadehasl & Ariasephr, 2010).

The researcher had to deal with a large population size based on the current and more recent 2021 Population and Housing Census projecting the total population of Ghana to be estimated around 30,832,019 million. As compared to the 2010 figure of 24,658,823 million (Ghana 2021 Population and Housing Census General Report).

According to the 2021 census the population size of the TMA has increased since the 2010 Population and Housing Census, but the sample size was determined based on the 2010 housing and population due to challenges encountered by the researcher to secure the current breakdown report for the Tema Metropolitan Area (TMA). Table 1 below shows the yellow highlighted communities withing the catchment area.

Table 1: Population by community

S/No.	Community Name	Total	Male	Female	House holds	Houses
1	Tema Newtown	71,711	34,639	37,072	18,838	7,975
2	Lashibi	47,530	23,323	24,207	12,037	8,605
3	Tema Community 1	32,712	15,437	17,275	7,073	3,712
4	Sakumono	22,713	10,870	11,843	5,588	3,241
5	Tema Community 2	22,547	10,670	11,877	5,539	2,564
6	Tema Community 4	14,623	6,760	7,863	3,100	2,025
7	Tema Community 5	13,043	6,127	6,916	2,940	1,985
8	Tema Community 7	12,398	5,734	6,664	2,731	2,011
9	Tema Community 8	10,958	5,038	5,920	2,626	1,863
10	Tema Community 9	8,350	3,822	4,528	1,881	1,449
11	Kanewu And Suncity	7,721	3,790	3,931	1,805	1,247
12	Adjei Kojo	5,801	2,852	2,949	1,359	821
13	Tema Community 3	5,691	2,699	2,992	1,476	737
14	Tema Community 11	5,313	2,523	2,790	1,216	876
15	Tema Community 12	5,287	2,494	2,793	1,119	780
16	Tema Community 10	3,546	1,768	1,778	802	583
17	Tema Community 6	1,504	735	769	303	258
18	Tema Main Harbour	844	455	389	220	154
19	Tema Industrial Area	481	222	259	144	70

Source: Ghana Statistical Service, 2010 Population and Housing Census

Based on the above the sample size of 250 was determined using the formula for determining sample size as used by Yamane (1967), calculation on the sample population size within the catchment communities is shown below:

Sample Size Calculation:

$n = N / 1+ N(\alpha^2)$

where n = sample size

N = sample frame = 19,837

α = Standard Error = 5% = 0.05

$n = 19{,}837 / 1+ 19{,}837\ (0.05^2) = 392.093$

The sample was taken from residents who lived within the catchment. Hence the purposive sampling method was used to select households since it was necessary to interview people who have been ever flooded in the past and present. Households in the various communities were targeted in order to get feedback from those who were truly affected by the floods.

The nature of the study design also allowed for snowball and convenient sampling, as a result the study focused on people who live in the communities along the lagoon and have been affected by or are subjected to floods.

This makes any of the probability sampling procedures difficult to apply. The snowball method was used to choose potential respondents and a rapport was established to discover the next respondent until the requisite sample of respondents for the quantitative data was exhausted. Contents of the survey questionnaire is attached in appendix A.

3.1.5 Difficulties in the field

Much time was spent in the field due to challenges in getting some respondents due to their work schedules. Most of them were mostly out during the day and return late in the evening. The researcher to overcome this decided to engage few people at a time and also targeted the time most people were available.

3.2. Flood Modeling

3.2.1 Catchment Area of Interest

The study will take place in the Tema Metropolitan Assembly of the Greater Accra Region of Ghana. Tema is the capital of the Tema Metropolitan Area, which has an area of around 87.8 km2. The metropolis is in the coastal savannah zone located about 30 kilometres East of Accra, Ghana's capital city. It is bounded in the northeast by the Dangme West District; in the southwest by Ledzokuku Krowor Municipal; in the north-west by Adentan Municipal and Ga East Municipal; in the north by the Akuapim South District; and in the south by the Gulf of Guinea(Ghana Statistical Service (GSS), 2014).The Tema Metropolitan Area (TMA) has been divided into several communities, but the specific catchment of interest includes communities 3,5,10, 11 and 12.These communities were of interest due to its exposure to flooding, closeness to the Tema Harbour and the Sarkumono Lagoon which was declared a Ramsar Site(Protected Wetland) due to its unique function of being home to over sixty bird species including international ones. The catchment area is approximately 27,634 acres in total. The site itself has approximately 1,365 hectares of brackish lagoon water with a limited link to the sea. The lagoon has a land area of approximately 350 ha and is surrounded by a 700 ha flood plain. The site is ranked as the third most significant for coastal birds along the coast of Ghana. Rapid urbanization within the catchment area has degraded natural resources, necessitating management actions, most importantly its ability to contain and hold run-offs form high intensity rainfall preventing flooding in and around the catchment area(Site, 2015). The catchment includes built up industrial and residential areas and its proximity to the Tema Harbour. The catchment is primarily an urban metropolitan area, and it is bordered on the western side by the second major access route to Tema, Ghana's bustling port city. Figures 4 and 5 below shows the catchment area(highlighted in yellow) and flood risk situation respectively.

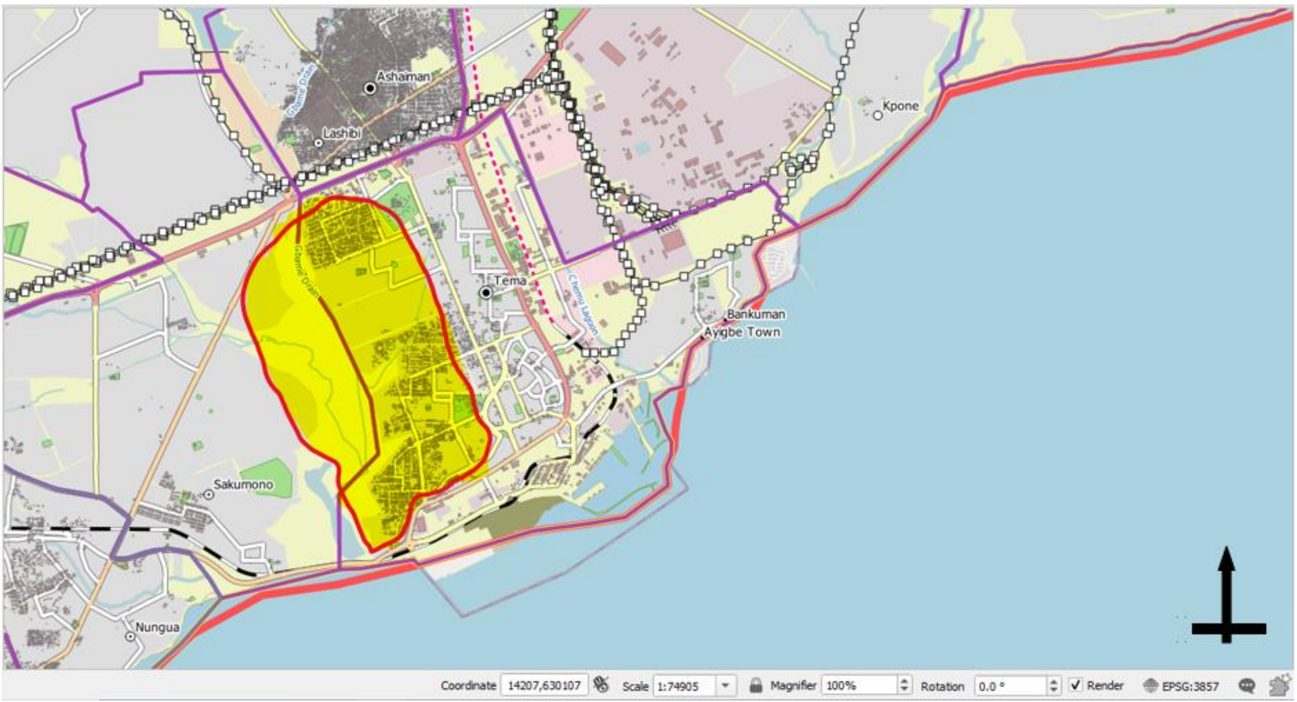


Figure 4:Catchment Area

Source: Taken from QGIS

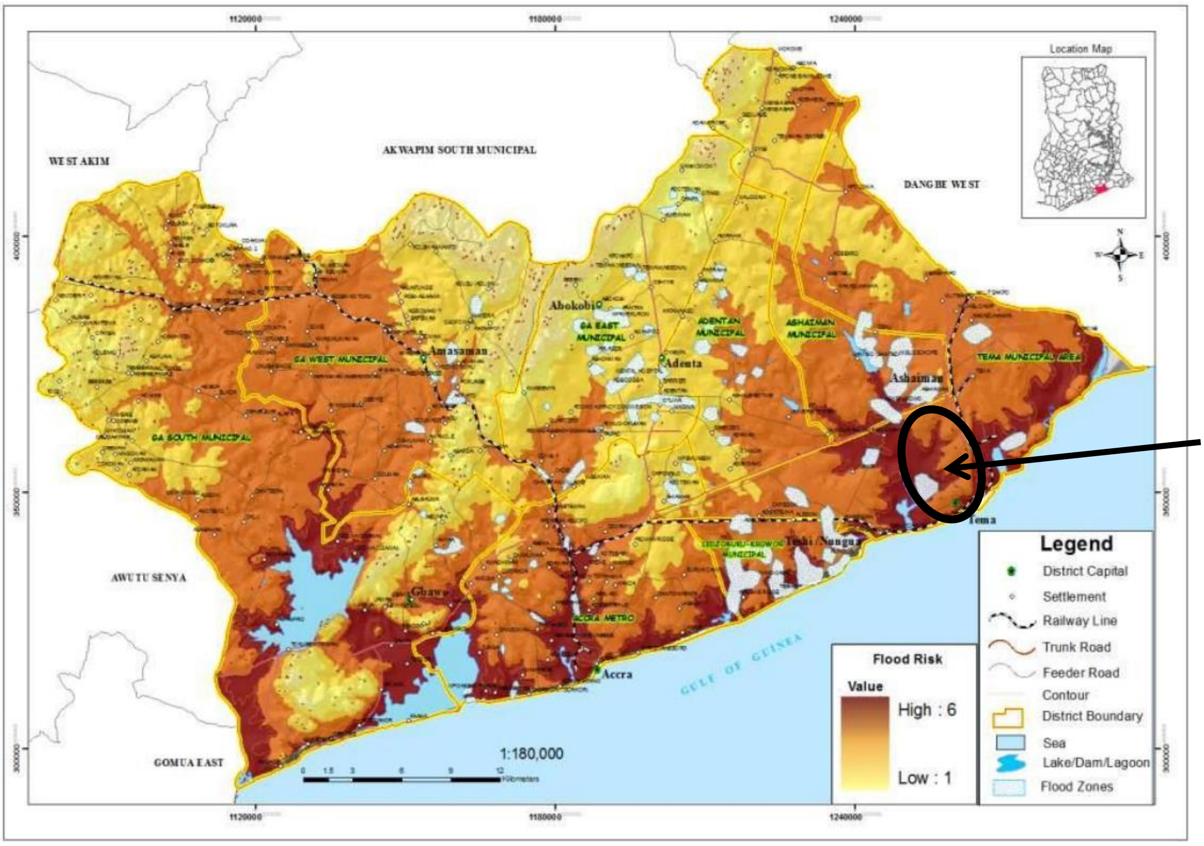


Figure 5:Flood Risk map and Flood Situation of catchment area circled in black

Source: : Developing Flood Risk Map for GAMA(Kagblor, n.d.)

3.2.2 Input Data

Some input data are required to build the model and below steps were taken in order to build the 2D Direct Rainfall Model using the Flood Modeller Software.

1) Firstly, by defining the catchment area of study using the DEM file from ASTER GDEM, and Google Street map of the catchment area.
2) Vector GIS data for roads, streams and buildings and other properties.
3) The second step was to generate designed rainfall data using observed rainfall time series data and water level for historical events.

