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Flood Disaster Risk Mapping in the Lower Mono River Basin in Togo

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ABBREVIATIONS

AR	Assessment Report
ASTER	Advanced Space-borne Thermal Emission and Reflectance Radiometer
BBC	Bogardi, Birkmann and Cardona
CFA	Commnuate Financière Africaine
CGIAR CSI	Consortium for Spatial Information of Consultative Group for International Agricultural Research
DRFIP	Disaster Risk Financing and Insurance Program
DEM	Digital Elevation Model
EM DAT	Emergency Events Database
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
EU	European Union
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GISM	Geographic Information System Model
GPS	Geographic Positioning System
GTZ	Gesellschaft für Technische Zusammenarbeit
HDI	Human Development Index
IDP	Internally Displaced Persons
IFRC	International Federation for Red Cross
IPCC	Intergovernmental Panel on Climate Change

ITCZ	Inter Tropical Convergence Zone
MODIS	Moderate-Resolution Imaging Spectroradiometer
MOVE	Methods for the Improvement of Vulnerability Assessment in Europe
NAPA	National Action Plan for Adaptation
NASA	National Aeronautic and Space Administration
OCHA	Office for Coordination of Humanitarian Affairs
RS	Remote Sensing
SRTM	Shuttle Rader Topography Mission
TIN	Triangulated Irregular Network
TM	Thematic Mapper
UNDP	United Nations' Development Program
UNDRO	Office of the United Nations Disaster Relief Coordinator
UNFCCC	United Nations Federation Convention on Climate Change
UN/ISDR	United Nations International Strategy for Disaster Reduction
UNU-EHS	United Nations University-Environment and Human Security
USGS	United States Geological Survey
WG	Working Group

ABSTRACT

Flood disaster is the most devastating hydro-meteorological event in the Lacs District, Togo. Communities in the Lower Mono River Basin experience flooding almost every two years. In light of this, the study focused on assessment and mapping of flood disaster risk in six selected communities in the Lacs District. Specifically, the study examined the pattern of rainfall in the basin, estimated and predicted flood return periods and the associated magnitude of river flow and, also mapped the nature of flood risk in the area. The study combined GIS and Remote Sensing, and statistical methods in risk mapping and analysis. Weighted overlay tool in ArcGIS was used for flood risk mapping, while statistical methods were employed in trend and flood frequency predictions. The study considered the pattern of rainfall in the entire Mono Basin due to the fact that the cause of flooding at the downstream is partly due to high rainfall in the upstream (Mono River).

Significant decreasing trend in rainfall was found at the station of Sokode (upstream), while an insignificant increase in rainfall was observed at Atakpame, Sotouboua, Aklakou and Tabligbo. Flood return periods for each 2 years and 5 years are 567.4 m^3/s and 847.1 m^3/s respectively. The resultant risk map shows that all the communities are exposed to flood disaster risk but Agbanakin, Azime Dossou and Togbavi communities are found in areas with high risk levels. Positive attitude towards early warning systems, collaboration among disaster relief institutions and appropriate building codes were recommended towards reducing flood disaster risk.

Key Words: Flood Disaster, Flood Risk, Mapping, Return Period, GIS, Mono River Basin, Togo

RESUME

La catastrophe liée à l'inondation est le phénomène hydrométéorologique le plus dévastateur dans la préfecture des Lacs au Togo. Les communautés se trouvant dans le bassin du bas Mono vivent des phénomènes d'inondation presque tous les deux ans. A la lumière de cela, l'étude s'est focalisée sur la cartographie du risque d'inondation dans six (06) communautés sélectionnées dans la préfecture des Lacs. Spécifiquement, l'étude a porté sur l'analyse d'évolution de la précipitation dans le bassin, estimé la période de retour des inondations et la magnitude du débit de la rivière ainsi que la cartographie de la nature des risques d'inondation dans la zone. L'étude a intégré les SIG et télédétection et les méthodes d'analyse statistiques dans la cartographie des risques.

L'outil de superposition pondérée dans le logiciel ArcGIS a été utilisé pour la cartographie des risques d'inondation, pendant que les méthodes statistiques ont été employées dans l'analyse des tendances et l'analyse fréquentielle des inondations.

D'importances baisses dans la tendance des précipitations ont été constatées à la station de Sokodé alors qu'une légère hausse, à peine perceptible, des pluies a été observée à Atakpamé, Aklakou et Tabligbo. La période de retour des inondations pour chaque deux (02) ans et cinq (05) ans sont de 567,4 m^3/s et 847,1 m^3/s respectivement. Le résultat de la carte du risque laisse entrevoir que toutes les communautés étaient exposées à la catastrophe du risque d'inondation. Cependant, les communautés d'Agbanakin, Azimé Dossou et Togbavi se retrouvent dans la zone de risque encore plus élevé. Les comportements positifs, tels que le système d'alerte précoce, la collaboration entre les institutions intervenant dans l'apport de secours aux victimes et des règles de constructions appropriées sont les recommandations à travers lesquelles le risque des catastrophes d'inondation peuvent être réduits.

Mots clés : Inondation, Risques d'inondation, Cartographie, Période de retour, SIG, Bassin du fleuve Mono, Togo

CHAPTER 1: INTRODUCTION

1.1 Statement of the Problem

The concern of most governments, organizations, unions and international bodies is to ensure the security of humans but one setback to their vision is disaster (Alexander *et al.*, 2011). An event becomes a disaster when there is a serious disruption to the functioning of a community involving widespread human, material, economic or environmental losses and impacts, which exceed the ability of the affected community to cope using its own resources (UN-ISDR, 2004). The worldwide increase in the occurrences of hydro-meteorological hazards is likely the result of climate change (Alexander *et al.*, 2011).

Climate change is explained as a change in the state of the climate that can be identified (e.g. by using statistical tests) by changes in the mean and/or the variability of its properties and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcing or to persistent anthropogenic changes in the composition of the atmosphere or in land use (IPCC, 2014). Changes in climate variables especially temperature is likely the driver of changes in precipitation and extreme hydrological events. It is extremely likely that human influence has been the dominant cause of the observed warming of the earth since the mid-20th century. It is observed that West Africa has been warming faster than the global average since 1970s (0.7^0C-0.8^0C). Climate variability has led to increase in the frequency and impacts of hydro-meteorological hazards (e.g. floods & drought) in West Africa and if nothing is done to reduce the greenhouse gas emissions today, the negative impacts of climate change are likely to become more severe by 2050 (IPCC, 2007). Togo is extremely vulnerable to the impacts of flood hazard due to a history of limited investment in infrastructure, high building vulnerability, settlement in flood zones and economic dependence on agriculture (DRFIP, 2012).

Despite all the efforts made by the government, institutions and other organizations in managing and reducing floods in Togo specifically in the Maritime Region, human lives and properties are lost each time flooding occurs. Again, government of Togo employs the services of Ministry of Environment, Ministry of Territorial Administration, Ministry of Civil Protection and the Red Cross, among others, to save lives and properties almost every year in the downstream of Mono

River but how long should this persist? According to IPCC (2007), it is likely that there will be an increase in extreme events such as flooding in West Africa, including Togo, due to uncertainties in rainfall patterns. This is likely to affect food, health and environmental domains of human security.

In 2007, as a result of flooding, over 127,880 people were affected, 13,764 people were displaced, and dozens were killed in areas located in the river basins in Togo. Again, in 2008, heavy rains caused severe floods in the downstream of the Mono River Basin, displacing about 20% of the people (IFRC, 2013). After both flooding events, food security was threatened due to shortage in food production and inflation rates rose by 1% in 2007 to 9.1% in 2008 (GFDRR, 2013). Moreover, 300 km of roads and 11 major bridges were destroyed, leading to an increase in transportation costs. Preliminary assessments of flooding indicated that in 2008, about 9% of the people had their cultivated lands destroyed, resulting in a serious loss of income for farmers (GFDRR, 2013). The 2010 flooding had great negative impacts on human security as most communities were affected (over 8 communities in Togo) and resulted in total cost of damages and losses of over US$38 million (GFDRR, 2013).

Geospatial techniques such as Remote Sensing and Geographic Information System (GIS) have been used to map hazards and flood disaster risks in most parts of the world, including countries like Germany, Bangladesh, Japan, India, Kenya, Vietnam Ghana, and Nigeria. Their outputs proved very efficient and important in disaster management planning (United Nations, 2009). Integration of remote sensing data, flood (hazard data), rainfall data and socio-ecological indicators using GIS is an efficient approach to generate flood vulnerability and risk maps for a given area (Forkuo and Mensa, 2012).

Recently, Amoussou *et al.* (2014) used statistical methods to model changes in peak flow of water for a 23-year period but did not carry out flood risk analysis. There are some current studies (Kissi *et al.*, forthcoming) which have looked at the social vulnerability to flood in the Bas Mono district, north of Lacs district (Maritime region). Also, during an interview with Togo Red Cross in February 2015, it came out that there is no known comprehensive study that has come out with flood risk maps showing the various levels of flood risk in the area, at community level. Location of temporal homes for flood victims have often been done based on mere observations by human eyes. Therefore, a comprehensive flood disaster risk mapping and analysis in the Lacs district, lower Mono River Basin is necessary to help close the gap. This current study fills in that gap

1.2 The general objective

The general objective of this study is to assess and map flood disaster risk in the Lower Mono River Basin focusing on Lacs District in Maritime Region, Togo.

Specific objectives are to:

i. examine the pattern of rainfall in the Mono River Basin;
ii. estimate flood return periods and the associated magnitude of river flow; and
iii. assess and map the nature of flood risk in the area

1.3 Research questions

i. What is the pattern of rainfall in the Mono River Basin in Togo?
ii. What is the frequency of flood occurrence and the associated magnitude of river flow?
iii. What is the nature of flood disaster risk in the Lower Mono River Basin?

1.4 Organization of the study

This study is organized into five (5) chapters. The introductory chapter includes problem statement, objectives of the study, research questions and chapter organizations. Chapter two covers review of basic concepts of flood disaster risk, flood risk and frequency analysis, impacts of climate change on human security, GIS and Remote sensing application, methods and frameworks for flood disaster risk analysis. The third chapter considers description of the study area, data collection and analysis. Chapter four covers presentation and discussion of results, while the final chapter covers conclusion and policy recommendations to the government, institutions and communities, and limitations of the study.

CHAPTER II: LITERATURE REVIEW

2.1 Flood risk concepts

2.1.1. Flooding

Flooding refers to the inundation of an area by unexpected rise of water by either dam failure or extreme rainfall duration and intensity in which life and properties in the affected area are under risk (Nyarko, 2000). Jeb and Agarwal (2008) view flooding as a general temporary condition of partial or complete inundation of normally dry areas from overflow of inland or tidal waters or from unusual and rapid accumulation or runoff.

There are different forms of flooding but the common ones are flash flood, river flood and coastal floods. These could further be classified as urban floods or rural floods (Merz *et al.*, 2007; EU Floods Directive, 2007). River flood has been defined as a general and temporary condition of partial or complete inundation of normally dry land areas from the usual and rapid runoff of surface waters from rainfall or dam break. Flood is used in a broader sense to cover several river activities that cause damage. Examples include inundation of floodplains and adjacent terraces, bank cutting, river channel shifting, and debris torrents during normally high river discharge (UNDRO, 1991). In this case, the concentration of this study is on river flooding in a rural area.

2.1.2. Hazard

Hazard could be described as potential occurrence of a natural or human-induced physical event or trend, or physical impact, which may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, and environmental resources. In IPCC reports, the term *hazard* usually refers to climate-related physical events or trends and their physical impacts (IPCC WGII AR5 Glossary, 2014). Also, hazard was simply described as a potentially damaging physical event, phenomenon or human activity that may cause the loss of life or injury, property damage, social and economic disruption or environmental degradation (UN-ISDR, 2004). Therefore, hazard is defined by the potentiality of geodynamics or hydro-meteorological processes to cause effects upon exposed elements.

2.1.3. Disaster

Intergovernmental Panel on Climate Change (2014) explains disaster as severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic, or environmental effects that require immediate emergency response to satisfy critical human needs and that may require external support for recovery. Also, IFRC (2013) sees disaster as a sudden, calamitous event that seriously disrupts the functioning of a community, which causes human, material, and economic or environmental losses that exceed the community's ability to cope using its own resources. All the two explanations of a disaster agree on the fact that the affected people need immediate external aid to cope with and recover from the disaster at hand.

2.1.4. Vulnerability

UN-ISDR (2009) sees vulnerability as the characteristics and circumstances of a community, system or asset that make it susceptible to the damaging effects of a hazard, while UNDP (2004) views it as a human condition or process resulting from physical, social, economic and environmental factors, which determine the likelihood and scale of damage from the impact of a given hazard. The definition of UNDP is human-centred and can affect the method of estimating disaster risk index (Birkmann, 2006). IPCC (AR4, 2007) perceives vulnerability as the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes.

It is true that all the above perspectives agree on the susceptibility of a community or a system to a hazard. Therefore, this research work combines all the above perspectives of vulnerability but it must be noted that none of the perspectives mentioned that vulnerability is dynamic because what is vulnerable to a hazard today may not be vulnerable tomorrow or may not be vulnerable to the same hazard but probably to a different hazard.

According to Schanze (2006), vulnerability refers to the characteristic of a system that describes its potential to be harmed. This can be considered as a combination of susceptibility and value of the elements that are exposed to a hazard (e.g. flood). Vulnerability is the conditions determined by physical, social, economic and environmental factors or processes, which increase the susceptibility of a community to the impact of hazards (UN-ISDR, 2004). It should be noted that while vulnerability is widely used in hazard and risk analysis, it lacks acceptable definition (Adger, 2006). The conceptualization of vulnerability depends on the topic, discipline, organization or institution (Birkmann, 2006; UN, 2009). Assessment of vulnerability in this study follows the definition of UN-ISDR (2004). It includes the four dimensions of vulnerability that a community is likely to face due to a flood hazard.

2.1.5. Flood Risk

A risk could be viewed as a factor, element, or course involving danger or can be seen as the possibility of suffering harm or loss. According to European Commission (2007) flood risk means the combination of the probability of a flood event and of the potential adverse consequences for human health, the environment, cultural heritage and economic activity associated with a flood event. Bollin *et al.* (2003) views risk as a function of hazard, exposure, vulnerability, and capacity measures. Manandhar (2010) indicates that flood risk is a complex interaction of hydrology and hydraulics of the river flow with the potential of damage to the surrounding floodplains.

2.2 Flood Risk Analysis

The element of flood risk has both spatial and temporal domains and is also a function of the level of human intervention of the surrounding floodplains (Awal, 2003).
Bollin *et al.* (2003) consider vulnerability within risk and hazard with four dimensions (physical, social, economic and environmental. Flood risk analysis factors in the probability of human life and properties within an area to be affected by high rainfall that results in flood (Nyarko, 2000). While risk and vulnerability are considered as continuums, a disaster is a materialization hazard. The dynamic nature of vulnerability and hazard phenomena means that risk is non-static; it changes over time and these changes have to be considered when applying specific assessments, as well as when developing risk reduction policies (Quarantelli, 1998).

According to Schanze (2006), risk is a function of probability of occurrence, exposure and vulnerability. Often, in practice, exposure is incorporated in the assessment of consequences. Therefore, risk can be considered as having two components: the probability that an event will occur and the impact (or *consequence)* associated with that event. The probability of occurrence refers to the hazard, while the consequences represent vulnerability. In order to carry out an effective risk mapping, Schanze (2006) used the Source-Pathway-Receptor-Consequence-Model below.

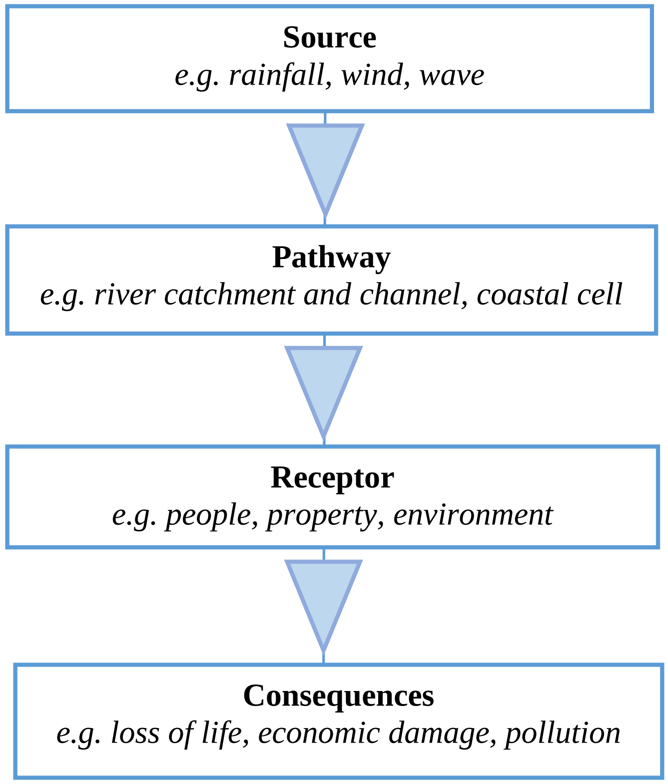

Figure 2.1. Source-Pathway-Receptor-Consequence-Model (Schanze, 2006)

In figure 2.1, receptor refers to the entity that may be harmed (a person, property, habitat etc.). For example, in the event of heavy rainfall *(the source)* floodwater may propagate across the flood plain *(the pathway)* and inundate housing *(the receptor)* that may suffer material damage *(the harm or consequence).* The vulnerability of a receptor can be modified by increasing its resilience to flooding (Schanze, 2006).

2.2.1 Risk mapping

This could be explained as the process of showing the spatial extent of risk (combining information on probability and consequences). Risk mapping requires combining maps of hazards and vulnerabilities. The results of these analyses are usually presented in the form of maps that show the magnitude and nature of the risk (Schanze, 2006).

2.2.2 Impacts of flooding on human security

The concept of human security stresses the freedom from fear and want, and freedom to live in dignity but these are often difficult to achieve due to challenges posed by disasters. According to the fourth Assessment Report of the IPCC (2007), developing countries are more vulnerable to impacts of climate extremes because they have low adaptive capacity. Human security is often threatened when a flood of high magnitude occurs. There are three main types of disasters in Togo: drought, flood and epidemic of malaria but flooding has greater negative impacts (Tenou and Wala, 2009).

EM-DAT (2013) records that Togo has suffered from about 60 flooding events between 1925 and 1992. Flood disasters has gained attention in Togo from 1989, partly due to the construction of the Nangbeto dam on the Mono River and partly due to climate variability. The housing sector is highly vulnerable to flood impacts for a number of reasons, notably: the absence of an effective national policy on housing and therefore the absence of a mechanism for state intervention, the high rate of poverty and high cost of building materials leading to low quality of construction (no building codes), poor and badly maintained infrastructure in and around growing settlements and lack of urban planning for the rapid expansion of cities (IFRC, 2010).

Community security has been threatened in the downstream of the Mono River Basin each time the river overflows its bank due to either heavy downpour or due to the opening of the Nangbeto dam (Ago, 2005; Tenou and Wala, 2009). The Districts that are usually affected by flood disaster are Yoto, Bas Mono and Lacs, all located in the downstream of the Mono River Basin below the Nangbeto Dam (Tenou and Wala, 2009).

In Ouagadougou, the capital of Burkina Faso, 150,000 people were affected and key infrastructures (including a central hospital, schools, bridges and roads) were damaged as a result of 623 ml flooding in 2009 (UN/OCHA, 2013).

One very important domain of human security that is usually threatened by floods is health security. It was recorded that one of the effects of the 2010 flooding was cholera epidemics with 1,182 deaths in Nigeria, with similar recorded deaths in Cameroon, Niger and Chad (UNOCHA, 2010). Floodwaters become special breeding homes for Malaria at times in some villages in Togo, though IPCC (2010) reported that cases of malaria are associated with higher temperatures.

2.3 Climate Change and Flooding

According to IPCC (2013), climate change and variability is a global issue but its impacts are local. Over the West African Sub-region, there have been severe disasters accelerated by the variation in climate. Hydro-meteorological hazards have been mentioned to be the common cause of disasters associated with climate change and climate variability worldwide. World Bank (2010) argued that impacts of climate change lead to land degradation which affects the quality of soil and reduces the infiltration rate of water by giving pace for high level of surface runoff. Unlike temperature, prediction of precipitation is quite difficult due to high level of uncertainty (IPCC, 2007). There is disagreement among regional climate models on projections of precipitation over the West African sub region. However, it has to be acknowledged that climate change challenges the historical knowledge of hazard events, particularly due to the modification of frequency and intensity of such events (Keiler *et al.*, 2010).

2.4 Flood Frequency /Return Period Analysis

Flood frequency analysis uses historical records of peak flows to produce guidance about the expected behaviour of future flooding. Two primary applications of flood frequency analyses are: to predict the possible flood magnitude over a certain time period and to estimate the frequency with which floods of a certain magnitude may occur (USGS, 2005). The flood frequency analysis is one of the important studies of river hydrology which is conducted based on maximum instantaneous flow (Yadav, 2002).

The recurrence interval or return period is explained as the average time between events of a given magnitude, assuming that different events are random. Common return periods include the 2–10– 25–50 and 100 years (USGS, 2008). The recurrence interval or return period of floods of different heights varies from catchment to catchment, depending on various factors such as the climate of the region, the width of the floodplain and the size of the channel. In a dry climate, the recurrence interval of a 3m-height flood might be much longer than in a region that gets regular heavy rainfall (Meyer, 2007). Therefore, the recurrence interval is specific to a particular river catchment. Similarly, based on the works by the USGS (flood return estimations, 2001), the return period is the time period over which it is likely that a particular magnitude flood will occur. Thus, a 25year flood is defined as a flood that can occur on average once every 25 years. In this example, 25 years is considered the return period. However, floods do not occur in exact cyclic events. That is, they do not occur at nicely spaced 25-year intervals as often presumed (USGS, 2011).

2.5. Geographic Information System (GIS), Remote Sensing (RS), and Flood Risk Analysis

GIS was first introduced and used in the 1960s and since then, the technique has developed into a useful means of gathering and analyzing different kinds of spatial data related to unique geographical locations (Atkinson *et al*., 2008, cited in Orok, 2011). In the context of flood hazard management, GIS can be used to create interactive map overlays, which clearly illustrate the areas of a community that are at risk of flooding. Such maps can then be used to coordinate mitigation efforts before an event and recovery after an event (Awal, 2003). Thus, GIS provides a powerful and versatile tool to facilitate a fast and transparent decision-making process. There are a number of GIS softwares, which include, ILWIS, GRASS, MapInfo, among others. ArcGIS (ArcView, Arc/Info, ArcMap, ArcEdit, etc.), a GIS tool developed by ESRI is a powerful, easy to use, point and -click graphical user interface that makes easy loading of spatial and tabular data so that it can display the data as maps, tables and charts (Manandhar, 2010). Geographic Information System provides a database from which the evidence left behind by disasters that have occurred earlier can be interpreted, and combined with other data to arrive at hazard maps, indicating which areas are potentially risky (USGS, 2008).

Remote Sensing, the technology instrumental in gathering spatial information, is used for identifying, classifying, mapping, monitoring, planning, mitigating and managing disasters (Manandhar, 2010; Orok, 2011). Remote sensing is an important tool that is applied in disaster risk assessment and management. Satellite images give a synoptic view and provide very useful environmental information, on a wide range of spatial scales, from entire continents to details of a few meters (Van-Western, 2000). Remote Sensing is useful for planning the flood control and related works, provides reliable and timely information about flooded areas, river behaviour and configuration prior to floods, during the floods and after the floods and such information is very difficult to acquire through conventional ground surveys. Advent of satellite remote sensing technology has helped in solving the problems of mapping, monitoring and management of floods (Awal 2003; Manandhar, 2010).