3.2.3 Justification for the modelling method

The Direct 2D Rainfall Model (DRM) was used to simulate the flood map for the catchment area that helped to ascertain the risk of surface water flooding. Some studies have produced National and Regional Risk Maps for Ghana that details and gives the areas susceptible to flooding. The catchment area falls within the high and medium flood risk zones already identified by other studies(Nyarko, 2000). Different modelling techniques have been used to model and develop flood risk maps and zoning with inputs such as soil texture, land slope, DEM but not much literature can be seen on Direct 2D Rainfall Modelling using the Flood Modeller software in the chosen catchment area. This will modeling technique is straight forward and easy to model looking at the short time frame for the project and will be useful for assessing flood risk in local areas.

The rainfall time series is applied to all 2D grid cells which spreads the resulting flows across the 2D chosen computational or active area and routing the flow through preferred channels such as roads or around and between buildings. Set GIS vector layers with elevated heights of buildings to deflect flows, depressing highways, and imprinting riverbeds into topographical data in the 2D domain to direct flow paths. Manning's roughness values are also specified for various land cover type GIS layers, bringing the 2D model closer to reality. Setting the soil type and accompanying soil infiltration values for parks and green spaces in the 2D domain can also help to generate a more detailed 2D model that can better simulate local flooding (Joel, 2015).

This project will investigate the consequences of the following scenarios:

a) 1 in 2-year return period floods

b) 1 in 5-year return period floods

c) 1 in 10-year return period floods

d) 1 in 25-year return period floods

e) 1 in 50- year return period floods

f) 1 in 100-year return period floods

3.2.4. Modelling

Merged Digital Elevation Model (DEM) and GIS data of the Tema Metroplitan Area (TMA) were assembled from the site below ASTER GDEM:

New Version of the ASTER GDEM | Earthdata (nasa.gov) .

The open-source base map data were defined to the study catchment area as required in QGIS and Flood Modeller software. The DEM extraction was then corrected to the right projection so Flood Modeller can read the files in metres as desired.

Producing the rainfall input: This data designed rainfall data was generated with the help of other sources of literature due to difficulty in obtaining actual observed rainfall time series data for the catchment area. Rainfall intensity-duration-frequency (IDF) estimation is frequently required for hydraulic control structure design as well as water resources engineering planning and development. Statistical analysis of rainfall data can be used to identify the relationship between rainfall intensity, duration, and return period of a specific rainfall amount. Rainfall data from four meteorological stations in Greater Accra Region were used to create rainfall intensity duration frequency curves with return periods ranging from 2 to 100 years and the Gumbel distribution for rainfall intensity values for 15, 30, 60, 120, 240, and 360 minute durations. For the prediction of rainfall intensities in Accra, the rainfall intensity duration frequency curves generated for these stations are recommended. Using a short duration rainfall intensity frequency curve (IDF) for the Greater Accra region which is obtained by plotting rainfall intensity values against their duration for the different return periods, rainfall hyetographs (profile) were generated as inputs into the 2D model as direct rainfall for a six-hour critical storm duration for the Tema Metropolitan Area (TMA). Figure 6a and 6b below shows the IDF – Rainfall Intensity Frequency Curves used(Logah & Bekoe, 2013).

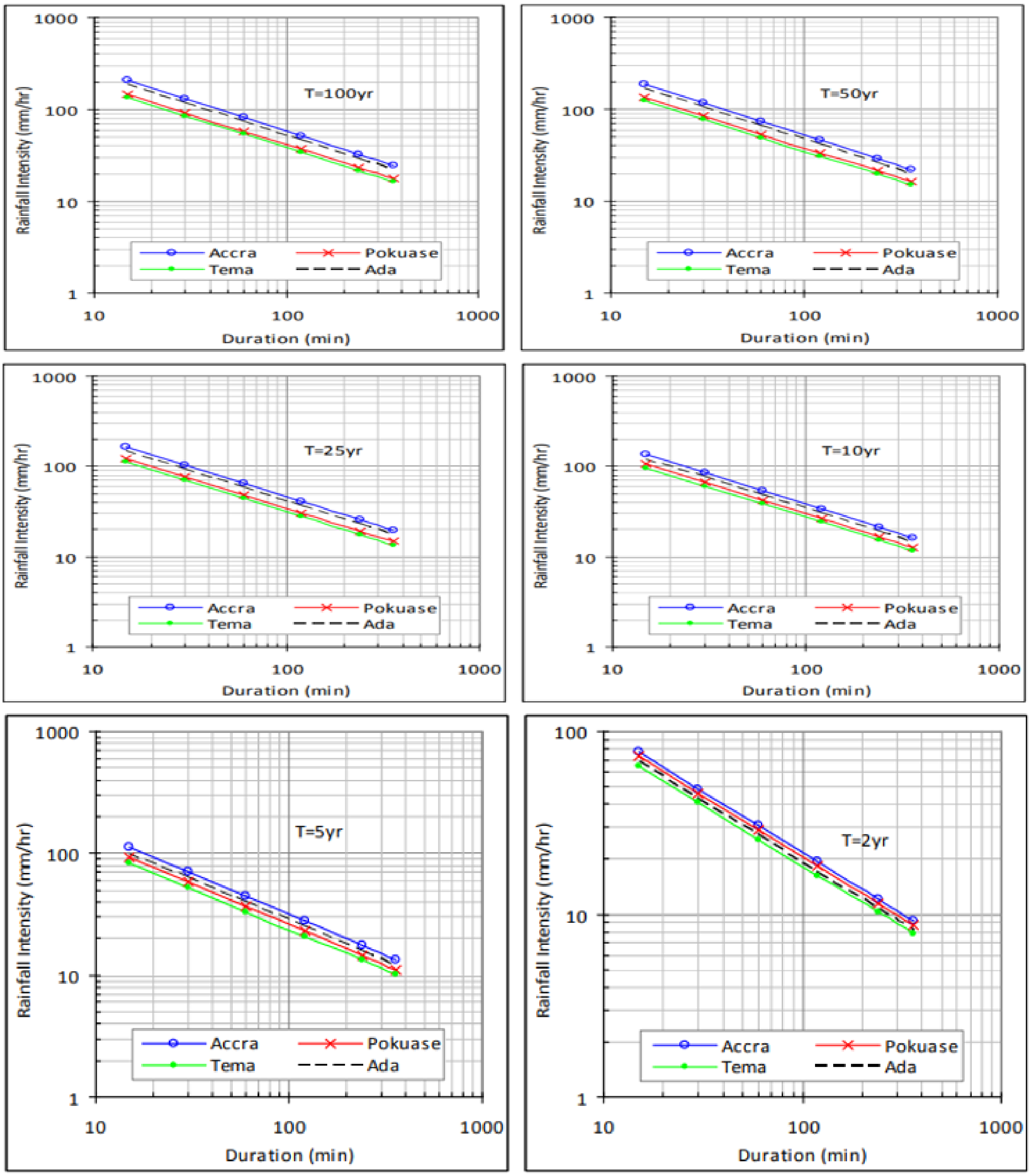


Figure 6: Rainfall Intensity Frequency Curves

Source: (Logah & Bekoe, 2013).

From the IDF curves in Figure 6a and 6b for Tema (in green line) above, the rainfall intensity values in mm/hr for each return period (RP) read for each duration 10 minutes to 360 minutes (6 hrs) was generated as shown in Table 2 below together with the 24-hour flood dept for each return period (RP).

Table 2:IDF-Tema Metropolitan Area, mm/hr

IDF-region Tema (mm/hr)						
			frequency			
Duration	2	5	10	25	50	100
5						
10	95.0	125.0	150.0	175.0	190.0	195.0
20	55.0	70.0	80.0	90.0	100.0	110.0
30	40.0	50.0	60.0	70.0	80.0	85.0
60	25.0	35.0	40.0	45.0	50.0	55.0
360	8.0	10.0	12.0	15.0	16.0	18.0
1440	2.97	3.78	4.50	5.64	6.06	7.05
24 HOUR DEPTH						
Tema	71.00	91.00	108.00	135.00	145.00	169.00

But we need the 24-hour rainfall intensity hence Table 3.2 is then used to plot the IDF for each return period and a trend line fit through.

Below is the IDF for 100-year RP plotted for 10 mins to 360 minutes (6hours) and a power trend is fitted through the points giving equation to predict the rainfall intensity for rainfall = 814.04 *time ^(-0.653). Therefore, a 24-hour (144 0 minutes) rainfall intensity for 100-year RP using equation which equals 7.05 mm/hr so if we multiple by 24 hrs the rainfall depth is 169.2 mm. Then we calculate the 24-hour rainfall depth by multiplying the rainfall intensity by 24 hours as shown in green On Table 3 below:

Table 3: 24-hour adjusted rainfall depth with Rainfall Correction Factor

Tema							
Gumbel FFA		Ave	Clock correction	RCF	PPT	ARF	Rain depth (mm)
100 year	169.2	169.2	191.2	0.64	122.0	0.90	109.5
50 year	145.4	145.4	164.3	0.66	104.8	0.90	94.0
25 year	135.2	135.2	152.8	0.67	97.5	0.90	87.5
10 year	108.0	108.0	122.0	0.67	77.9	0.90	69.9
5 years	90.6	90.6	102.4	0.66	65.4	0.90	58.6
2year	71.4	71.4	80.6	0.67	51.5	0.90	46.2

We then apply corrections to the 24-hour rainfall depth to then calculate adjusted rainfall depth 24 hour. Table above shows the corrections made using:

- Clock adjustment = 1.13 (all return periods)

- Rainfall Correction Factor (RCF) = (Rainfall depth critical storm duration (6 hour) / rainfall depth 24 hour)
- Areal Reduction Factor (ARF) = formula from Watkins and Fiddes (1974).
- The rainfall depth highlighted in yellow is then used to create the rainfall hyetograph or profile. The example below in Table 4 is for 100-year **RP** and a storm duration of **D** of 24 hour. **M** is using the rainfall depth (yellow) for the return period / Time in hours (24hours) * 0.5.
- Then accumulated rainfall for each time increment (15 mins) is M * time increment in hours ^ 0.5. The final column is created to produce the profile.