Provided by Moderate-Resolution Imaging Spectrometer (MODIS), Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER), GeoEye-1, Landsat, among others, satellite images could be selected and analyzed to obtain information for both before and after a disaster, hazard or any geospatial events of an area (Forkuo, 2010). Integration of remote sensing and GIS data has been very useful in assessing land use and land cover; it has played a key role in flood reduction in Europe (European Commission, 2007).

Moreover, information on important criteria for flood risk analysis including elevation, slope orientation, closeness of built-up areas to drainage, drainage network and density, presence of buffers, extent of inundation, land cover/land use information, rainfall data, cultural practices as well as attitudes and perceptions are needed for flood risk mapping which could be obtained through GIS and Remote Sensing (Nyarko, 2000; Tanavud *et al*., 2004; Forkuo and Mensa, 2012). Also, Agarwal, (2004) stresses the importance of flood risk maps:

- they can be used to identify flood vulnerability areas especially around the flood plains;
- they provide planners with useful information for development of land use policies and planning of new urban areas;
- they help in the identification of the worst affected areas thus facilitate proper planning for dispatch of relief materials and allocation of resources for compensation of flood victims; and
- aid humanitarian response in flood disasters management (rapid response and rapid recovery).

2.6. Influence of Land use and Land cover on Flooding

Land use refers to the total arrangements, activities, and inputs undertaken in a certain land cover type (IPCC, 2007). The term land use is also used in the sense of the social and economic purposes for which land is managed. For example, grazing, timber extraction, and conservation. Land use change refers to a change in the use or management of land by humans, which may lead to a change in land cover (IPCC). Land cover and land use change may have potential impacts on the surface albedo, evapotranspiration, sources and sinks of greenhouse gases, or other properties of the climate system and may thus give rise to radiative forcing and/or other impacts on climate, locally or globally (IPCC, 2007).

According to Pouraghnyaii (2001), the main reason for the torrential destructive flood in the Kasilian Basin is the destruction of the upstream land cover. The reduction of the forestlands has increased the runoff coefficient from 10 to 15% in the Kasilian Basin (Mazandaran province, Iran). Similar results, are observed in the Neka River hydrographs during the deforestation activities of the 1967-2000 period and after the forest cuttings in the Gilan province of Iran (Pouraghnyaii, 2001). Many studies have concluded that floods result from factors such as the human intervention in the natural hydrologic cycle, through destruction of vegetation of the river basins, and expansion of impermeable surfaces through the urbanization processes (Pouraghnyaii, 2001). UNISDR (2009) confirms that degradation of the environment can alter the frequency and intensity of natural hazards and increase the vulnerability of communities.

Also, it was found that climate change has an influence on land cover, apart from the human factors. Climate change can accelerate the rate of land degradation through drought and floods. Vegetation cover increases the rate of infiltration, depending on the type and condition of the soil therefore reducing the magnitude of floods (Panahi et *al.*, 2010). A study conducted by Kundu *et al.* (2011) in Nyando River basin in Kenya also showed that removal of vegetation cover increases surface runoff. They used Landsat images for land use and land cover classification. After classification into dry farming, built up area, water bodies, roads, grazing lands, irrigated farming and bare lands, it was revealed that the rate of urbanization has increased in the river basin. This was linked to increase in paved lands, which provokes runoff.

2.7. Review of Methods

2.7.1. Remote Sensing and GIS Integration for Flood Risk Analysis

Aderogba *et al.* (2012) used MODIS (30m resolution) images to map and analyse the 2012 flood disaster in Lagos, Nigeria which was very helpful for policy and structural planning. Also, Orko (2011) used Landsat 7 ETM+ image (30m resolution, 2000 & 2010) to map flood risks in Kano State in Nigeria by integrating spatial data with non-spatial data (population data), using overlay operation tools in ArcGIS (10.0). Similarly, Nyarko (2000) used hydrological model (modified rational model) and integrated it into the GIS platform, through arithmetic overlay operation method, using operators such as addition and division to delineate flood risk zones in Accra, Ghana. The application of a Geographic Information System Model (GISM) to study hydrological event in its spatial form is therefore appropriate, the reason being that it has the capabilities of incorporating physical and stochastic models for spatial analysis of hydrological events (Nyarko, 2000).

In Saxony, Germany, Meyer (2007) relied on GIS-based Multi-criteria method, using a disjunctive approach and an additive weighting approach to come to an overall assessment and mapping of flood risk in the area. Kundu *et al.* (2011) also used spatial analyst tools in the ArcGIS tool box to delineate flood risk zones in the Nyando River basin in Kenya. The Weighted Sum Overlay technique was used by Surjit *et al.* (2012) for flood risk mapping in Ghaggar River basin in India. Relative weights were applied to each factor. The most important factor was represented by 1, while 6 represented the least significant factor. Similarly, relative weight to each main factor and their sub-class elements were assigned and normalized, using rank sum method and the final composite flood risk index (FRI), was computed using weighted sum overlay analysis with raster calculator in Arc GIS 9.3 (Surjit *et al.,* 2012). Overlay of data layers is very important in flood and land suitability selection analysis. This is usually done using *Weighted Overlay* or *Raster Calculator* in ArcGIS (ESRI, 2011). In order to use this method, the *"percentage of influence*" of each data layer needs to be considered with caution since it has a great influence on the output. One limitation of this method is that it requires perfect and expert knowledge in assigning relative weights to each variable, which may be influenced by differences in individual perception (Heywood, 2006).

2.7.2. Flood frequency and Return Period Analysis

The return period is the time period over which it is likely that a particular magnitude of flood will occur. Thus, a 100–year flood is defined as a flood that can occur on average once every 100 years. In this illustration, 100 years is considered the return period. However, floods do not occur in exact cyclic events. That is, they do not occur at nicely spaced 100–year intervals. Flood frequency analysis uses historical records of peak flows to produce guidance about the expected behaviour of future flooding.

Flood frequency or recurrent period is often done in most flood risk zones in Europe and South-East Asia, using different methods. According to European Procedures for Flood Frequency Estimation (2013), the annual maximum flood series is the maximum volume flow rate passing a particular location (typically a gauging station) during a storm event. This can be measured in m^3/sec, and is calculated using the following formula: $Tr = (N + 1)/ M$ (where $Tr =$ Return Period of flooding; $N =$ Peak annual river flow; and $M =$ Rank, according to order of highest flow). Where a number of tributaries exist within the catchment of interest, methods of gauging flows on each watercourse may be necessary.

2.7.3. Statistical Testing and Trend Analysis

In the process of organizing and analyzing time series data, statistical tests are often done to unravel the nature of the variables. Trend analysis are carried out in climate data that have been collected over a period of time to find its statistical significance in terms of rainfall and temperature (Tabari *et al.,* 2011; Mavromatis *et al.*, 2011). The most commonly used method for trend estimation and analysis in hydrology is the Mann-Kendal test. This is usually done by formulating hypotheses: null-hypothesis and alternative hypothesis (Motiee *et al.,* 2009; Mavromatis *et al.*, 2011). The null-hypothesis is formulated with the assumption that there is no trend in the data set, while the alternative hypothesis states that there is a trend. If a linear trend is present in a time series data, then the slope (change per unit time) can be estimated by using a simple nonparametric procedure developed by Sen (1968). This means that a linear model $f\ (t)$ can be described as $f\ (t)\ = Qt\ + B,$ where Q is the slope and B is the constant. Mann-Kendall test is suitable for cases with monotonous trends and with no seasonal or other cycles in the data (Motiee *et al.*, 2009). One advantage of this test is that the data need not conform to any particular distribution (Tabari *et al.* 2011; Drápela *et al.*, 2011).

2.7.4. Conceptual Framework for Disaster Risk

In the world of increasing hazards and disasters, many schools of thoughts, institutions and organizations, among others, have come out with different views on hazard and vulnerability. Likewise, various analytical concepts and models of how to systemize disasters are created. These conceptual models are an essential step towards the development of methods and systematic identification of relevant indicators (Downing, 2004). The common conceptual models are "The double structure of vulnerability" as defined by Bohle (2003), "The sustainable livelihood framework", the ISDR framework for disaster risk reduction, "onion framework" and the "BB conceptual framework" by UNU-EHS. The Vulnerability Framework by Turner *et al.* (2003), Vulnerability within the framework of hazard and risk, and the MOVE framework, among others, are additional examples (Birkmann, 2006).

2.7.5. Vulnerability within the Framework of Hazard and Risk

This framework was developed by Davidson (1997) and adopted by Bollin *et al*. (2003). It considers vulnerability, coping capacity and exposure as separate features (Birkmann, 2006). The conceptual framework distinguishes four components of disaster risk, namely: hazard, exposure, vulnerability and capacity measures (Birkmann, 2006).

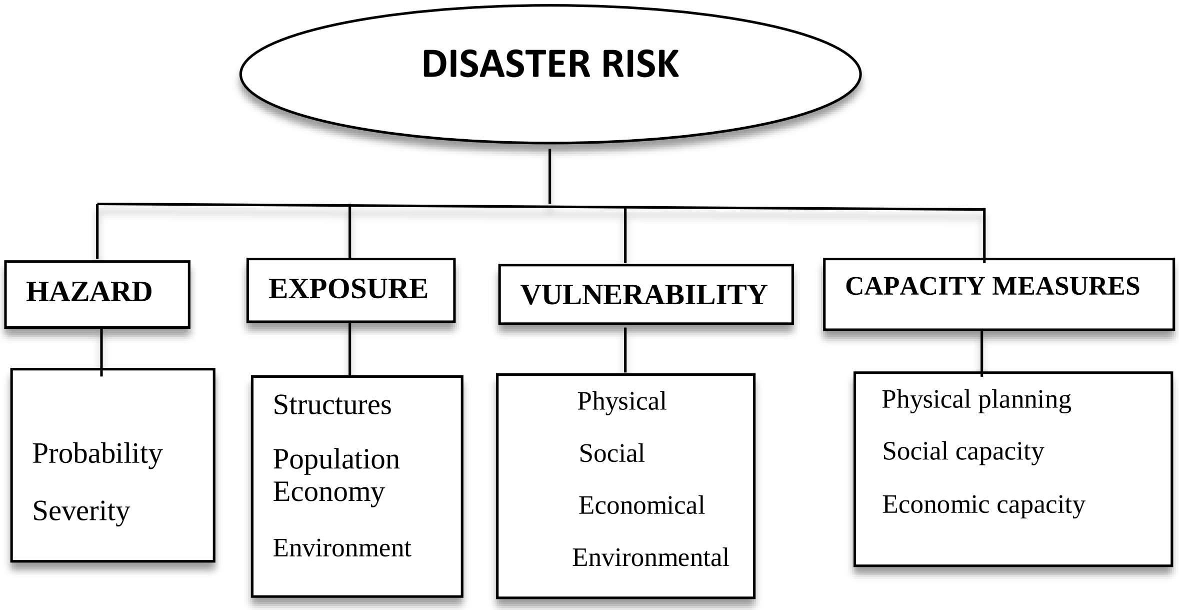

Figure 2.2. Flood Risk Framework

Source: Davidson (1997) and Bollin et al. (2003)

In this framework, the hazard considers the probability and severity of an extreme event or disaster. Elements at risk (Exposure) involves the physical structures, population, economy and environmental factors that are found in the risk hazard zone. Vulnerability here covers four dimensions: physical, social, economic and environmental. Measures and capacity to face a disaster encompass the physical planning of a community or ecosystem. Social and economic capacity measures are also considered crucial in order to face a disaster risk (Bollin *et al*., 2003).

2.7.6. Development of indicators for risk assessment

There are many methods for developing indicators. These could be inductive or deductive procedures (Birkmann, 2007). Bollin *et al.* (2006) have developed a set of indicators for Community-Based Risk Index of natural hazards that are widely used in most quantitative studies. The indicators developed were based on the conceptual framework of Davidson (1997) and Bollin (2003), which established a disaster risk as a function of hazard, exposure, vulnerability and capacity measures. A total of 47 indicators were developed, arranged and categorized into four main factors and further calculated into factor components. The indicators selected to measure vulnerability focused on four different thematic areas: physical and demographic, social, environmental and economic vulnerability (Birkmann, 2007).

Development of indicators of vulnerability is less advanced but increasingly discussed in both decision-making and research contexts (Moss *et al*., 2001). Within the UNFCCC, indicators of vulnerability have been proposed not only to assist in determining what levels of climate change might be dangerous but also to identify countries or groups that are especially vulnerable for the purposes of allocating the proceeds of the clean development mechanism (Moss *et al*., 2001). Indicator usage and indices construction are found in the studies of UNDP's HDI reports which illustrated the various normalization and weighting of specific indicators (UNDP, 2004). It is meaningful to combine social-ecological indicators in flood risk mapping so as to capture a full conceptualization of risk and vulnerability of human factors (Merz *et al.*, 2007).

The indicators developed for Community-Based Risk Index by GTZ is commonly used and widely applicable in a wide range of natural hazards. Therefore, this study follows the definition of Davidson (1997), adopted by Bollin (2003) on conceptualization of risk and vulnerability. The indicators used are given in table 2.1.

Table 2.1. Community Based Disaster Risk Indicators

Main factor	Indicator name	Indicator
Exposure		
Structures	(E1) Number of housing units (E2) Life lines	Number of housing units (living quarters) % of homes with piped drinking water
Population	(E3) Total resident population	Total resident population
Economy	(E) Local gross domestic product (GDP)	Total locally generated GDP in constant currency
Vulnerability		
Physical/ demographic	(V1) Population Density (V2) Demographic pressure (V3) Unsafe settlement (V4) Access to basic services	People per km^2 Population growth rate Homes in hazard prone areas (ravines, river banks, etc.) % of homes with piped drinking water
social	(V5) Poverty level (V6) Literacy rate (V7) Attitude (V8) Decentralization (V9) Community participation	% of population below poverty level % of adult population that can read and write Priority of population to protect against a hazard Portion of self-generated revenues of the total budget % voter turn out at last communal elections
Economic	(V10) Local resource base (V11) Diversification (V12) Small businesses (V13) Accessibility	Total available local budget in US $ Economic sector mix for employment % of business with fewer than 20 employees Number of interruption of road access in last 30 years
Environmental	(V14) Area under forest (V15) Degraded land (V16) Overused land	% of area of the commune covered with forest % of area that is degraded/eroded/desertified % of agricultural land that is overused
Capacity Measures		
Physical Planning and engineering	(C1) Land use planning (C2) Building codes (C3) Retrofitting/maintenance (C4) preventive structurers (C5) Environmental management	Enforced land use or zoning regulations Applied building codes Applied retrofitting and regular maintenance Expected effect on impact-limiting structures Measures that promote and enforce nature conservation
Societal Capacity	(C6) Public awareness programs (C7) School curricula (C8) Emergency Response drills (C9) Public participation (C10) Local risk management/emergency groups	Frequency of public awareness and programs Scope of relevant topics taught at school Ongoing emergency committee with public representatives Grade of organization of local groups
Economic capacity	(C11) Local emergency fund (C12) Access to national emergency funds (C13) Access to intl. emergency funds (C14) Insurance market (C15) Mitigation loans (C16) Reconstruction loans (C17) Public works	Local emergency funds as % of local budget Release period of national emergency funds Access to international emergency funds Availability of insurance for buildings Availability of loans for disaster risk reduction measures Availability of reconstruction credits Magnitude of local public works programs
Management and institutional capacity	(C18) Risk management/emergency committee (C19) Risk map (C20) Emergency plan (C21) Early warning system (C22) institutional capacity building (C23) Communication	

Source: (Bollin and Hidajat, 2006)

Furthermore, all indicators for the four sub-components (hazard, exposure, vulnerability and capacity) were integrated into one index. Depending on the scaled indicator values, the factor indices varied between 0 and 100. This was achieved by distributing a total of 33 weighting points according to the assumed importance of the indicators for each factor (Bollin and Hidajat, 2006, cited in Birkmann, 2007).

The physical and demographic vulnerability considers indicators such as population density and demographic pressure, while social vulnerability is quantified by assessing poverty levels, literacy rate and decentralization, among others (Bollin and Hidajat, 2006). Moreover, the different indicators were weighted according to their importance for the specific hazard.

One very useful application of these indicators is that it has the function of comparing risk between different communities, as well as the goal of identifying whether the level of risk basically results from the hazard, the exposure, the vulnerability or the capacity component (UNISDR, 2004; Birkmann, 2007)

In summary, it was found that Ago *et al.* (2005) used Landsat (4 TM) images to map the impact of land cover on the volume of water in the hydro-electric dam at Nangbeto, while Hangnilo (2013) also modelled the pond slope of the Mono River with equivalent electric scheme for flood forecasting. Recently, Amoussou *et al.* (2014) used statistical methods to model changes in peak flow of water for a 23-year period but did not carry out flood risk analysis. There are some current studies (Kissi *et al.*, forthcoming) which have looked at the social vulnerability of flood in the Bas Mono district, north of Lacs district (Maritime region). During an interview with Togo Red Cross in February 2015, it came out that there is no known comprehensive study that has come out with risk maps showing the various levels of risk in the area of study. Spatial technology was not fully used as a tool. Location of temporal homes for flood victims have often been done based on mere observations by human eyes. Therefore, this comprehensive study on flood disaster risk mapping and analysis in the Lacs district and lower Mono River Basin is necessary to help close the gap.

CHAPTER III: MATERIALS AND METHODS

3.1. Study Area

The study is conducted in the Lacs district in the lower part of Mono River Basin in Maritime region, Togo. As the largest river system in Togo, Mono River occupies an area of 20,600 km^2 and is 560 km long (Klassou, 1996). The targeted district is located in the downstream of the river below the Nangbeto Dam (UN OCHA, 2010). It is located (6° 22' N and 1° 40' E) at the immediate south of Bas Mono. To the west is the Vo district and the eastern part is the Republic of Benin, while on the southern part lies the Bight of Benin and Atlantic Ocean. It covers a land area of about 406 km^2 with an average elevation of about 10 meters above sea level, which decreases towards the Atlantic Ocean (Ago, 2005)

The Villages that are usually flooded almost every year in the Lacs district include: Agouégan, Aklakou-Zongo, Avévé, Kpondavé, Adamé, Agbanakin, Ganavé, Atchamey, Sakpové, Togbavi, Tokoto, Azime Dossou, and Zanvé, among others (Togo Red Cross, 2014). Both the Republic of Togo and the Republic of Benin manage the Mono River Basin though, the river takes its source water from Atakora table ranges (Mount Togo) at an altitude of about 400 m, the eastern side of the Central region of Togo (Klassou, 1996). The two countries have come together to form Mono River Basin Authority for efficient utilization of water resources in the basin. The district is further divided into about eight counties including Agbodrafo, Agoegan, Aklakou, Anfoin, Fiata, Ganave, Glidji and Aného. The study area is presented in figure 3.1 below.

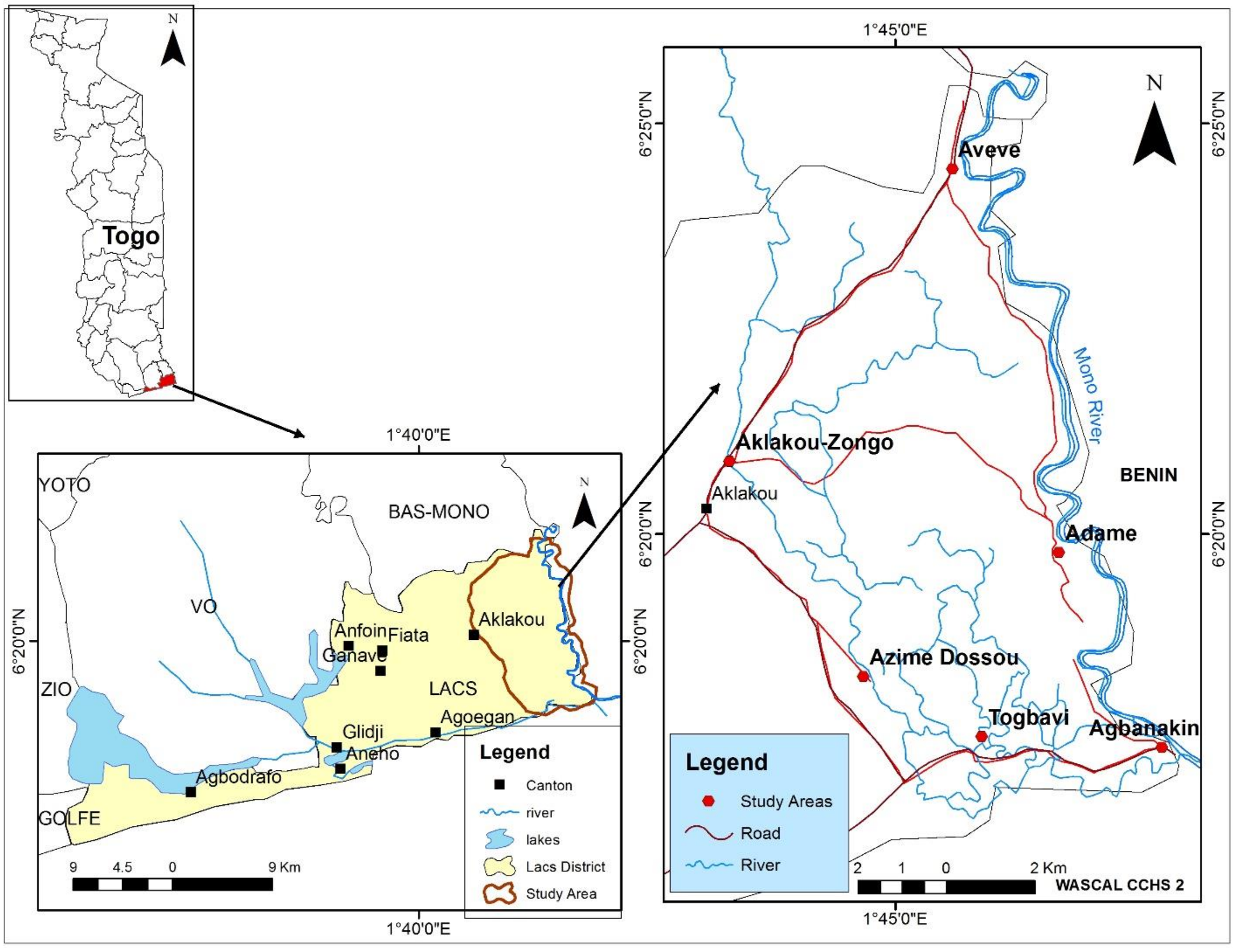

Figure 3.1. Map showing the study area in the Lacs District, Togo.

Source: Author of the study

3.1.1 Population and Economic Activities

The Lacs district has a population of about 172,148 people with a population density of 301 per km^2. Aného is the district capital town with a population of about 24,891. Along the coast, fishing and agriculture are the main economic activities in communities like Agbavi, Agbodrafo, among others, but increased rate of coastal erosion is the major challenge to the livelihood of the people. In some rural settlements in the district, agriculture is the main source of livelihood. The major food crops produced are maize, beans, palm fruits, coconut, cassava and some vegetables like cabbage, lettuce and cucumber (FAO, 2010). They also practice the free-range system of animal raising on smaller scales. Petty trading is another economic activity in the area. In some communities, local gin (Sodabi) is produced on small scale for sale. This serves as source of income for the brewers. In many other places within this area, buying and selling of goods is common but on a smaller scale (FAO, 2010).