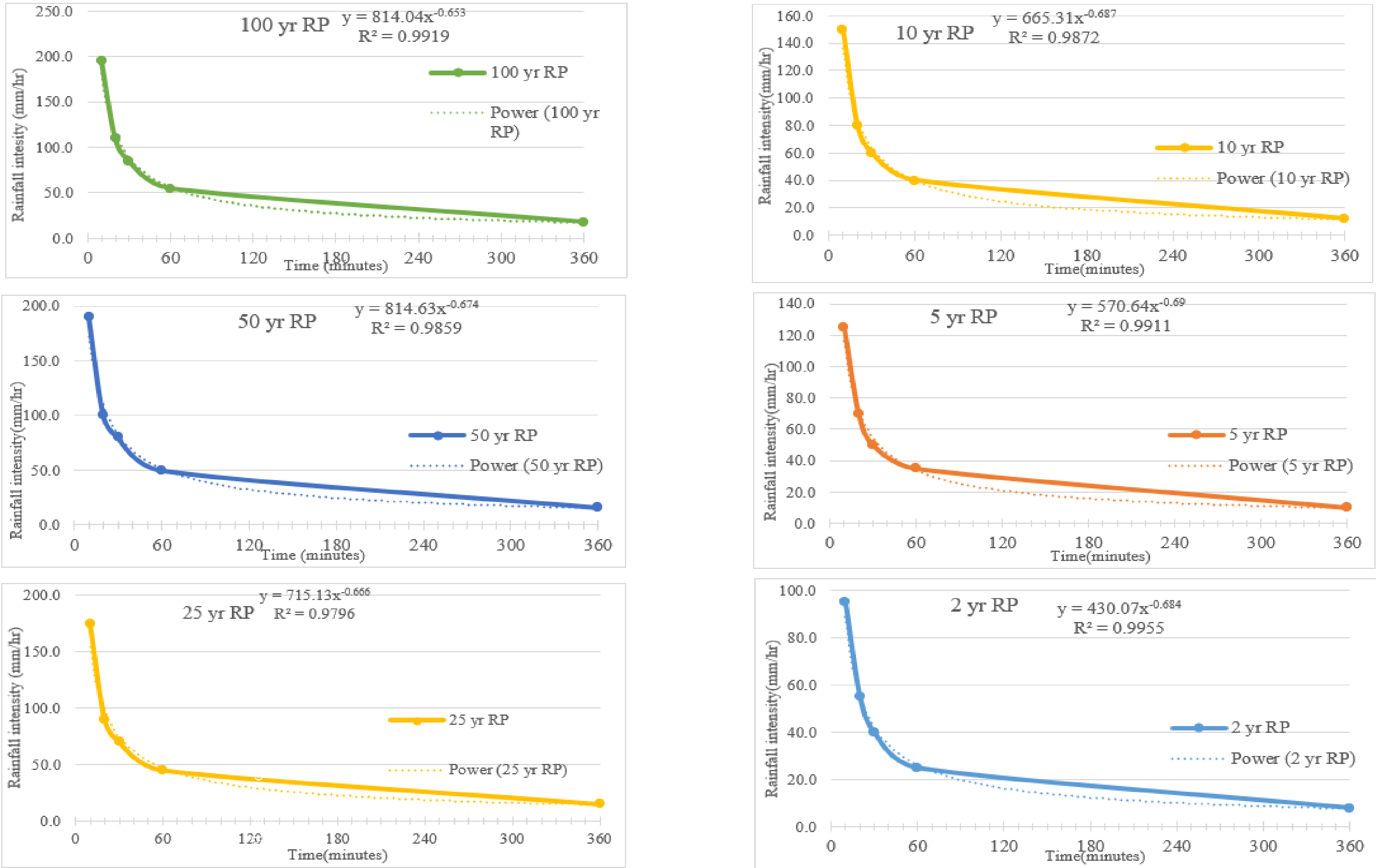


Figure 7: Plot of return periods with power line

However, in this study a rainfall hyetograph or profile for a 6-hour critical storm was generated for all the return periods using the procedures above. Table 3.4 below shows calculation of the 100-year return period hyetograph highlighted in yellow, these values were then entered into the 2D model for the simulation: Appendix B shows designed hyetograph data for all return periods.

Table 4: Rainfall Hyetograph-100-year Return period

Subcatchment =			Tema	Accra		
Min	**hr**			**Cum. Pre**		**100yr**
15	0.25	**100yr**	109.45	22.3	22.34	2.30
30	0.5			31.6	9.25	2.41
45	0.75			38.7	7.10	2.53
60	1	**M**	44.68	44.7	5.99	2.67
75	1.25			50.0	5.27	2.84
90	1.5			54.7	4.77	3.04
105	1.75			59.1	4.38	3.29
120	2			63.2	4.08	3.63
135	2.25			67.0	3.83	4.08
150	2.5			70.7	3.63	4.77
165	2.75			74.1	3.45	5.99
180	3			77.4	3.29	9.25
195	3.25			80.6	3.16	**22.34**
210	3.5			83.6	3.04	7.10
225	3.75			86.5	2.93	5.27
240	4			89.4	2.84	4.38
255	4.25			92.1	2.75	3.83
270	4.5			94.8	2.67	3.45
285	4.75			97.4	2.60	3.16
300	5			99.9	2.53	2.93
315	5.25			102.4	2.47	2.75
330	5.5			104.8	2.41	2.60
345	5.75			107.1	2.36	2.47
360	6			109.5	2.30	2.36
375	6.25			111.7	2.26	2.26
				SUM	**109.5**	
100 year						
Min	**hr**			**Cum. Pre**		**100yr**
60	1	**100yr**	109.45	44.7	44.68	11.97
120	2			63.2	18.51	18.51
180	3			77.4	14.20	44.68
240	4	**M**	44.68	89.4	11.97	14.20
300	5			99.9	10.55	10.55
360	6			109.5	9.54	9.54
				SUM	109.5	

Simulation was saved and organized according to their file names as outlined below:

1. 1 in 2-year return period event with a storm duration of 6hrs (Baseline_RP2yr_D6hr_S1)
2. 1 in 5-year return period event with a storm duration of 6hrs (Baseline_RP5yr_D6hr_S2)
3. 1 in 10-year return period event with a storm duration of 6hr (Baseline_RP10yr_D6hr_S3)
4. 1 in 25-year return period event with a storm duration of 6hr (Baseline_RP25yr_D6hr_S4)
5. 1 in 50-year return period event with a storm duration of 6hr (Baseline_RP50yr_D6hr_S5)
6. 1 in 100-year return period event with a storm duration of 6hr (Baseline_RP100yr_D6hr_S6)

The result files (shapefile and grids) that is flood depths, flood extend, velocity is then exported to QGIS for the determination of the number of properties and critical infrastructures at risk. To achieve this, the exported output files were clipped to buildings, roads and other critical infrastructures with flood maps to determine the number of properties at risk of flooding.

3.2.5 Model Run Efficiency

The duration of the model's execution is six hours, beginning at time 0 and ending at time 6. As rainfall accumulates to its greatest volume on the ground takes some time therefore the simulation time of six hours is optimal for representing the most severe storm in the 2D domain. In general, all simulations performed consistently with a rather small mass error. The simulation progress window for the 1 in a 100-year return period (S6) is depicted in Figure 8, and the mass error was -2.1%, which is within the permitted range of ±3%. Table 3.5 shows the mass errors of the simulations, and almost all of them fall within the acceptable range.

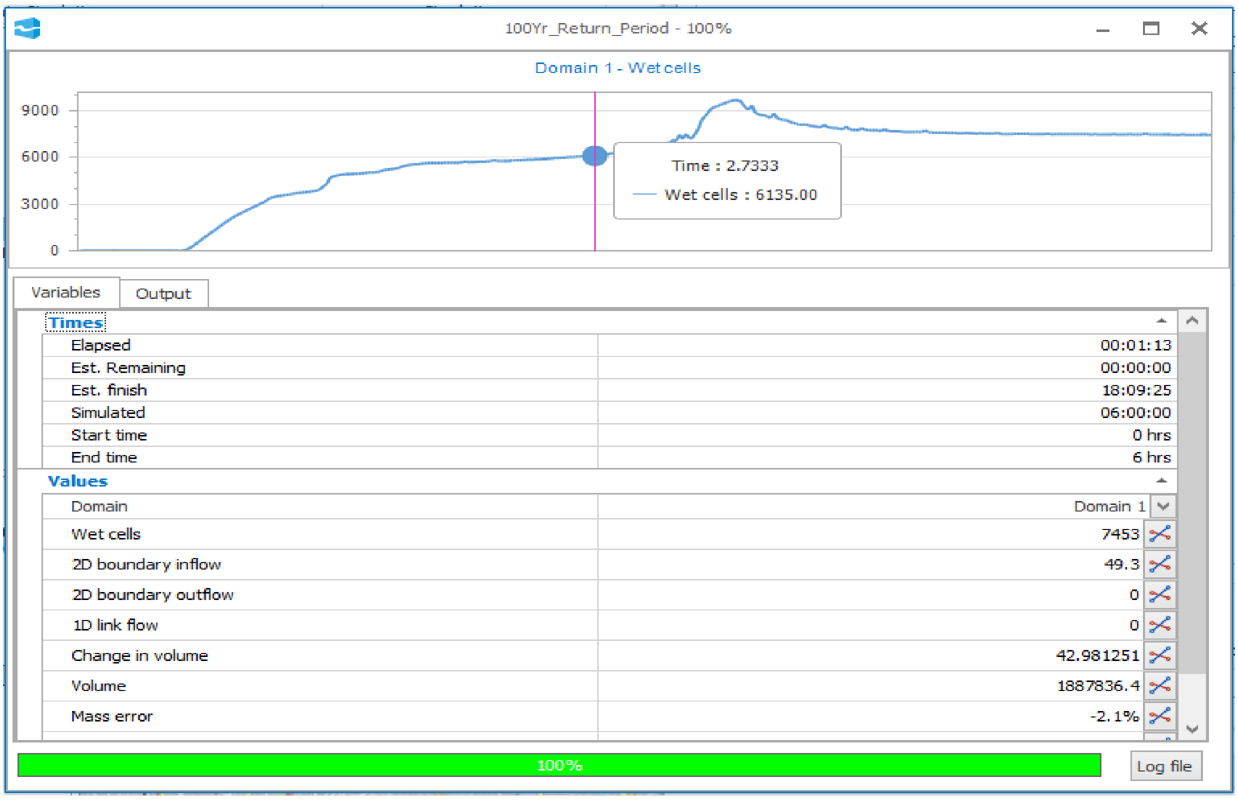


Figure 8: 1 in 100-year progress view

Table 5: Simulation mass errors

SCENARIO	MASS ERROR
1. 1 in 2-year return period event with a storm duration of 6hrs (Baseline_RP2yr_D6hr_S1)	-2.22
2. 1 in 5-year return period event with a storm duration of 6hrs (Baseline_RP5yr_D6hr_S2)	-2.31
3. 1 in 10-year return period event with a storm duration of 6hr (Baseline_RP10yr_D6hr_S3)	-2.10%
4. 1 in 25-year return period event with a storm duration of 6hr (Baseline_RP25yr_D6hr_S4)	-2.01%
5. 1 in 50-year return period event with a storm duration of 6hr (Baseline_RP50yr_D6hr_S5)	-2.20%
6. 1 in 100-year return period event with a storm duration of 6hr (Baseline_RP100yr_D6hr_S6)	-2.10%

3.2.5 Validation of model

There is no known or published flood simulation for the catchment area for validation of the model there fore in order to validate the model flood simulations were compared with the flood risk map of the Greater Accra Region. As shown in Figure 3.5 the flooded area from simulated flood maps corresponded with the areas identified as high-risk flood zones identified in other literature.

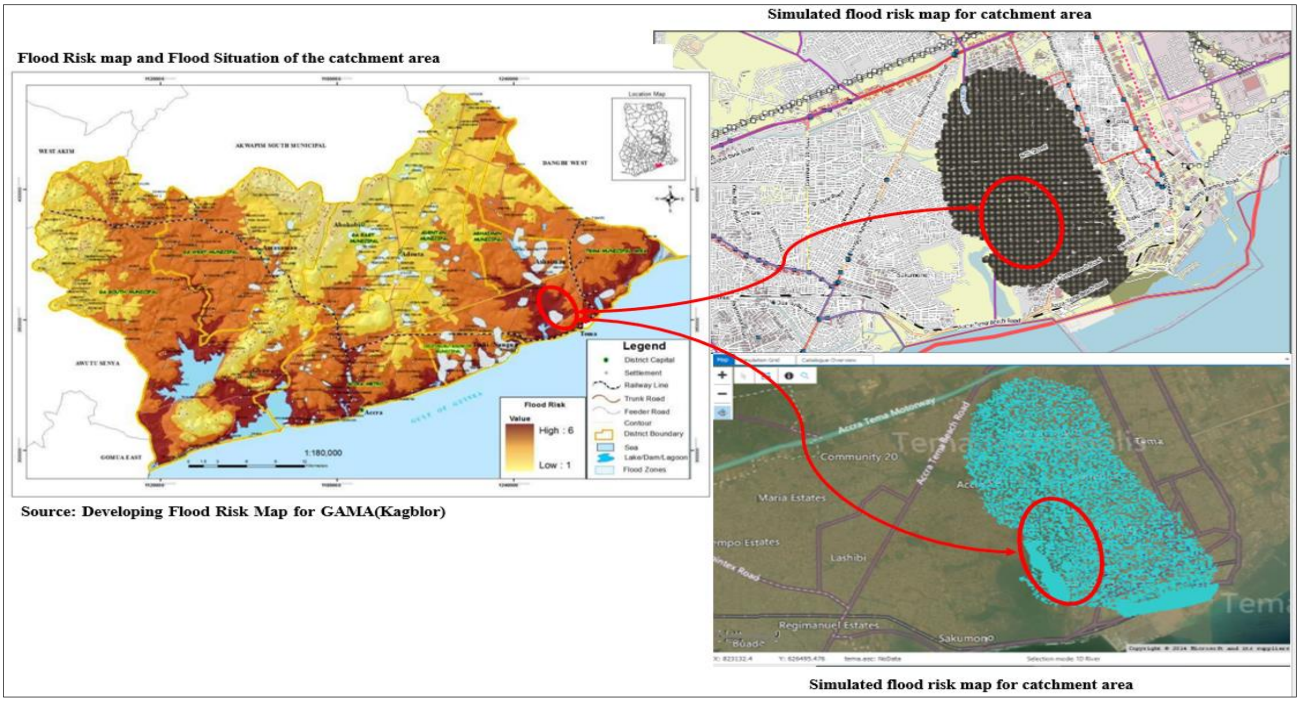


Figure 9:Flood maps showing corresponding flood risk map for catchment area

Chapter 4: Results and Discussions

4.1 Results and discussion

4.1 Introduction

The findings of the data analysis are presented in this chapter, along with a discussion of the related literature. It covers topics such as respondents' socio-demographic origins, flood causes, flood socio-economic consequences, and how flood victims frequently prevent and manage flooding. The research findings were presented using charts, tables and graphs. The results were looked at and discussed to bring attention to the problems that had been investigated.