3.1.2 Climate and Vegetation Characteristics

The climate of Lacs district is classified as tropical savannah with a subtropical forest biozone. The mean annual temperature ranges from 22°C to 30°C and annual precipitation varies between 800 mm and 1,210 mm (McSweeney *et al.*, 2010). The area is influenced by two major winds: the warm and moist winds (Monsoon), and the cold and dry trade winds, which usually meet at a zone called Inter-Tropical Convergence Zone (ITCZ). The north and south movement of ITCZ is what influences the seasonal distribution of rainfall over the area. In a year, two rainy seasons are experienced but separated by a dry season. (McSweeney *et al.*, 2010). The North-eastern part of the area is covered by shrubs, coconut and palm trees, and grasses, while south-eastern part is covered by scattered mangroves that rather serve as firewood for the surrounding communities due to increasing demand for fuel wood (Amoussou, 2011).

3.1.3 Topography and Soils

The area is located in a relatively low-lying sedimentary formation of the coastal plain. It is believed that the eroded sediments from the highlands have been deposited in the Maritime region which includes the study area (Tenou and Wala, 2009). The common groups of soil in Lacs district are hydromorphous soils, ferralsol, halomorph soils and Gley soil, which does not permit rapid infiltrating of water (Ago, 2005; FAO, 2005). The soil in this area is high in acrisols, alisols plinthosols, acid soil with clay-enriched lower horizon and low saturation of basis (Amoussou, 2011). See Appendix VI.

3.2 Data Collection

3.2.1 Data Sources

In this study, both primary and secondary data were collected from various sources and used for analysis.

3.2.1.1 Primary Data

The primary data were obtained through fieldwork. In doing so, a total sample size of 110 was chosen through simple random sampling. Structured interviews were conducted through purposive techniques. Also, focus group discussion was conducted as a means of gaining in-depth knowledge on the nature of flood disaster in the area. Field observation of the nature of building and housing conditions, and measurements of floodwater depth were also carried out to complement the data acquired during a transect walk. Geographic coordinates of important elements were obtained with the help of Geographic Positioning System (GPS).

3.2.1.2 Secondary data

Secondary data on flood history and distribution are obtained from Togo Red Cross. Also, rainfall data are obtained from the National Meteorological service, Togo, while river flow data are obtained from National Hydrological service of Benin. Population distribution data for the area are obtained from Statistical department of Togo. Spatial data on slope and elevation are extracted from Shuttle Radar Topography Mission (SRTM)'s digital elevation model (30m resolution), satellite image was obtained from the United States Geological Survey (available at http://earthexplorer.usgs.gov/). Table 3.1 below summarises the various data sources.

Table 3.1. Secondary data sources used in the study

Data type	Description	Source
Population Distribution	2010 Pop. &Housing Census	Department of Statistics, Togo
Soil data	Digitized map	Amoussou (2011)
SRTM (DEM)	Resolution (30 meters)	CGIAR-CSI (http://srtm.csi.cgiar.org).
Landsat 7 ETM+	Resolution (90 meters), 2010	USGSS (http://earthexplorer.usgs.gov/).
Rainfall Data	1961-2014	National Hydrological service, Togo
Mono River flow Data	1944-2011	Athieme, Benin Hydrological Service
Topographical Map	2013 (scale: 1: 50,000)	Department of National Cartography and the Cadastre, Togo
Flood profile data	Flood impacts and distribution	Togo Red Cross, EM-DAT

Source: NASA (2011; USGS, 2011; Orok, 2011)

3.2.1.3 Transect Walk

A walkover survey was carried out in the Lacs district, lower Mono River Basin in April, 2014, May, 2015 and August, 2015 to get the general landscape pattern and acquire a detailed understanding of the land use/land cover status, observe the soil type and soil erosion, disaster history of the study area, and validation of the research problem. Photographs and GPS points of the area were taken for the visual interpretation of the nature of land use and land cover patterns of the study area.

3.3 Data Processing and Analysis

3.3.1 Trend analysis of rainfall time series data

In order to identify the trend in the time series data of rainfall and river flow, statistical methods were used (Drápela *et al.,* 2011). Trend in rainfall over the basin was analyzed, using available rainfall time series data from the meteorological and hydrological stations in Mono River Basin. The analysis was done by dividing the Mono Basin into 3 classes. The upper part of the basin, the middle and the lower part of the basin since river flow at the lower course is a collection of water flow from the upper course of the river (Appendix VIII). Trend analysis in the rainfall and river flow are done, using Mann-Kendell test and Sen's slope.

3.3.2 Mann-Kendell Test and Theil-Sen's slope Estimation

Time series data is often tested to identify the nature of trends, homogeneity and heterogeneity in the data set over a period of time. The Mann-Kendell test is most widely used in nonparametric test for trends in hydrological analysis due to its relative robustness. Mann-Kendall test is suitable for cases with monotonous trends where no seasonal or other cycles in the data is required (Motiee *et al.,* 2009). According to this test, the null hypothesis $(H0)$ assumes that there is no trend in the data series, while the alternative hypothesis (Ha) assumes that there is a trend. The null hypothesis was tested at a confidence level of 95% and a significance level of 5% for both rainfall and river flow data. In a case where a linear trend was present in the time series data, the slope (change per unit time) was estimated by using a simple nonparametric estimation procedure developed by Sen (1968). This was done by using the linear model $f\ (t)$ which could be described as $f\ (t)\ =\ Qt\ +B$, where Q is the slope and B is the constant.

The statistical procedures for the Mann-Kendell test and the Sen's slope estimator are integrated in Anddinsoft (XLSTAT 2015) software, which was used for this study. The test interpretation was done by accepting H_0 for no trend in the rainfall time series and rejected for the (Ha) when a trend is found in the time series.

3.3.3 Flood Risk Assessment Framework and development of indicators

Conceptual frameworks are very useful in research investigations and most forms of inquiries due to their ability to present the entire study in a simple skeletal frame. This framework was selected because of it is able to capture disaster risk on a broader scale. It was also developed for community based risks index, which makes it more appropriate for this study. Figure 3.2 below presents the conceptual framework.

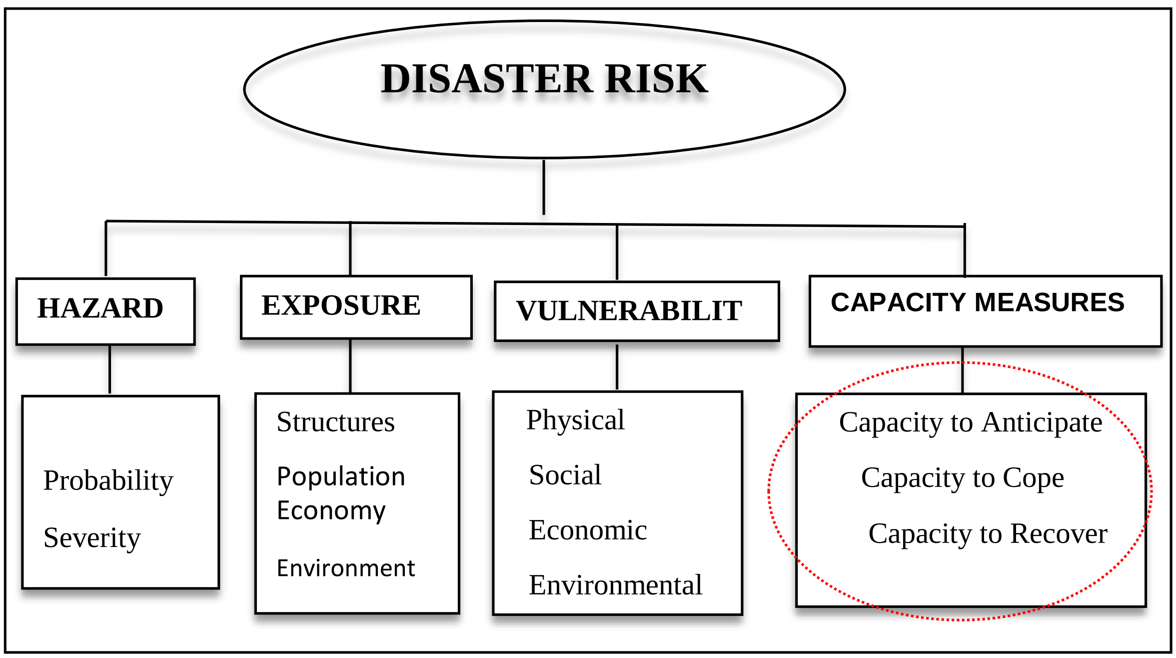

Figure 3.2. The conceptual framework to identify disaster risk

Source: Davidson (1997) and Bollin *et al.* (2003). *Modified*

From figure 3.2, the hazard considers the probability of occurrence and severity of flood in terms of magnitude. The elements at risk such as human structures, population, economic and environmental factors were classified under the exposure. As defined by Davidson (1997), vulnerability includes four dimensions (physical, social, economic and environmental factors).

Unlike the GTZ's component of capacity, in this modified version, the capacity measures of communities consider the capacity to anticipate, cope and recovery from flood disaster, which were adopted from the MOVE framework (Birkmann, 2006).

3.3.4 Flood Hazard assessment

This section considers hydrological analysis of the topography and characteristics of the lower Mono River Basin. The methodological process that was used for the flood hazard mapping is given in figure 3.3 below.

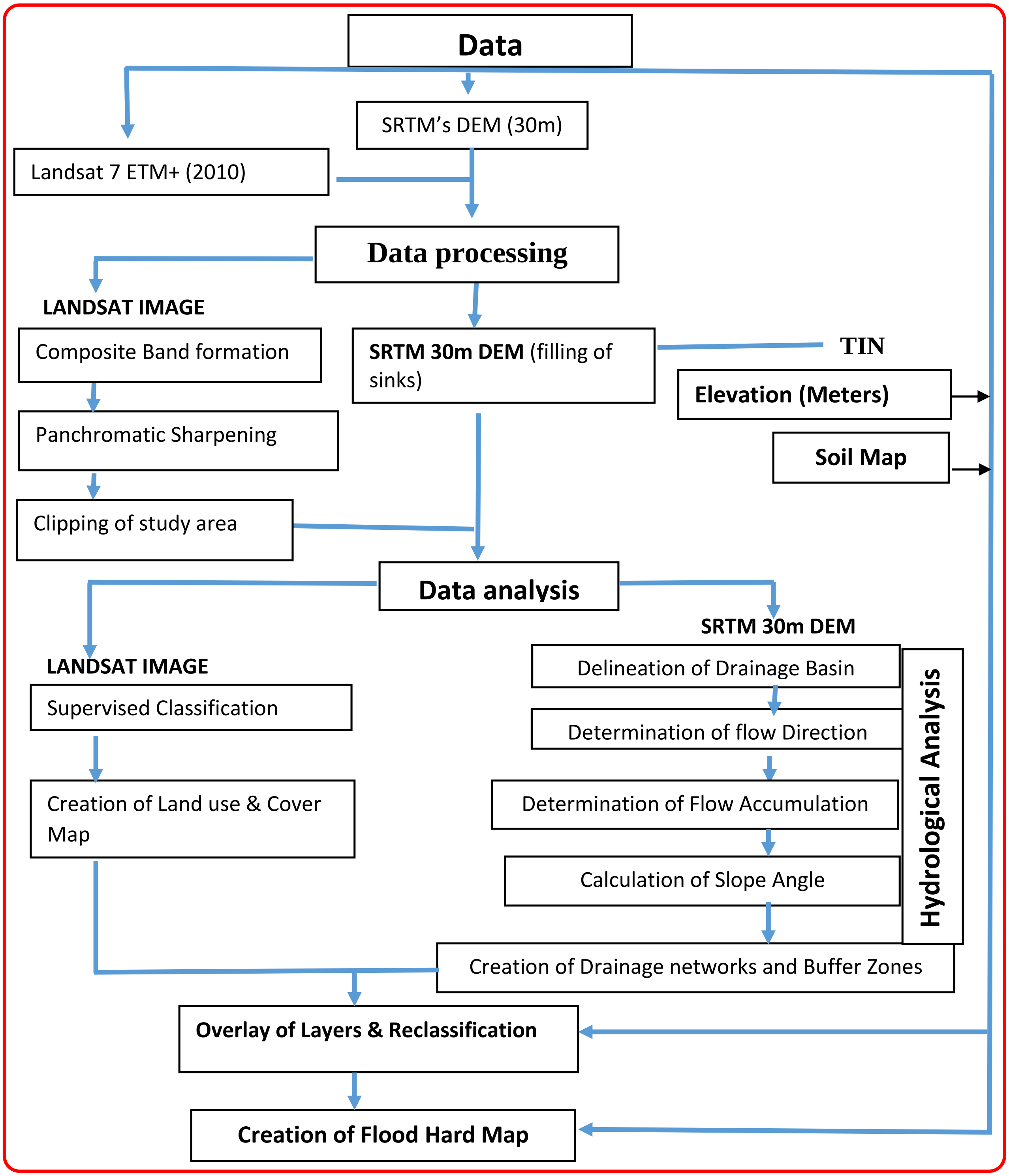

Figure 3.3. Flow chart summarising methodological processes for the creation of a flood hazard map: adopted from Orok (2011). ***Modified for this study.***