4.2 Field Survey

4.2.1 Background Characteristic of Study Participants

Table 1 shows the background characteristics of study participants. The total number of participants were 392. It can be seen that 89 (22.8%) of the participants were below 25 years of age and 303 (77.2%) aged 26 years and above. 216 (55.2%) of the study participants were males while the females were 176 (44.8%). Majority of the participants were employed 196 (50%). 141 (36%) were self-employed and 55 (14%) were unemployed. Also, it was found that the participants were mainly service and sales workers, traders, students, craft and related trade, artisans, fishermen and public servants. Accommodation in the area is mostly for the middle- and lower-class income earners. It was observed that 61 (15.6%) of the participants had attained primary school education, 99 (25.2%) are secondary school graduates, 199 (50.8%) had obtained tertiary education, and 32 (8.4%) had never attended school. 250 (64%) of the study participants were tenant while 97 (24.8%) were owner-occupant and 45 (11.2%) were free occupant.

Table 6: Background Characteristics of Study Participants

Background Characteristics of Study Participants		
Variable	**Frequency (N=392)**	**Percentage (%)**
Age		
25 years and below	89	22.8
26 years and above	303	77.2
Gender		
Male	216	55.2
Female	176	44.8
Occupation		
Employed	196	50
Self Employed	141	36
Unemployed	55	14
Education		
Tertiary	199	50.8
Secondary	99	25.2
Primary	61	15.6
Never attended school	32	8.4
House ownership		
Own a house	97	24.8
Tenant	250	64
Free occupant	45	11.2

Source: Field Data, 2022

It was realized that most of the respondents (64%) were tenants who lived in rented apartments. Further engagement with them revealed that the decision to rent in these communities were largely influenced by their ability to afford or due to economic factors as well as the proximity to workplaces and the Tema Harbour.

4.2.2 Causes of Flooding in catchment area

Figure 1 shows the cause of flooding in within the catchment area. It can be seen that the major cause of flooding is building within and around the lagoon with a percentage of 38.4 and 25.4% of the respondents indicated that the bad refuse disposal was also a major cause of flooding in the area and they believed that it was one of the causes of the problem since drains and the channel for the lagoon were choked with refuse. Thus, chocked drains also had impact in causing flood in the area. The least cause of flooding in the area were lack of drains and building in water courses at a percentage of 4 and 3.2 respectively.

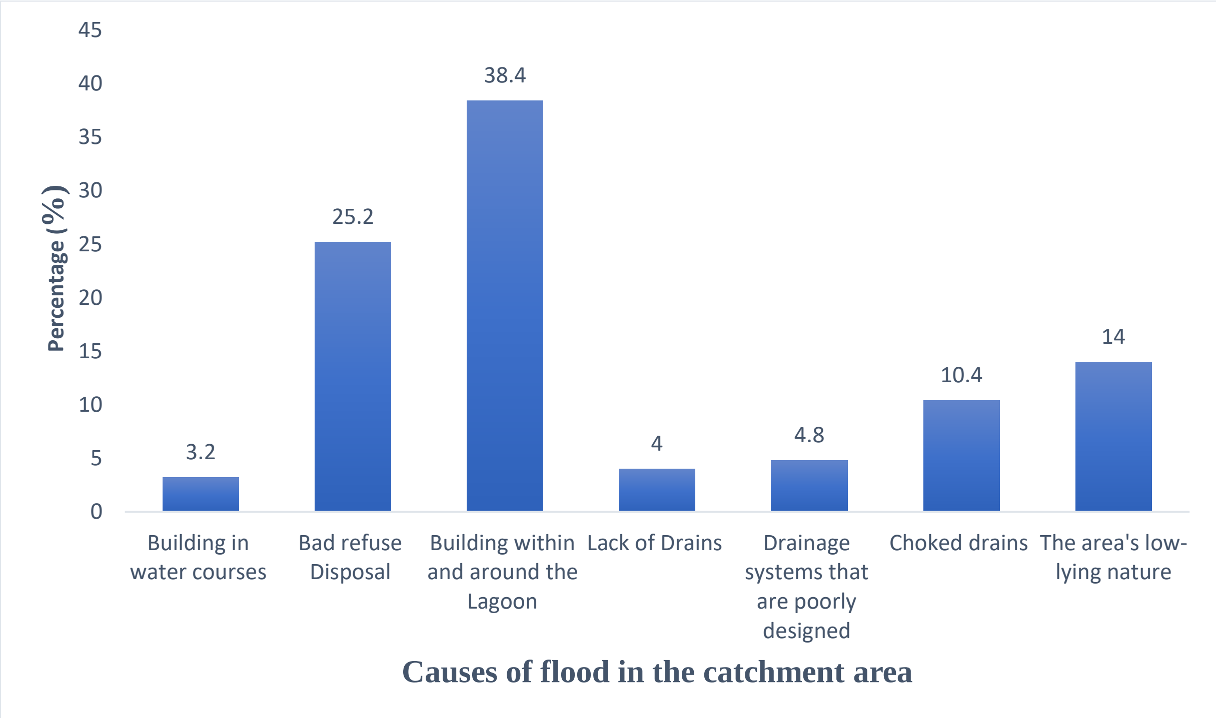


Figure 10: Causes of flooding in catchment area

Source: Field Data, 2022

Feedback from respondents indicated that building structures within and around the lagoon is the most significant contributor to flooding in the towns, the study indicated that dumping of trash in and around the lagoon, as well as drainage systems, increased the severity of flooding. This is contrary to the situation at the Kwame Nkrumah Circle in Accra, where bad refuse disposal practises were reported to be the main causes of flooding from the Odaw, and the

Aboabo River in the Kumasi metropolitan flooded its bank due to refuse disposal, lack of drains, low lying terrain, and choked drains (Oppong) (2011). Figure 2 below shows development of structures in and around the lagoon site that confirms data gathered.

Figure 11: Construction activities around the lagoon area

Figure 12: Wall constructed acting as an obstruction

Figure 13: Walled apartment within the lagoon area

Figure 14:Ongoing construction activities around the lagoon

Source: Field Data, 2022

4.2.3 Flood Issues in the catchment area

Table 2 flood issues in Tema Metropolitan Area. With the reason for staying in flood zone area, 201 (51.2%) of the participants stated that the area is close to Tema harbor and central business area (community 1), 118 (30%) of the study participants said is due to the proximity to their work, 39 (10%) of the participants were concern about affordability of housing while 34 (8.8%) of them said they didn’t face any problem earlier on. 210 (53.6%) of the participants said they are not willing to relocate due to the flood while 182 (46.4%) were willing to relocate. With the duration of flooding, it was seen that 205 (52.4%) of the participants started that the flooding normally takes hours, 132 (33.6%) of them stated that the flooding normally takes days with 36 (9.2%)of the correspondents agreeing to duration taking weeks and the least of 19(4.8%) being months. Most of participants, 267 (68%) stated that the Tema Metropolitan Assembly (TMA) is the major institution that comes to their aid during flooding. The NADMO(National Disaster Management Organization) was also recommended by (26%) of the participants as a major institution after the Tema metropolitan Assembly that support them during flooding. About 24 (6%) of the participants said that they did not receive any support from any institution when they experience flood cases. 303 (77.2%) said the form of support they receive is rescue team support while 89 (22.8%) of them receive relief items such as such as food, medicine, blankets, etc.

As clearly outlined above the reasons for staying in these flood prone communities is a result of economic reasons largely due to closeness to the Tema Harbour and the central business areas. As to why they continued to stay there, majority of them about 53.6% were not willing to relocate due social ties, such as the necessity to care for a family home without paying rent. Others wish to relocate but that was if only they could afford to do so due to their financial situations. This agrees with the findings made by Odoi, 2019 that the continued presence of residents in flood-prone locations is motivated by socioeconomic restrictions.

When the question of how long the floods lasted, most respondents stated that it lasted for hours leading to days before receding. This is agreeing with the outputs of the various flood return periods simulated which shows increasing dept of water levels with the increasing number of return periods. Site visits also revealed that the flood plains and Lagoon could no longer collect and contain the volumes of surface run off water as was the case in the past. The respondents who said water levels lasted for weeks were those that stay close the lagoon and also as a result of the low lying nature of the area they lived. This could mostly be attributed human activities which were also revealed through other aspect of the questionnaire. It was also observed during site visits that the channel through which the lagoon empties itself into the sea could be narrowed by waste and weeds which could slow down the flow rate of collected rainwater into the sea. This ultimately leads to flooding of communities within the catchment.

For flood relief supports the respondents pointed out the Tema Metropolitan Assembly coming to their aid with some form of relief items such as food, building materials, blankets, etc. followed by National Disaster Management (NADMO). This was further explained by some opinion leaders who clarified that whilst the NADMO is overwhelmed due to similar or even worst flooding situations usually puts the institution in varied forms of logistical constraints. The assembly then steps in as the first point of contact to attend to flood victims.

Table 7: Flood Issues in the catchment area

Flood Issues in the catchment area

Variable	Frequency (N=392)	Percentage (%)
Reason for in Staying Flood zone Area		
Proximity to work	118	30
Affordability of housing	39	10
Did not face problems before	34	8.8
Closeness to the Tema harbour	201	51.2
Willing to relocate due to the flooding		
Yes	182	46.4
No	210	53.6
Duration of Flood		
Hours	205	52.4
Days	132	33.6
Weeks	36	9.2
Months	19	4.8
Institution for Support during Flood		
National Disaster Management Organization (NADMO)	101	26
Tema Metropolitan Assembly	267	68
None	24	6
Form of Support		
Supply of relief items (food, building materials, blankets, etc.	89	22.8
Sent rescue team to support	303	77.2

Source: Field Data, 2022

4.2.4 Frequency of Flooding in the catchment area

Figure 10 shows the frequency of flooding in Tema Metropolitan Area. It can be seen that the flooding occurs most between May and June and June-July with a percentage of 38.8 and 34 respectively. Flooding can also be seen between July and August at a percentage of 15.2. The least flooding frequency was observed in the other months at a percentage of 4.

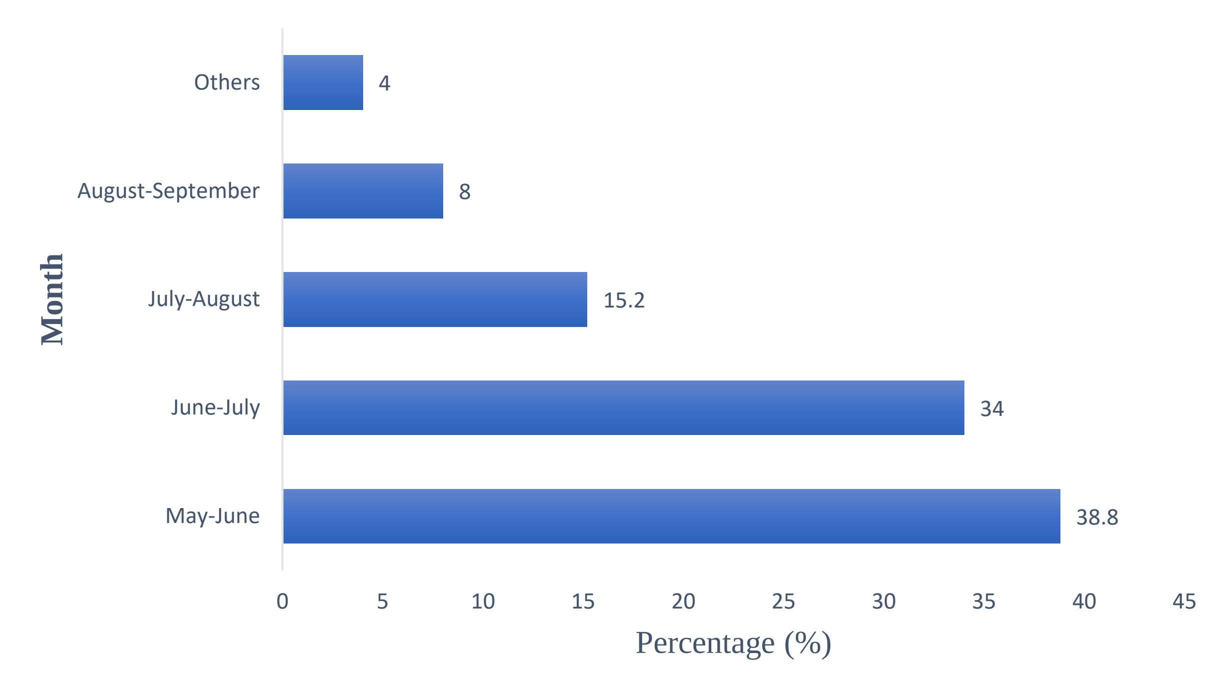


Figure 15: Frequency of flooding in the catchment area

Source: Field Data, 2022

Feedback of respondents aligned largely aligned with the rainfall seasons of Ghana mainly April, May, and June are the rainy months, with a small break from July to August. In September, October, and the first half of November, the rainy season is significantly shorter. Table 4.3 shows the chronicles of flood events that mostly occurs within the months of May-June and July being the highest for flooding. This confirms information gathered from respondents as shown on Figure 2(McSweeney et al., 2008).

Table 8: Major flood hazards and their impacts

Date	No. of communities affected	No. displaced	Casualties	Estimated cost of damage (million US$)
7 May & 5 Jun 2000	49	6,584	12	5.65
1 June 2001	65	41,450	13	10
6 Jan, 9 & 13 Jun 2003	25	2,787	3	2.54
18 Jun 2003	30	3,140	5	1.71
13 Apri 2004	9	250	-	0.61
12 Mar 2005	22	2,370	3	7.35
13 Jun 2007	40	13,140	5	1.14
27 Mar 2008	12	1,456	-	0.91
19 Jun 2009	33	15,616	7	4.12
20 Jun 2010	42	19,833	17	2.78
25 & 26 Oct 2011	149	65,236	14	4.72
Jun & Oct 2012	157	6,888	4	2.18
5 – 12 Jun 2014	4	4,166	3	no data
3 Jun 2015	no data	>8,000	159	0.38
Total	637	190,916	245	44.09

Source: Amoako and Boamah 2014 (data for 2000–2012) and Frick-Trzebitzky (2014)

4.2.5 Waste Disposal Practices of Study Participants

Table 3 shows the waste disposal practices of study participants. Majority of the participants about 160 (40.8%) practiced public dumping of waste.122 (31.2%) of the participants practiced dumping at the banks of the lagoon and 78 (20%) of the participants dump their waste in the lagoon. 22 (5.6%) of the study participants disposed their waste by open burning. Door to door waste disposal by contractor was least practiced among the study participants with a percentage of 2.4.

Table 9: Waste Disposals Practices of Study Participants

Waste Disposals Practices of Study Participants		
Variable	**Frequency**	**Percentage (%)**
Burning	22	5.6
Door to Door by waste contractor	10	2.4
Dumping in the lagoon	78	20
Dumping at the banks of the lagoon	122	31.2
Public Dump	160	40.8
Total	392	100

Source: Field Data, 2022

One of the key objectives of this study was to understand the environmental impact of flooding on the chosen communities and to achieve this the respondents were asked what they thought could be contributing to flooding withing their communities. The data gathered shows that public dumping of refuse was the highest followed by the dumping of refuse at the banks of the lagoon as well as in the lagoon. This leads to the chocking of drains and gutters that is carried by the surface run off into the lagoon narrowing the flow of water into the sea which is eventually causes flooding back in the communities. This finding is in line with Adams (2010) and Karley (2009) who stated that perennial flooding of Accra was largely due to activities of men in waste disposal and physical planning. The findings further established that residents along the big drains do empty their waste into the drains and some also illegally raised structures in water courses. Similarly in this study the situation has been the same and even on the rise, leading to the devastating impact on the environment as a result of flooding.

The findings of this study confirm one of the outcomes of Alhassan et al. (2010), that human actions alter the natural condition of things by leaving their mark on the natural landscape. Some of these alterations increase the frequency of flooding, resulting in severe implications for humans and the ecosystem in general.

Figure 16: waste disposed in the lagoon

Source: Field Survey Report, 2022

4.2.6 Effect of Flooding

Table 4 shows the effect of flooding in the catchment area 222 (56.8%) of the participant said they were charged GH₵ 5-7 for disposing waste. 122 (31.2%) of the participants said they were charged GH₵ 2-4 for disposing waste and 31(7.6%) charged between GH₵ 8-10 whilst 17 (4.4%) said they were charged above GH₵ 10 for disposing waste. Majority of the participants, 251 (64%) dispose waste weekly, 127 (32.4%) of the participants disposed wasted daily and 14 (3.6%) dispose waste monthly. 165 (42%) of the participants stayed indoors when there is flood, 111 (28.4%) and 90 (23.2%) of the participants just stays there and packed valuables respectively while 26 (6.4%) abandon their homes. Economically, 116 (29.6%) were affected with flooding. Most of the participants, 183 (46.8%) were affected with accommodation. About 64 (16.4%) of the participants had their property damage with flooding and 28(7.2%) had their education and health affected.

Table 10: Effect of Flooding in the catchment area

Effect of Flooding in the catchment area		
Variable	**Frequency (N=392)**	**Percentage (%)**
Amount charged for disposing waste		
GH₵ 2-4	122	31.2
GH₵ 5-7	222	56.8
GH₵ 8-10	31	7.6
Above GH₵ 10	17	4.4
Frequency of payment for waste disposal		
Daily	127	32.4
Weekly	251	64
Monthly	14	3.6
Strategies Adopted during Flooding		
Stay indoors	165	42
Do nothing, just stay there	111	28.4
Packed valuables	90	23.2
Abandon homes	26	6.4
Effect of flooding on participants		
Economically	116	29.6
Property Damage	64	16.4
Education & Health	28	7.2
Accommodation (Housing)	183	46.8

Source: Field Data, 2022

This study has one of its objectives to ascertain the environmental impact of floods in the within the catchment area. As has been established by other studies the impact is great especially in the instances where human settlement activities have encroached on the banks of the lagoon (Darteh,2010). The effect of flooding in and around the catchment area could lead to loss of life and property hence the study sort to find out the impact on the respondents according to their social, economic and housing needs. The housing and accommodation need especially in the urban and city is one that is very challenging as party as a result of economic challenges. According to the 2021 Population and Housing Census (PHC 2021), 20% of structures in Ghana are metal containers, wooden structures or kiosks. The findings of this study affirms that the most impacted aspect of the communities affected by flood is their housing units as a result of the make-shift nature and temporary accommodation in the form of metal containers, wooden structures or kiosks erected by most squatters in an around the catchment area.

Another finding was made during the field visit which is worth mentioning is the impact on the aftermath of flooding on the health of some respondents. During the floods a lot of stagnant waters and flood ponds generated causes breeding of mosquitos which causes increase in malaria infections and other water-borne diseases like cholera and affirms the findings of Atuguba & Amuzu (2006), that due to the spawning of mosquitoes in stagnant unclean or muddy water that stays for a time after floods before drying up, more money is spent on the treatment of water-borne diseases, particularly malaria. This is frequently exacerbated by the sanitation situation in the region, mostly leaving the environment prone to disease outbreaks such as malaria and Cholera.

The economic impact of the floods was also key feedback from the respondents (29.6%), this is due to property destruction which is yet another negative consequence of flooding in the catchment area where the majority of the property destroyed by floodwaters consists of domestic goods and equipment, including furniture and electrical gadgets such as televisions, radios, and sound systems(Odoi, 2019).Figure 12 shows some flood victims salvaging their properties after the floods.

Figure 17: Some flood victims counting their losses

Source: www.myjoyonline.com, May 2022.

4.2.7 Ways of Handling the Dangers of Flood

Table 5 shows the ways and measures adopted to cope with the dangers of flood. In anticipation to flood, 265 (67.6%) of the participants desilt gutters in and around neighborhood and 127 (32.4%) of the participants construct temporal gutters. During flooding, 160(40.8%) of the participants clear chocked drains, 111 (28.4%) construct temporal drain, 67 (17.2%) create alternate access to homes, 36 (9.2%) relocate to join family and friends and 17 (4.4%) of the participants construct barriers/walls to prevent water entry. When it comes to the events after the floods 223 56.8% of correspondents count their loss of items whilst the remaining (43.2 %) focused on clearing remaining debris brought in by the floods.

These were categorized into the activities done before, during and after the floods and these activities mainly included the desilting of drains and construction of temporary barriers in the neighborhood before the floods set in. In the event of the floods clearing of chocked drains and construction of temporal drains to make way for the water to flow out, others who are badly affected have no choice than to relocate to family and friends until flood waters subsides. This study agrees with that made by Musa and Usman (2013), who noted that desilting of gutters, dredging of watercourses, removal of buildings obstructing waterways, and measures to prevent flooding of waterways were determined to be the most prevalent techniques employed by flood victims.

Table 11:Was of handling the danger of floods

Ways of handling the danger of floods		
Variable	**Frequency (N=392)**	**Percentage (%)**
In anticipation of flood		
Desilt gutters in and around neighborhood	265	67.6
Construct temporary gutters	127	32.4
During flooding		
Clear choked drains	160	40.8
Construct barriers/walls to prevent water entry	17	4.4
Create alternate access to homes	67	17.2
Construct temporal drain	111	28.4
Relocate to join family and friends	36	9.2
After flooding		
Count loss of items	142	56.8
Clear remaining debris brought by flood	108	43.2

Source: Field Data, 2022

4.2.8 Flood Preventive Measures Adopted by Study Participants

Table 6 shows the preventive measure of flood in catchment area by Study Participants. In ways of preventing flood, 172 (44%) participants said they should avoid disposing waste in drains, 130 (33.2%) said authorities must prevent building in water ways and 89 (22.8%) said there should be avoidance of waste disposal into the lagoon. With the effort made by Tema Metropolitan Assembly to prevent flood, 216 (55.2%) of the participants said, they organized proper waste collection system and 176 (44.8%) said they organize proper waste disposing system. 273 (69.6%) of the participants said they report flood issues to the Tema Metropolitan Assembly, 107 (27.2%) said they report flood issue to the Assembly member of the community and 13 (3.2%) reported to the chief and other community council members. Most of the participants, 311 (79.2%) said the distribution of waste collection containers through the local assembly was cited as a major attempt to reduce the careless disposal of trash. 81 (20.8%) of the participants said authorities visit areas to inspect activities leading to flooding. With the inappropriate actions of authorities, 271 (69.2%) of the participant's said authorities are not proactive with flood preventive measures and 121 (30.8%) said authorities only act during flood.