3.3.5 Processing and analysis of Landsat ETM+ Image

Landsat 7 was launched on April 15, 1999 with an Enhanced Thematic Mapper plus (ETM+). Landsat satellites have seven spectral bands (but Landsat 7 ETM+ has an additional 8^{th} band known as the panchromatic band with 15m spatial resolution and it responds spectrally from green through near infra-red region of the wavelength of the electromagnetic spectrum (NASA, 2011; Orok, 2011). The 2010 Landsat 7 ETM+ image was downloaded for this study from USGS *Earth Explorer* website (http://edcsns17.cr.usgs.gov/NewEarthExplorer). The Landsat 7 ETM+ image used was acquired on 9^{th} September, 2010 on the Path and Row of 198/52. Table 3.2 below gives a brief description of Landsat images.

Table 3.2. Properties of Landsat images

Band Number	Spectral Response	Wavelength	Resolution / Pixel size	Applications
1	Blue-Green	0.45- 0.52 µm	30 m	Useful in mapping aquatic ecosystems and classification of forest features.
2	Green	0.52 - 0.60 µm	30 m	Useful in vegetation discrimination and identification of man-made features
3	Red	0.63 0.69 µm	30 m	Useful in identification of plant species, vegetation health monitoring
4	Near infrared	0.76 - 0.90 µm	30 m	Useful in vegetation monitoring, water body discrimination and defining water/land interface.
5	Mid-infrared (SWIR)	1.55 - 1.75 µm	30 m	Useful in monitoring moisture content in vegetation and distinguishing between clouds and snow.
6	Thermal infrared	10.40 - 12.50 µm	60m/30 m (ETM+),120 m (TM)	Useful in monitoring volcanic features, surface temperatures and cloud differentiation
7	Mid-infrared (SWIR)	2.08 - 2.35 µm	30 m	Useful in soil and geological mapping especially in mineral and rock discrimination
8 Pan band (ETM+only)	Green-Near infrared	0.5 0.9 µm	15 m	More spatially detailed mapping of land features

Source: NASA (2011; USGS, 2011; Orok, 2011)

3.3.5.1 Composite band formation and panchromatic sharpening

The various bands in the 2010 Landsat 7 (ETM+) image were combined in ArcGIS to produce a composite image with seven bands. This was done to create a raster dataset containing subset of the original raster bands. In order to create a new raster dataset with a specific band combination and order, this process is needed (ESRI, 2009). Panchromatic sharpening involved the fusion of the high resolution (15 m) panchromatic band/image with the lower-resolution Landsat image (USGS, 2011). The Landsat 7 (ETM+) composite image was pan-sharpened with its panchromatic image (15 m).

3.3.5.2 Image classification

Classification of images is of two types: supervised and unsupervised and its objective is to designate classes of cells or pixels in a study area. Each class description relates to features, properties, characteristics, conditions of those cells that make it up (ESRI, 2009; Forkuo, 2010). When the features of pixels in an image are known, supervised classification is performed on the image but when the features are unknown, unsupervised classification is the alternative method (ESRI, 2009).

In this sense, supervised classification was carried out on the 2010 Landsat 7 image, using maximum likelihood classification in the ArcGIS tool box. This was done by initially creating training samples. The process of creating training samples was validated by taking training samples for various land use and land cover forms from the field with a GPS receiver, through the assistance of expert knowledge. As a result, 4 classes of land cover were identified through reclassification process with the Spatial Analyst tool (Reclassify tool) in ArcGIS 10.1. The reclassification was done by using natural breaks. The natural breaks scheme determines the break points between classes by analysing how the data are clustered. Class boundaries were set where there are relatively large jumps in data values. The output land cover classes were water bodies, built-up areas/bares soil, savannah with shrubs, swampy areas, and mangroves.

3.3.6 Hydrological Analysis using SRTM (30 m) DEM

A digital elevation model (DEM) is a digital representation of the Earth’s relief that consists of an ordered array of elevations relative to a datum, and referenced to a geographic coordinate system (Forkuo and Mensa, 2012). The DEM (30 m) for the study area was derived from USGS/NASA SRTM data and was in decimal degrees and datum WGS84. The data was downloaded from the CIAT-CSI website (available at http://srtm.csi.cgiar.org). SRTM data have been applied in a lot of hydrological assessments especially for extraction of drainage networks and upstream catchment areas in flood disaster risk assessments (Demirkesen *et al.*, 2007). This was geometrically corrected and all the sinks were filled using the Spatial Analyst tools in the ArcGIS (Reuter *et al*., 2007). The study area was then clipped, using the clip raster tool in ArcGIS tool box.

3.3.6.1 Processing and analysis of SRTM (30m) DEM

The various hydrological analyses were carried out in ArcGIS 10.1, using the SRTM's digital elevation model with a spatial resolution of 30 meters. All the depressions (sinks) were filled, using the Spatial Analyst tools in the ArcGIS (Reuter *et al*., 2007). The study area was then clipped using the "clip raster" tool in ArcGIS tool box. The hydrologic modeling tools in the ArcGIS Spatial Analyst extension toolbox provided the methods for describing the physical components of the surface (ESRI, 2014). These hydrological methods were used to identify sinks, flow direction, flow accumulation cells, watersheds, and creation of stream networks.

3.3.6.2 Delineation of Drainage Basins

A drainage basin is an area that drains water and other substances to a common outlet. Other common terms for a drainage basin are watershed, basin, catchment, or contributing area. This area is normally defined as the total area flowing to a given outlet, or pour point (ESRI, 2014). Surface water on the landscape of a basin flow in stream channels and the characteristics of the basin such as its area and slope affect the extent and frequency of runoff and help to explain the likelihood of flooding in any particular basin (Nyarko, 2000; ESRI, 2009; USGS, 2011). In delineating drainage basins in the study area, hydrological tools in the Spatial Analyst tools of ArcGIS 10.1 were used and DEM was the input data. The drainage basin was delineated within the analysis window by identifying ridge-lines between basins. The input flow direction raster was analyzed to find all sets of connected cells that belong to the same drainage basin. The drainage basin was created by locating the pour points at the edges of the cells as well as sinks, then identifying the contributing area above each pour point. This result is a raster of drainage basin.

3.3.6.3 Determination of Flow Direction

The depressionless DEM was used to generate a flow direction raster. The flow direction shows the possible direction of water run-off on the elevation model (ESRI, 2009). This analysis was performed, using the flow direction tool in Arc Toolbox's Spatial Analyst tools.

3.3.6.4 Determination of Flow Accumulation and Stream Network Estimation

Flow accumulation was the next step that was performed. The flow direction was used as the input data for delineating the flow accumulation. Flow accumulation was calculated for each cell by determining the number of upstream cells that drain into it. Grid cells with high flow accumulation values are areas of concentrated flow and are identified as stream channels according to the specified flow accumulation threshold (ESRI, 2009; Forkuo, 2012). Grid cells with flow accumulation values of zero are topographic highs or ridges.
In order to estimate a stream network from a flow accumulation layer, a flow accumulation threshold must be chosen. The threshold is the minimum number of cells that must drain into a cell for it to be determined to be part of a stream network. In the literature there is no agreement on the ideal threshold value for reproducing actual stream networks (Heywood, 2006). In practice, the determination of the threshold is an interactive process in which several values are used until the desired resolution of the stream network is achieved. In this protocol, after testing numerous thresholds, a threshold value of 100 cells (equating to a drainage area of 100 km^2) was used.

3.3.6.5 Determination of elevation from SRTM (30m) DEM

The elevation of a place above sea level affects its exposure to flooding with low-lying areas at more risk as against highland areas, which are virtually safe from the hazard (EPA, Ghana, 2012). The likelihood of a flood increases as the elevation of a location decreases, making it a reliable indicator for flood susceptibility (Islam and Sado, 2000; Nyarko, 2002). The elevation of the entire Mono basin was obtained by converting the SRTM DEM to Triangulated Irregular Network (TIN). The conversion tool in the 3D Analyst tool of ArcGIS 10.1 was used to convert raster to TIN. This allowed the generation of the surface features such as elevation, Hill shade, contours and slope angle. The output elevation was further reclassified into 5 classes, using natural breaks. The lowest point on the entire basin was 5 m below sea level, while the highest point was 990 meters above sea level.

3.3.6.6 Calculation of Slope Angle

Slope angle and general topography are undoubtedly important determinants of water flow (Boakye *et al*., 2008). Flooding becomes acute when slope angle is below a critical value and then decreases logarithmically (ESRI, 2009). Slope identifies the steepest downhill for a location on a surface. Slope was calculated for each triangle in TIN and for each cell in raster. This was done to obtain the maximum rate of change in elevation across each triangle (ESRI, 2014). The resultant values were reclassified into 4 classes. This was done for only the study area, the lower part of the basin and not for entire basin.

3.3.7 Flood frequency Analysis

The flood frequency analysis is one of the important studies of river hydrology which could be conducted based on maximum instantaneous flow by Gumbel distribution (Yadav, 2002). In this study, the Gumbel's distribution (Doubly exponential) was used in HYDRACCESS software.

3.3.7.1 Estimation of return period with HYDRACCESS

For the purpose of this study, 68 years (1944-2011) annual maximum river flow data of Mono River for Athieme station was used. Estimation of return periods of flood disaster was done by using HYDRACCESS. This software package was designed for hydrological modelling of extreme events such as droughts and flood. The annual maximum river flow data was entered into the HYDRACCESS and the necessary parameters and estimation laws were selected. Also, both the lower limit and the threshold were chosen and finally the resultant fitting positions for frequency and return period (2-5-10-20-50-100-year) were generated. Figure 3.4 below presents the working environment of HYDRACCESS.

The tool is very useful but its limitation is times series rainfall data is required to calculate return periods. To accept a 10% error margin, at least 90-year river flow data is needed which most synoptic stations in West Africa do not have due to insufficient equipment.