Table 12: Flood Preventive Measures by Study Participants

Flood Preventive Measures by Study Participants		
Variable	**Frequency (N=392)**	**Percentage (%)**
Ways of preventing flood		
Avoidance of disposing water into lagoon	89	22.8
Authorities must prevent building in water ways	130	33.2
Avoidance of disposing waste in drains	172	44
Effort made by TMA to prevent flood in catchment area		
Organizes proper waste collection system	216	55.2
Organizes proper waste disposal system	176	44.8
Appropriate authorities that flood issues are reported to		
Tema Metropolitan Assembly	273	69.6
Assemblyman	107	27.2
Chief and Others	13	3.2
Authorities effort to prevent flooding		
Distribution of waste collections bins through local assembly	311	79.2
Monthly inspection of area to avoid flood	81	20.8
Inappropriate actions of Authority		
Not proactive with flood preventive measures	271	69.2
Only act during the floods	121	30.8

Source: Field Data, 2022

Amongst the questions posed as preventive measures, the respondents believe that the authorities preventing the building of unapproved structures in water courses is one of the major ways in which flooding can be prevented or minimized. This was followed by the suggestion that a proper waste management and disposal system by the assembly would go a long way to reduce the incidence of flooding in the communities. The findings with regards to these measures agrees with that of Odoi, (2019) whose findings pointed out that most of the time, victims tried to stop floods by cleaning out drains, dredging water bodies, pulling down buildings that block water ways. Actions taken by the central government through the NADMO has been to dredge existing water channels and courses as well as clearing of illegal structures built in water ways (Attipoe,2014). However, on the contrary it was observed in this study that there was great effort by authorities in distribution waste bins to most households however the problem of waste disposal was still prevalent due to two main issues gathered on the field. The first one was that most households could not afford to pay for the frequent disposal of their waste by the waste disposal contractors. Secondly most of them were ignorant of the impact of damping waste in and around waster courses and flood plains.

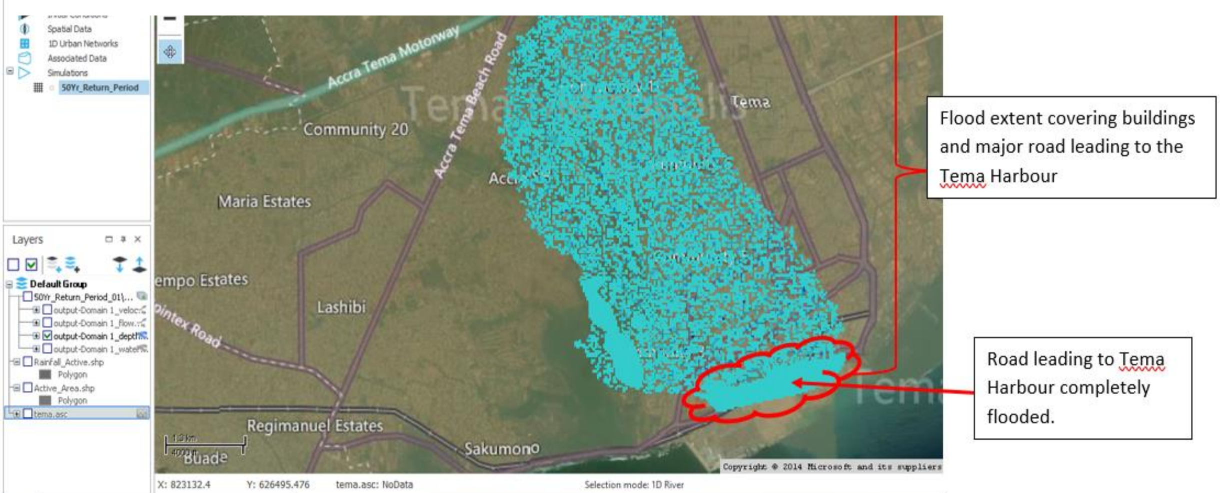
For actions supposed to be taken by authorities to prevent flooding, majority of the respondents were of the view that they were not proactive towards the implementation of flood prevention related projects. The authorities rather act more aggressively during flooding periods where the harm might have already been caused. This may eventually lead to respondents taken matter into their own hands before during after floods events which was the case I the study by Odoi, (2009).

4.3.0 Flood Modeling

Flooded properties were utilised in this study to demonstrate the various effects of flooding in various flood return periods. Based on outputs from modelling the various return period scenarios, it was obvious that six (6) hour critical storms for all return periods flooded major and critical infrastructures such as the major and main road leading to the Tema harbour and links the main business community centre was flooded and blocked. Flooded properties include accommodations, community markets and schools, church buildings, apartments for businesses and health facilities. Clipped building points flooded for the 1–100-year return period was 6,415. Overall, the flood maps show that 1 in 100-year return period rainfall scenarios causes more flooding than 1 in 50,25-,10-,5- and 2-year return periods respectively. The results for selected scenarios and flooded properties for 100 year return period can be found in appendix B. It was also realised from flood dept values that over the same time period, climate change has also caused more rain and floods.

The extent of flooding forecast in the catchment area of the TMA for the various return periods have been been highlighted in Figure 18, identifying the most vulnerable flood risk areas. Consequently, a description of the affected areas that would benefit from the incorporation of innovative flood protection measures under the current circumstances.

Figure 18: Flood extent map showing flooded area



5.Limitations

5.1. Survey and assessment

There were several limitations faced during data gathering from respondent's key amongst these are: Some were more concerned about their problems being solved for them as the flood continue to rake havoc on their livelihoods, they thus regarded surveys as one of those activities that are documented and shelved without key or concrete immediate nor medium long term solutions to their plight.

Secondly field visit was a bit challenging due to weather conditions, this posed difficulties in accessing some communities which were flooded.

Thirdly identifying the respondents to fill out questionnaire was a bit of challenge as most of them were traders and workers who could only be seen mostly in the evenings, however, to overcome this challenge some were administered electronically to the educated elites and as well as manually to those who were readily available.

Lastly some respondents were semi-illiterates needed assistance in filling out questionnaires which must have had influence in their choice of answers to some of the questions.

5.2. Flood Modeling

Data and modelling are two parts of this research that have limits. The first consideration is data accuracy and reliability. The information such as DEM, vector polygon files and rainfall hyetograph data came from open-source websites and literature reviews respectively. The third facet of unreliability is modelling.

This study is in partial fulfilment for a Master's degree and should be completed within few months due to time and financial constraints. After comparing several modelling methodologies, 2D Direct Rainfall Modelling (DRM), which can only depict changes in surface water flooding rather than a thorough flow beneath the ground, was chosen. A 1D/2D model can better represent water above and below ground, with 1D representing network water and 2D representing surface water. But because of time and money constraints, 2D is a good way to show water running through a city, by using a certain period of rainfall show how well the city drains.

Modelling of urban catchments response to extreme floods comes with lots of factor’s worth considering however in this study sewage network was not available and not considered. Also, to improve the accuracy of flood modelling, the resolution of the 2D domain should be as high as possible. Nonetheless, the highest resolution of the catchment area available was a 30m resolution which impacted the quality of grid cells that was utilized. Consequently, a grid cell size smaller than 30m could not be specified. In this study a 30m resolution used for the modelling.

Buildings, roads, soil types are key components in defining flood paths in general, but also the Sakumono Ramsar wetland site shares boundary with the catchment area but all the above categories of factors were not included in the modeling as the study only aimed at assessing the extent of flooding within the catchment area.

6.Summary and Conclusions

6.1. Survey and Environmental Impact

The catchment area was strategically chosen due to its closeness to the Sarkumonor Ramsar site (wetland), the Tema harbour and the sea. The outcome of the study has shown the potential increase in rainfall because of climatic changes and the likelihood of increase in flood events. The low-lying nature of this catchment makes it susceptible to flooding but also most immortally the human factors speeding up the gravity and impact of the floods on livelihoods as well as the environment. It can therefore be established that human factors such as dumping of refuse in and around water courses, lagoon, drains and gutters are the major factors adding to the severe impact of flooding in the communities.

The negative impact of human activities has caused the Sakumonor Ramsar wetland which also serves as flood plain to gradually lose its ability to contain more surface runoff from the city and immediate surrounding communities. The damping of waste into drains and water courses from the city center and nearby communities are eventually carried by surface runoff water which eventually end up in the lagoon thereby have narrowing the lagoon bed making it shallow. This has the potential of causing a backflow pressure in the nearby communities and back in the city centers as a result of restricted flow of water into the sea.

One of the other key human factors established by this study is the building of housing and other structures in water courses, in and around the lagoon areas which becomes a blockage to the free flow of surface run off water during high intensity rainfall hence causing flooding and its accompanying devastating effect.

Waste disposal: It was established that about 31.2% of respondents could only afford 2-3 Ghana Cedis for waste disposal hence even though the assembly has made much efforts in the provisions of some waste bins, it is still not enough to curb the waste disposal menace amongst residents many of whom are not earning enough to be able to afford a waste disposal contractor.

Environmental problems: The environmental impact of flood is so enormous but since the study is not a full Environmental Impact Assessment (EIA) study of flood in the catchment area it was limited within the confines of the catchment area and the short time frame of the study, below are the environmental impacts captured by way of interviews with opinion leaders and residents, assembly men, questionnaires and flood modeling. The environmental problems identified includes stagnant puddle and ponds of water breeding mosquitoes which causes rise in malaria infections, poor sanitation due to chocked drains, damage to human life and property, destruction of aquatic plant (hydrophytes and macrophytes) life in the case of the Sakumono Ramsar site lagoon, soil erosion, land pollution as a result of debris collected by floods. Though flooding in Ghana is perennial recovering from its impact can take a very long time with housing and economic challenges was established by the study to be the most impactful on the livelihoods of the respondents.

With regards to proactive and preventive measures by authorities towards the prevention of floods, 69.2% of the respondents believe that authorities are not proactive towards these measures.

It is worth noting that residents also adopted their own mean of dealing with flooding situation since they were already aware of the flooding situation. Notable amongst these was about 67.6% said they desilted chocked gutters in and around the neighbourhood whilst about 32.4% constructed temporary trenches within the neighbourhood before and during the floods.

Lastly it has also been established that the Sarkumono Ramsar site plays a critical role in reducing the impact of flooding by acting as a flood plain receiving surface runoff into the sea.

6.2. Flood Modeling

There is indeed no iota of doubt that that the resilient of the TMA area to flooding has been eroded over the time mainly due to human activities and practices which is the cause of current and future flooding of the catchment area. This is indeed backed by results of the simulations which shows future flood at-risk hotspots including the major road leading to the Tema Harbour, residential and some community business centres. The main critical infrastructure at risk includes the Accra Tema beach road leading to the Tema harbour and city centre, housing and health facilities. Also, a study of the results of simulations from various scenarios of flood return periods shows flood depths increasing as a result of increase in rainfall levels notably considering the anticipated frequency and intensity of future extreme rainfall events due to climate change which was also supported by data from generated rainfall hyetographs (Smith and Laswon, 2012).

It is observed that in addition to climate change one of the greatest impacts affecting the extent of flooding is the encroachment and filling up of the Sakumono Lagoon Ramsar wetlands which has led to the reduction in the volume of rainfall water the flood plain close to the catchment area can contain hence the increase in flood extent and dept over the simulated return periods. Figure 18 below shows part of the Accra-Tema beach road caving in during the floods. Even though this portion of the road leading to the Tema harbour is not within the catchment area, it confirms return period rains which flooded portions of the road leading to the Tema harbour has the potential of causing damage to the road infrastructure.

Figure 19: Part of the Accra-Tema beach road caved in after the floods

Source: www.myjoyonline.com, May 2022.

7. Recommendations

This study has established a combination of factors that makes the approach to dealing with the perennial flooding not effective. In the advent of climate change resulting in more rainfall it is critical and behooves on state authorities to act within the shortest possible time to avert current and future floods. The traditional ways of tackling flood by desilting drains, dredging of riverbeds and removal of illegal structures and buildings from waterways only when the rainy season is approaching and when there are floods is no longer sustainable.

Reasonable efforts must be made by the Town and Country Planning Department of the metropolitan assembly (TMA) to enforce rules regarding land use in urban catchments this is as a result of increasing rural urban migration in the capital Accra. This will guard and protect flood plains and wetlands that serves critical sources of mitigating the impact of floods in the city from encroachers. The laws must be seen to be working and not favoring only people in authority or the political elite.

To deal with the issue of waste disposal into drains, gutters, lagoon and other water bodies it is critical that the Environmental Protection Agency (EPA) together with the National Disaster Management Organization (NADMO) engage the metropolitan and district assemblies to educate residents on good waste disposal practices. The second aspect with regards to this is to ensure an effective and affordable waste disposal system by city authorities since residents will only patronize waste disposal contractors when they can afford. Authorities are also encouraged to continue and even widen the scope of the provision of waste bins for the various communities as this will go a long way to reduce the impact of flooding in the communities.