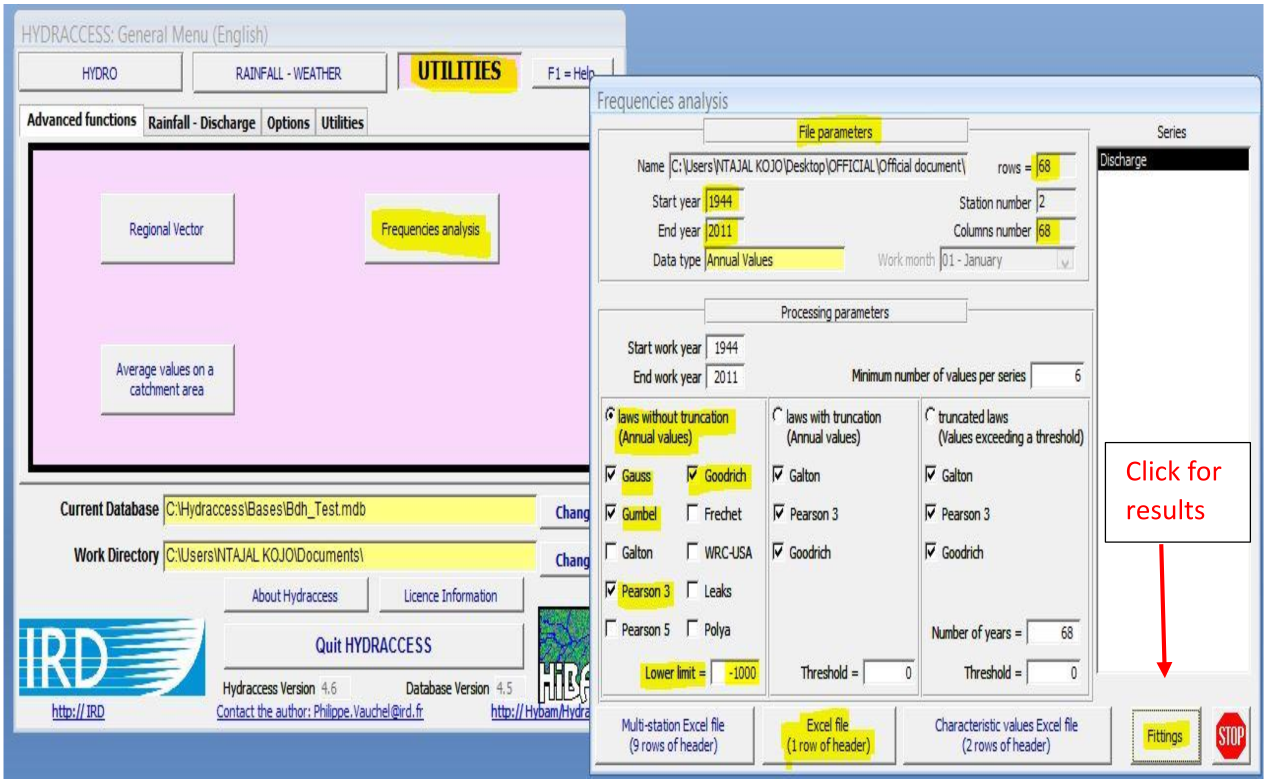

Figure 3.4. HYDRACCESS working environment

From figure 3.4 above, the utility window was selected and the options given were *regional water, average values on the catchment and frequency analysis*. The frequency analysis option was selected and a new window was displayed for setting up the parameters. The yellow-highlighted areas show the parameters that were selected. Regarding data entry, the annual series of river peak river flow in the excel format (1 row of header) was entered. Selecting the various probability distribution laws, the option (Laws without truncation) was chosen because the data set does not contain zero values. The default value (-1000) for lower limit was accepted and finally, fitting option was clicked to generate the results.

3.3.7.2 Fitting to sample values of river flow, using Gumbel distribution

Fitting of sample values was done with the HYDRACCESS hydrological software. The doubly exponential law and Gumbel distribution, which are integrated into the software, were used for the fitting of the sample values. Using the Gumbel distribution, the variate X (maximum river flow) with a recurrence interval T is given by;

$$x_T = \bar{x} + K_T s \text{ .... } (3)$$

Where $X_T =$ estimated flood magnitude, K_T = frequency factor, T = return period, $\bar{x}$ = sample mean, s = standard deviation

The accuracy of the results is tested on the coefficient of variation between 0 and 1. When the coefficient of variation is equal to or less than 0.5, it shows good correlation. However, a higher coefficient of variation that is above 0.5 indicates a bad correlation.

3.3.8 Indicator-Based Flood Exposure, Vulnerability and Capacity Assessment

3.3.8.1 Selection of Indicators

Following the conceptualization of disaster risk of Davidson (1997), adopted by Bollin *et al*. (2003), the following indicators were adopted and modified to help gather the needed data from the communities. Some of these indicators were adopted due to their applicability at local scale and community level. Table 3.3 below presents the selected indicators and their functional relationship with the components of risk.

Table 3.3. Selected indicators for flood disaster risk assessment at community level

Components	Indicators	Measurements (Variables)	Relationship
Exposure	Population of people in Floodplain	% of people in floodplains	**(+)**
	Flood duration	Average flood duration (days)	**(+)**
	Floodwater depth	High depth of floodwater (m)	**(+)**
	Proximity of Field Crops to active water channels	Farmlands located close to water bodies	**(+)**
Vulnerability			
Physical	Material in which the building is made.	Poor building material.	**(+)**
	Material in which the roof is made of	Building with poor roof material.	**(+)**
Social	Poverty level	People spending on less than US & 1/day	**(+)**
	Literacy level	Adult literacy rate (%)	**(-)**
Economic	Income level	Low Income levels	**(+)**
	Unemployment	Unemployment rate (%)	**(+)**
	Household expenditure per capita	Households with the low expenditures per capita	**(+)**
Environmental	Forest area	Area covered with forest	**(-)**
	Protected area	Protected forest area	**(+)**
Capacity			
Capacity to Anticipate	Early warning system	Access to early warning system	(-)
	Meteo. Data	Access to climate data	(-)
	Community awareness	Awareness in flood occurrence	(-)
Capacity to cope	Training to cope with flood	Access to flood training programs	(-)
	Financial aid	Access to financial aid	(-)
	Health service	Accessibility of health service	(-)
	Evacuation routes and facilities	Ability to evacuate	(-)
Capacity to Recover	District disaster aid prog.	Availability of disaster mgmt. committee	(-)
	Community Disaster mgmt. committee		(-)

Source: (Moss *et al.*, 2001; Bollin *et al.*, 2006; UN-ISDR, 2004; Merz *et al.*, 2007)

The indicators were selected by following the conceptual framework of Davidson and the GTZ's indicators developed for community-based risk index but the weighting and normalization were done through the functional relationship by UNDP (UNDP, 2006).

3.3.8.2 Normalisation of indicators using functional relationship

The method that was used to normalize the indicators was adopted from the UNDP's Human Development Index (UNDP, 2006). In order to use this method, the functional relationship between the indicators and vulnerability were identified. There exist two relationships: positive and negative relationships. The indicators have a positive relationship when they tend to increase vulnerability of a community to flood, while indicators with negative relationship lead to decreased vulnerability of a community to flood.

When the variables have positive functional relationship with vulnerability, the normalization is done, using the formula:

$$V_{bc} = (Y_{bc} - MinY_b) / (MaxY - MinY_b)$$

When the variables have negative functional relationship with vulnerability, the normalization is done, using the formula:

$$V_{bc} = (MaxY_b - Y_{bc}) / (MaxY_b - MinY_b)$$

Where; V_{bc} stands for the standardized vulnerability score with regard to vulnerability component b, for community c; Y_{bc} stands for the observed value of the same component for the same community;

$MaxY_b$ and $MinY_b$ stand for the maximum and minimum value of the observed range of values of the same component, for all settlement of the index.

3.3.8.3 Constructing Vulnerability Index

There are several ways of estimating vulnerability index but for the purpose of this study, equal weights (simple average of the scores) were used. This was found to be simple and relatively reliable (UNDP, 2006). Each index is obtained by averaging the variable within each component of vulnerability following the formula:

$$AI = \frac{1}{N}\sum_{i=1}^{n} C_i$$

Where AI is the average index of each of the sources of vulnerability, $\boldsymbol{N}$ is the sum of the index and $\boldsymbol{C_i}$ is the value of the index

The vulnerability index for each community was obtained by averaging the four values of each component of vulnerability, using the formula given below:

$$Vul_0 = (Vul_1^{Phy} + Vul_2^{Soc} + Vul_3^{Eco} + Vul_4^{Env})/4$$

Where $Vul_1^{Phy} + Vul_2^{Soc} + Vul_3^{Eco} + Vul_4^{Env}$ are respective average values of each source of vulnerability. Vul_0 is the overall vulnerability for the community c; in the floodplain of the lower part of Mono River Basin. After obtaining the overall vulnerability weights for each of the communities, the values were added to the corresponding shapefiles for the 6 selected villages in ArcGIS. This was used to generate the overall vulnerability map for the study area. The methodological procedure for the creation of the overall vulnerability map is given in figure 3.5 below.

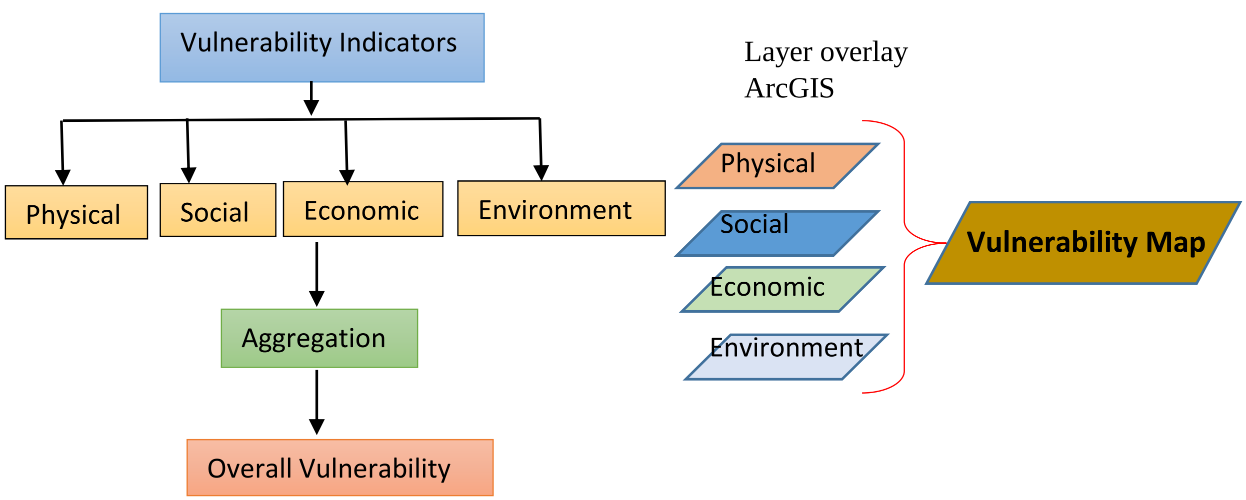

Figure 3.5. Processes for creating vulnerability map

Source: UN-ISDR (2004)

3.3.8.4 Creation of the flood risk map

The flood risk map for the Lower Mono River Basin was generated by overlaying the data layers of flood hazard, exposure, vulnerability, and capacity measures through weighted sum overlay analysis in ArcGIS (10.1). The resultant risk layer was reclassified into three (3) classes to obtain the various levels of flood risk (Low, Moderate and High) in ArcGIS (10.1)

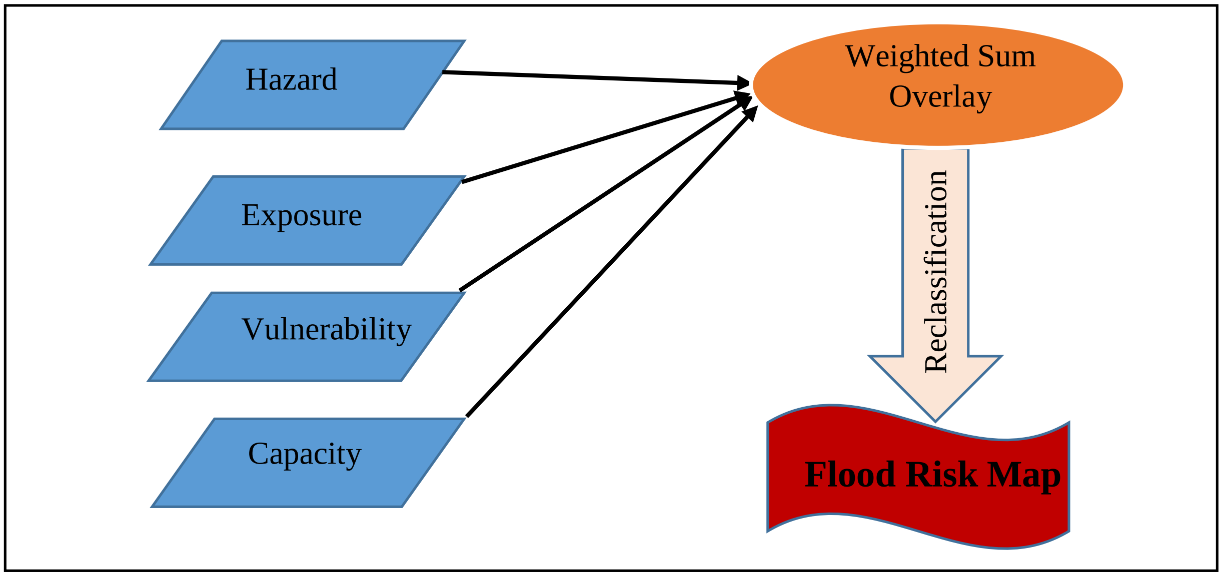

Figure 3.6. Methodological processes for the creation of the flood risk map

Source: Author of the study

CHAPTER IV: PRESENTATION OF RESULTS

4.1 Main sources of livelihood in the selected communities

The livelihood activities are very crucial in disaster impact analysis. Recovery from flood impacts, to some extent, depends on the percentage of livelihoods of victims which is lost. The over-dependence on nature as a source of livelihood exposes communities to hydro-meteorological hazards. The table below presents the main sources of livelihood in the area.