As a long term measure a conscious effort must be made by the TMA to ensure people who have encroached the lagoon and flood plains especially those occupying the nature reserve are relocated to protect the environment by way of reducing the impact of flooding. The possibility of replanting and growing shrubs to protect the banks of the lagoon and wetlands should also be done to restore the nature reserve.

Drains and flood channels: as the city keep expanding and climate change increasing the amount of rainfall there is the need for a re-engineering approach in the design and construction of appropriate drain and food water channels. These must be big enough to contain the volumes of water during critical storms and return periods.

Based on findings it is recommended that further studies be carried out to examine the real impact of the encroachment on wetlands and their inability to contain more rainstorms on flooding extent. A detailed 2D modelling in the future is worth pursuing to understand the impact of integrating sewage network and drainage systems, soil types and filtration systems, buildings and road network on current and future floods.

Finally further modelling studies could include the water flow above and below the Sakumo Lagoon Ramsar wetland and how it impacts flooding of surrounding communities. Model outputs of flood extent, and flood depth and velocity of the surface water runoff could inform current traditional approach to solving flooding issues and this could be used as great resource in finding integrated solutions such as green solutions, improving the flood ponds, increasing drainage capacity to reduce the impact of the perennial floods in the catchment area.

Lastly the importance of the Sakumono Ramsar site wetlands which also acts as a flood plain is very critical in averting or reducing the impact of flooding hence it is recommended that future research studies be done to access the role wetlands play in averting the impact of floods situations.

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Appendices

Appendix A: Questionnaire for Survey

CENTRAL EUROPEAN UNIVERSITY

DEPARTMENT OF ENVIRONMENTAL SCIENCES AND POLICY

QUESTIONNAIRE FOR RESIDENTS

This research aims mainly at performing an Environmental Flood Risk Assessment and Urban Resilience Building: A case study of communities around the Sakumono Lagoon (Wetland) Area of the Tema Metropolitan Assembly.

It also aims at suggesting recommendations to remedy the problem using a flood modelling software analyse future flood events.

NOTE OF CONCERNT: I agree to voluntarily partake in this survey solely for the purpose of academic research and my anonymity is assured.

Information given will not include names or any form of identification and is purely for academic research purposes. Thank you for participating

SECTION A: DEMOGRAPHIC DATA

1. (a) Sex: a. Male [ ] b. Female [ ]

(b) Age: ....

(c) Ethnicity: …………………………………………………………………

(d) Household status…………………………………………………………

(e) Occupation: ……………………………………………………………

(f) Level of educational (i) Primary [ ] (ii) Secondary/A level [ ] (iii) Tertiary [ ] (iv) Never attended school [ ]

(g) Length of stay in the community (i) 0 – 5 years [ ] (ii) 6 – 10 years [ ] (iii) 11 – 15 years [ ] (iv) 16 – 20 years [ ] (v) Above 20 years [ ]

(h) Residential status: Free occupant [ ] Tenant [ ] Owner-occupant [ ]

SECTION B: THE CAUSES OF FLODDING IN THE CATCHMENT AREA

2. Have you ever had floods in your neighbourhood? a. Yes [ ] b. No [ ]

3. If yes, why do you still live here?

a. proximity to work [ ]

b. affordability of housing [ ]

c. did not face problems before [ ]

d. closeness to the Tema harbour [ ]

e. other [ ] , specify ....

4. What do you think are the causes of these floods?

a. Building in water courses [ ]

b. Bad refuse Disposal [ ]

c. Building within and around the Lagoon [ ]

e. Lack of Drains [ ]

f. drainage systems that are poorly designed [ ]

g. Choked drains [ ]

h. The area's low-lying nature [ ] i. other [ ], specify

5Are you willing to relocate due to the flooding?? a. Yes [ ] b. No [ ]

6. What is the frequency of flooding in this area? a. Once a year [ ] b. Twice a year [ ] c. Several times a year [ ]

7. When do floods occur during the year (Which Month/(s)? ....

8. How long do the floods usually last? (a) ....Hours (b) ....Days (c) ....Weeks (d)...........Months (e) Other [] specify...

9. During the floods, which agency or organization (s) came to your aid?

a. National Disaster Management Organisation (NADMO) [ ]

b. Tema Metropolitan Assembly [ ] c. None [ ] Other [ ], specify..

10. In what form was their support?

a. Supply of relief items (food, building materials, blankets, medicine, and so on)) [ ]

b. Sent rescue team to support [ ] c. Other [ ], specify...

11. Do you believe the procedures for alocating land for use in this community are followed? a. Yes [ ] b. No [ ]

12. How do you dispose of waste in this area? (a) Burning [ ] (b) Door to Door [ ] (c) Dumping in the lagoon [ ] (d) Dumping at the banks of the lagoon [ ] (e) Public Dump [ ] (g) others [ ] specify...................……………………………………………

SECTION C: EFFECTS OF FLOODING IN THE CATCHMENT AREA

13. How much are you charged to dispose off your waste(a) 2 – 4 GHC [ ] (b) 5 – 7 GHC [ ] (c) 8 – 10 GHC [ ] (d) above 10 GHC [ ]

14. What is the frequency of payment for the waste disposal service ? a. Daily [ ] b. Weekly [ ] c. Monthly [ ] d. Other [ ], specify...

15. What do you do when the floods occur? ....

....

16. In what ways are you affected by the floods? a. Economically [ ] b. Property Damage [ ] c. Education & Health [ ] d. Accommodation (Housing) [ ] e. Others (specify) …………………

SECTION D: PREVENTIVE MEASURES

17. Do you believe that these floods can be avoided? a. Yes [ ] b. No [ ] 18. If yes, how can this be achieved? ……………………………………………….…......................

19. Has the Tema Metropolitan Area authorities made any efforts to prevent flooding? a. Yes [ ] b. No [ ] 20. Kindly explain your answer.........………………………………………………………

21. How do you do you prepare in anticipation of the floods? ....

22. What action do you take when the floods finally occur?….….………………………………

23. How do you protect yourself from danger during flooding in your area?

(a) Relocate to join family and friends [ ] (b) Construct barriers/walls to prevent water entry [ ] (c) Create alternate entry to access your home [ ] (d) Construct temporary drains [ ] (e) Clear choked drains [ ] (f) I only hope and pray that the floods do not happen. [ ] (g) Other [ ], specify...

24. What actions do you take after flood incidents?..

25. Do you generally report floods to the appropriate authorities? b. No [ ]

26. If yes, which of these (a) Tema Metropolitan Assembly [ ] (c) Other [ ], specify................................

27. Are you aware of the city authorities' (TMA) efforts to solve this problem? a. Yes [ ] b. No

28. If yes, what exactly have these efforts been? ....

29. Additional Comment/Observation (if any): ……………….……………………………….

Appendix B: Results from simulation scenarios

100 year						
Min	**hr**			**Cum. Pre**		**100yr**
60	1	**100yr**	109.45	44.7	44.68	11.97
120	2			63.2	18.51	18.51
180	3			77.4	14.20	44.68
240	4	**M**	44.68	89.4	11.97	14.20
300	5			99.9	10.55	10.55
360	6			109.5	9.54	9.54
420	7					

50 year						
Min	**hr**			**Cum. Pre**		**50yr**
60	1	**50yr**	94.0	38.4	38.38	10.28
120	2			54.3	15.90	15.90
180	3			66.5	12.20	38.38
240	4	**M**	38.38346	76.8	10.28	12.20
300	5			85.8	9.06	9.06
360	6			94.0	8.19	8.19

25 year						
Min	**hr**			**Cum. Pre**		**25yr**
60	1	**25yr**	87.5	35.7	35.71	9.57
120	2			50.5	14.79	14.79
180	3			61.9	11.35	35.71
240	4	**M**	35.71376	71.4	9.57	11.35
300	5			79.9	8.43	8.43
360	6			87.5	7.62	7.62

10 year						
Min	**hr**			**Cum. Pre**		**10yr**
60	1	**10yr**	69.9	28.5	28.52	7.64
120	2			40.3	11.81	11.81
180	3			49.4	9.06	28.52
240	4	**M**	28.51997	57.0	7.64	9.06
300	5			63.8	6.73	6.73
360	6			69.9	6.09	6.09

5 year						
Min	**hr**			**Cum. Pre**		**10yr**
60	1	**10yr**	58.6	23.9	23.93	6.41
120	2			33.8	9.91	9.91
180	3			41.5	7.61	23.93
240	4	**M**	23.93383	47.9	6.41	7.61
300	5			53.5	5.65	5.65
360	6			58.6	5.11	5.11

2 year						
Min	**hr**			**Cum. Pre**		**2yr**
60	1	**10yr**	46.2	18.8	18.84	5.05
120	2			26.6	7.80	5.99
180	3			32.6	5.99	18.84
240	4	**M**	18.84253	37.7	5.05	7.80
300	5			42.1	4.45	4.45
360	6			46.2	4.02	4.02

Figure 20:6-Hour Design Rainfall Hyetograph

Appendix C: Results from simulation scenarios

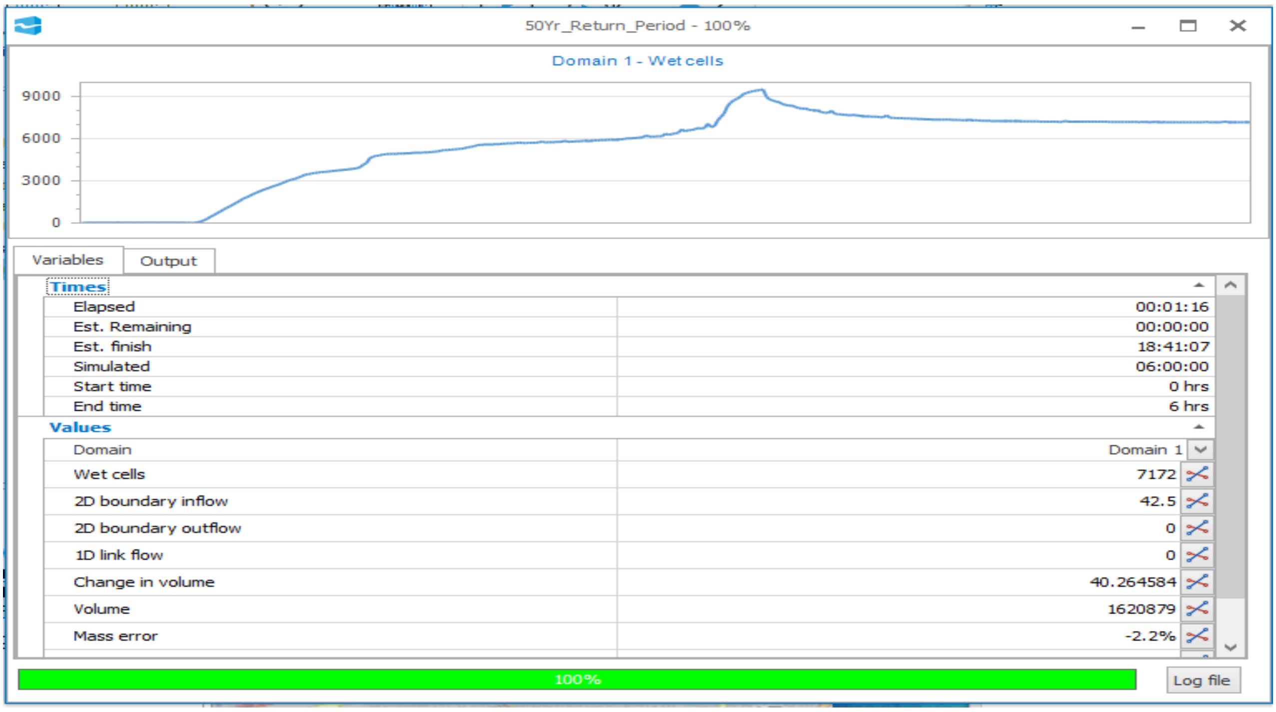
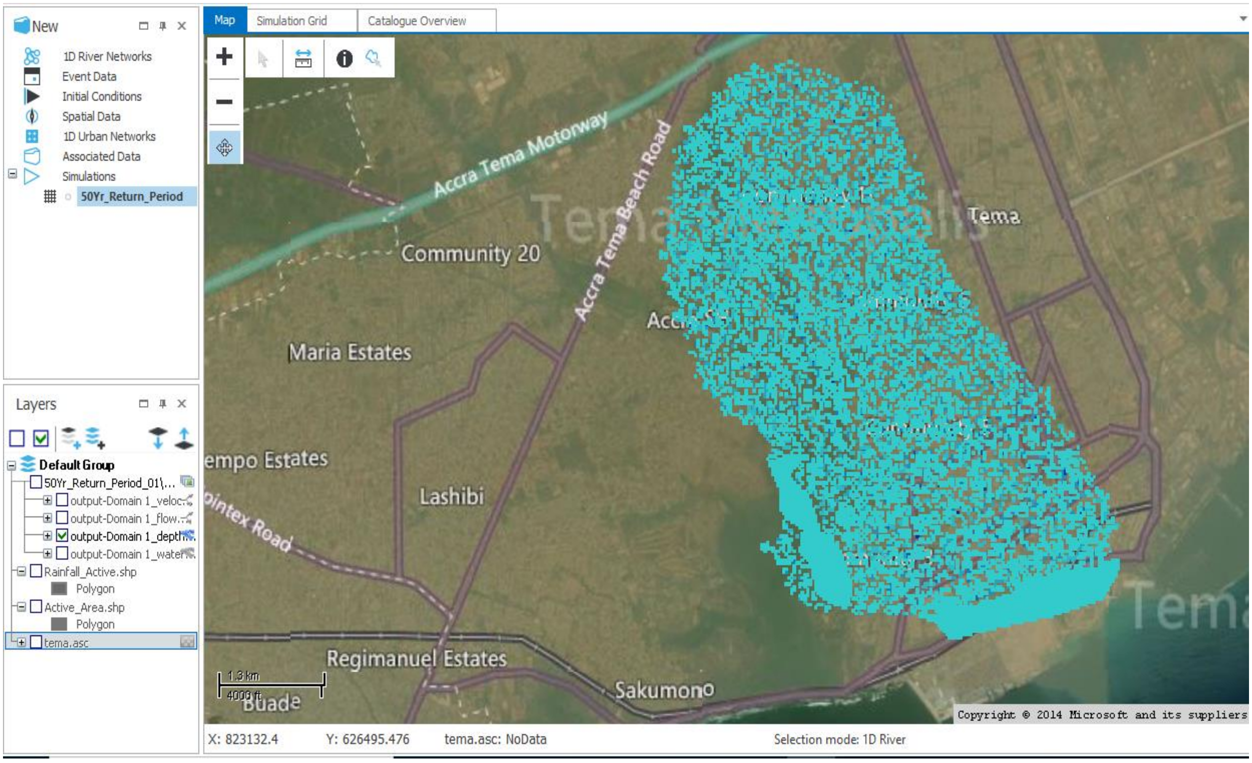


Figure 21: Wet Cells Progress Report_50YRP



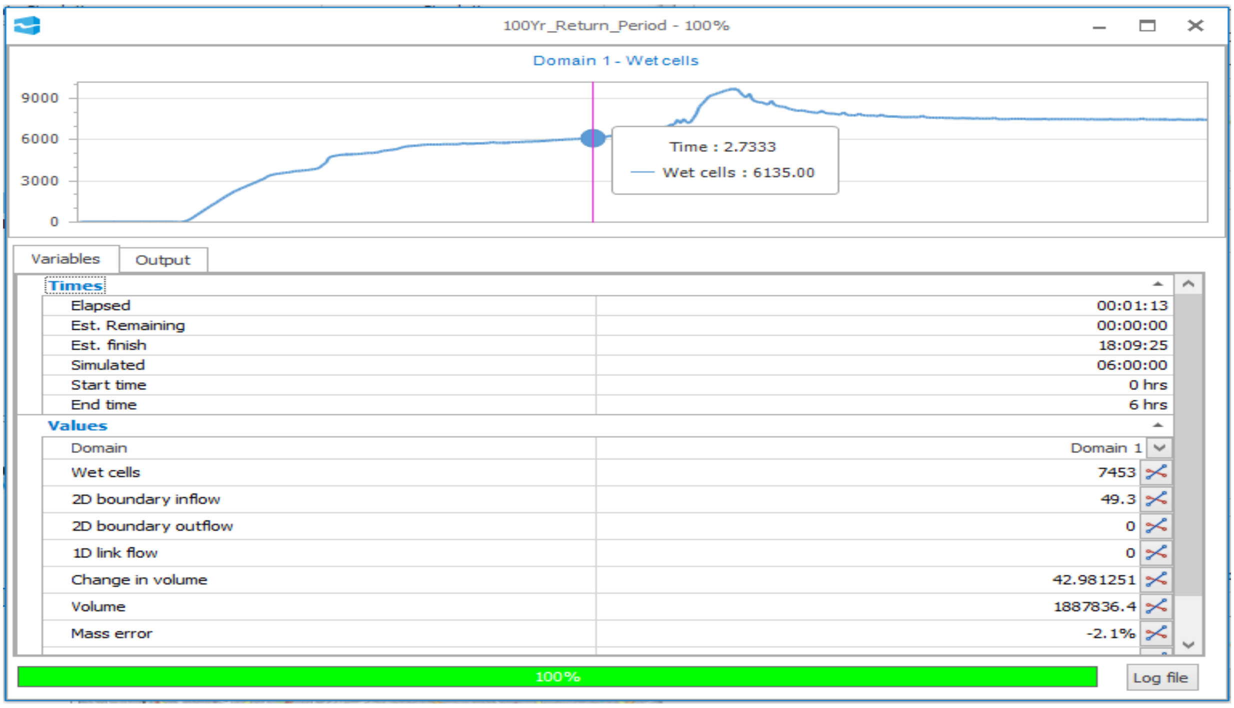


Figure 24: Wet cells Progress report _100YRP

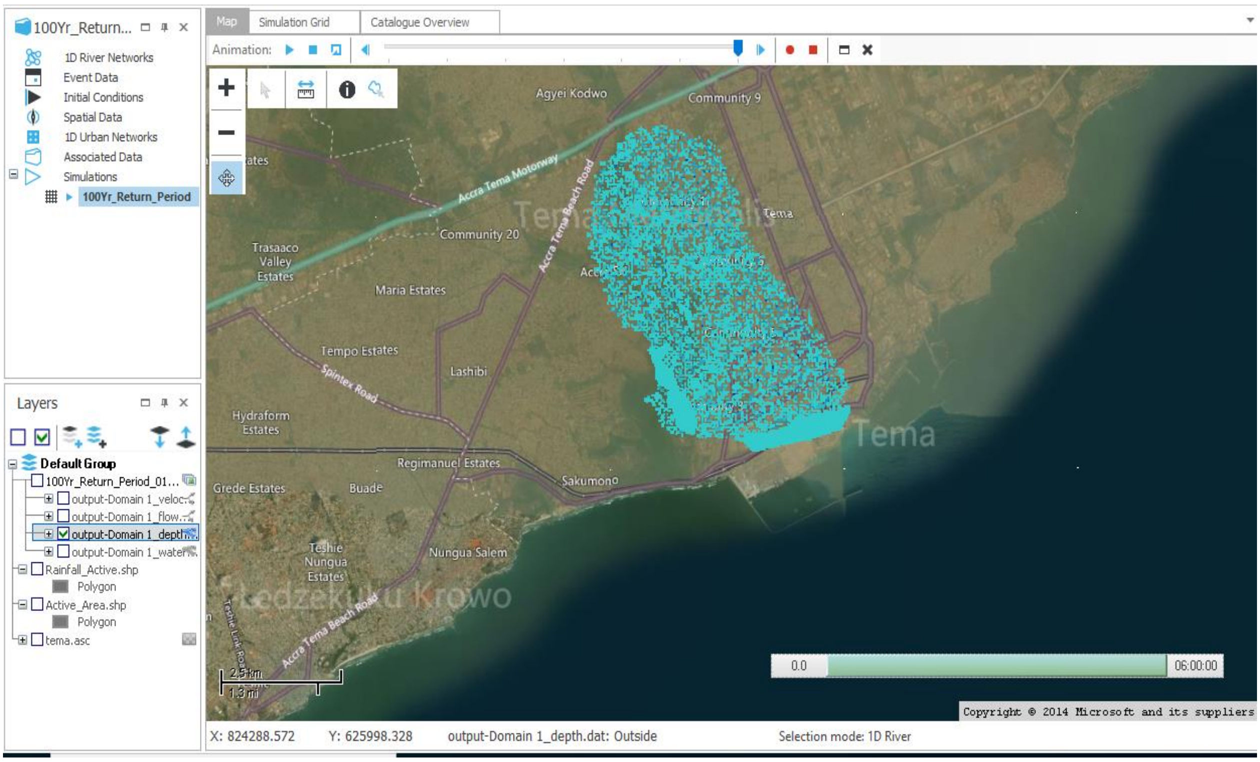


Figure 23: Flood extent map_100YRP

Figure 27: Clipped properties with flood extent map

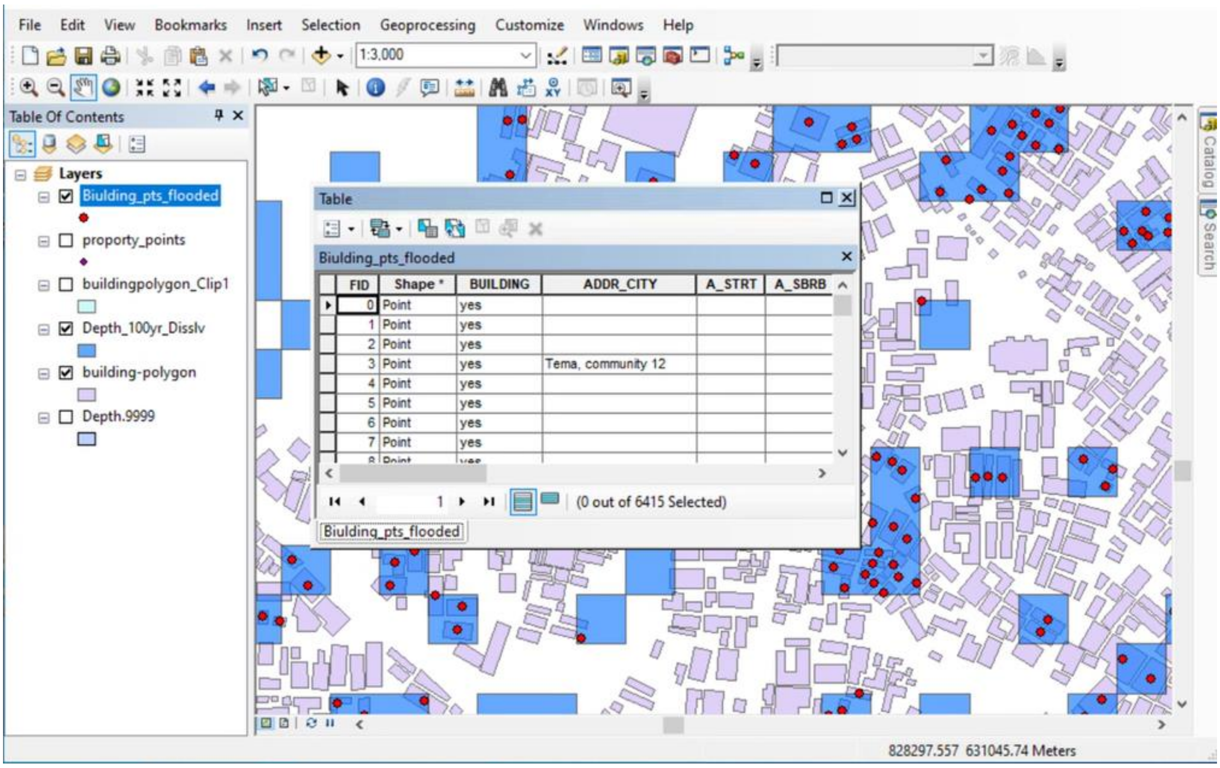


Figure 26: Number of flooded properties