Table 4.1. Major economic activities in the study area (%).

Main occupation	Adame	Agbanakin	Aklakou Zongo	Aveve	Azime-Dossou	Togbavi
Farming	83	79	76	78	87	72
Fishing	2	1	0.6	0	2	9
Small scale bus.	5	11	12	13	4	2
House wife	10	9	11.4	9	7	17
Total	100	100	100	100	100	100

The major source of livelihood in the communities of investigation was farming (e.g. 83% at Adame) as indicated in table 4.1. Farming as an agricultural activity in the area is vulnerable to extreme climate events such as drought and flooding. The farming activities are done along Mono River and its tributary, Gbaga, which is one of the exposure factors. Farm plots that are located closer to the active water channel are more at risk than places at far distances (Forkuo, 2010).

4.2 Results of statistical analysis of the trend in rainfall in the Mono River Basin

Two rainfall stations were selected in the upstream, two at the middle and two stations in the lower part of the basin, based on data availability and also due to the fact that the cause of flooding is partly due to extreme high rainfall in the upstream. The annual rainfall plots for the selected stations in the upper course are given in figure 4.1 below. The statistical summary of the maximum, minimum, mean and standard deviations for the selected stations are given in appendix II.

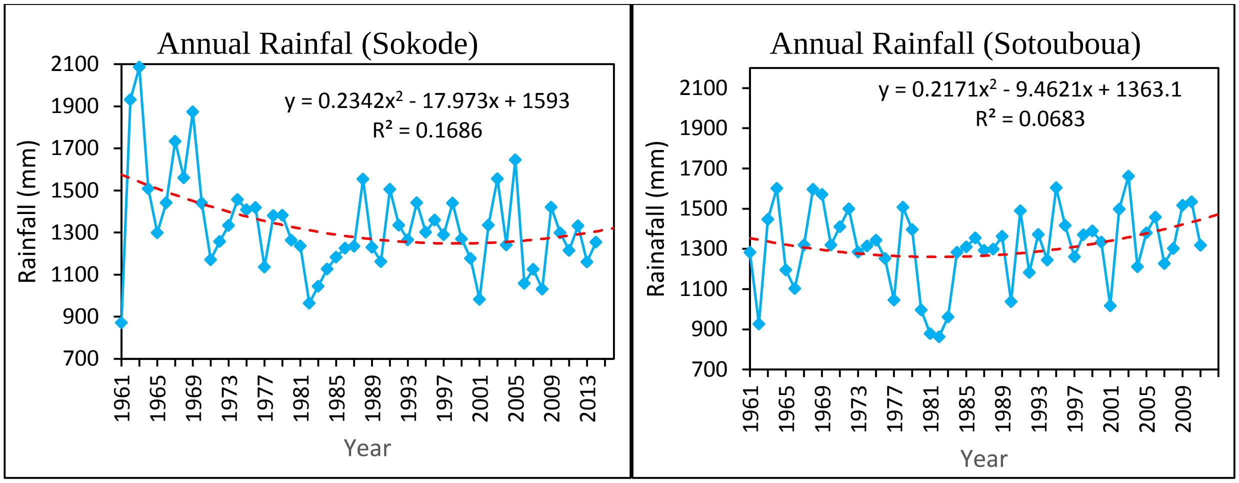

Figure 4.1. Annual rainfall at Sokode station (1961-2011) and Sotouboua Station (1961-2014)

The H_0 was rejected for the station of Sokode, which means there is a trend in the rainfall. The decreasing trend is significant because the P-value (0.020) is lower than the significant level of 0.05 (Appendix I). In contrast, at station of Sotouboua**,** Kendell's test shows that P-value (0.173) is greater than the significant level (0.05), hence the H_0 was accepted: there is no trend. This was further explained by the Sen's slope (1.579), which shows an increase in rainfall but not significant. Obviously**,** the pattern of rainfall is marked by high variability. It is obvious that the general low rainfall over West Africa in the early 1980, affected the area as observed in 1980, 1981, 1982 and 1983 in figure 4.1. Higher variation in rainfall with extreme events may have serious impacts on the activities of the communities through drought and flooding (IPCC, 2012). Alternating droughts and floods have great impacts on food and environmental security (IPCC, 2012; Amoussou, 2011).

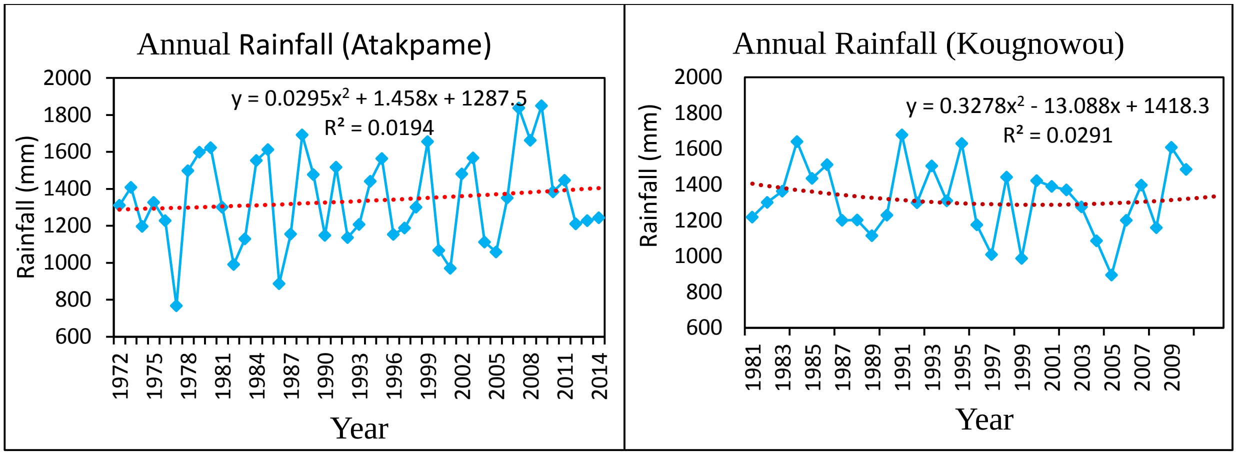

Figure 4.2. Annual Rainfall observed at Atakpame (1972-2014) and Kougnowou (1981-2010)

Similarly, trend analysis was tested on the rainfall data from the middle section of the basin. The P-values for Atakpame and Kougnowou are 0.532 and 0.486 with Sen's slope (change in rainfall/time) being 2.16 and -2.471 respectively. The null hypothesis was accepted in both cases, that is there is no trend in time series (see Appendix I). There has been an increase in rainfall at Atakpame but a decrease in rainfall was observed at Kougnowou. The increase in rainfall at Atakpame and the decrease in rainfall at Kougnowou are both not significant at the given P-values and a significant of 5%. The slight increase in the rainfall at Atakpame may be explained by the topography of the place as it is located on the mountain ranges. Mountains, at times, aid in orographic lifting of air and thus most often, formation of rainfall.

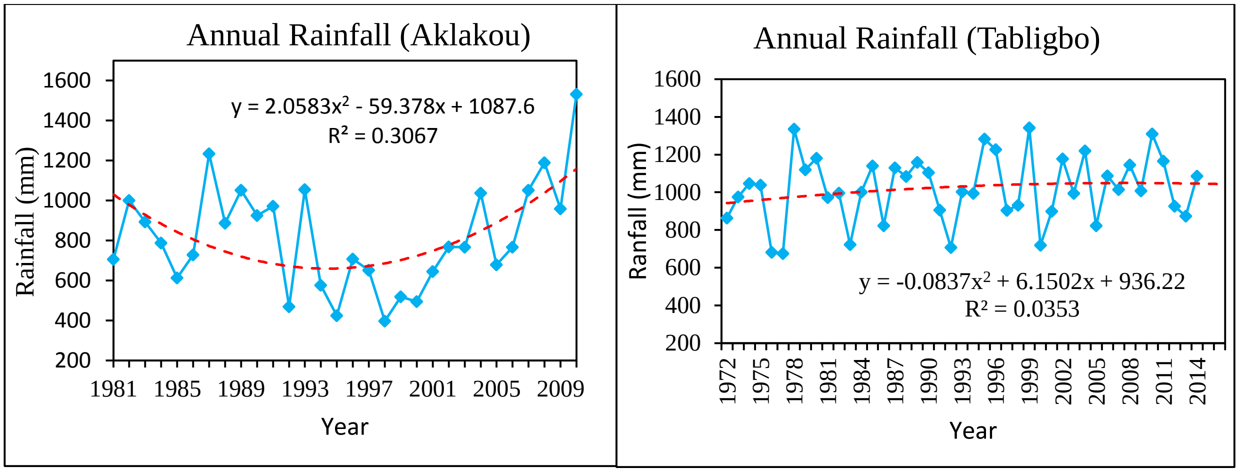

Figure 4.3. Annual Rainfall observed at Aklakou and Tabligbo, the lower section of the basin

As previously done with the other rainfall stations, the Mann-Kendell's test was carried on the observed times series in the lower section of the Mono River Basin (figure 4.3). The null hypothesis was accepted for both places given the P-values of 0.572 and 0.327 for Aklakou and Tabligbo in that the P-values are greater than the significant level (0.05). Statistically, no trend was found in both stations. Sen's slopes (3.31, 1.907) showed an increase in rainfall at the two stations but not significant because the P-values are greater than the significant level (0.05).

4.3 Trend Analysis of variation in instantaneous annual river peak river flow

Flood as a hydrological hazard is of concern as a result of its internal characteristics. Since flooding in the lower basin of Mono is due to both heavy rainfall and the opening of the Nangbeto Dam, changes in the instantaneous river flow is very important. The instantaneous annual maximum daily river flow between 1944 and 2011 was 951 m^3/s in 1999, while the minimum value of 95 m^3/s was observed in 2009 (See Appendix I). The mean annual river flow is 602.39 m^3/s and the coefficient of variation is 0.491 (49.1%). On running the Mann-Kendell test on the river flow data for the Mono River at Athieme hydrological station, the result depicted that the P-value (0.009) was lower than the alpha (0.05), hence the null hypothesis was rejected: there is a positive trend. The Sen's shows a decreasing trend in river flow and the rate of decrease in the river flow is -3.94 m^3/year. The decrease in river flow was significant since the P-value (0.009) is less than the significant level (0.05). Consider figure 4.4 below.

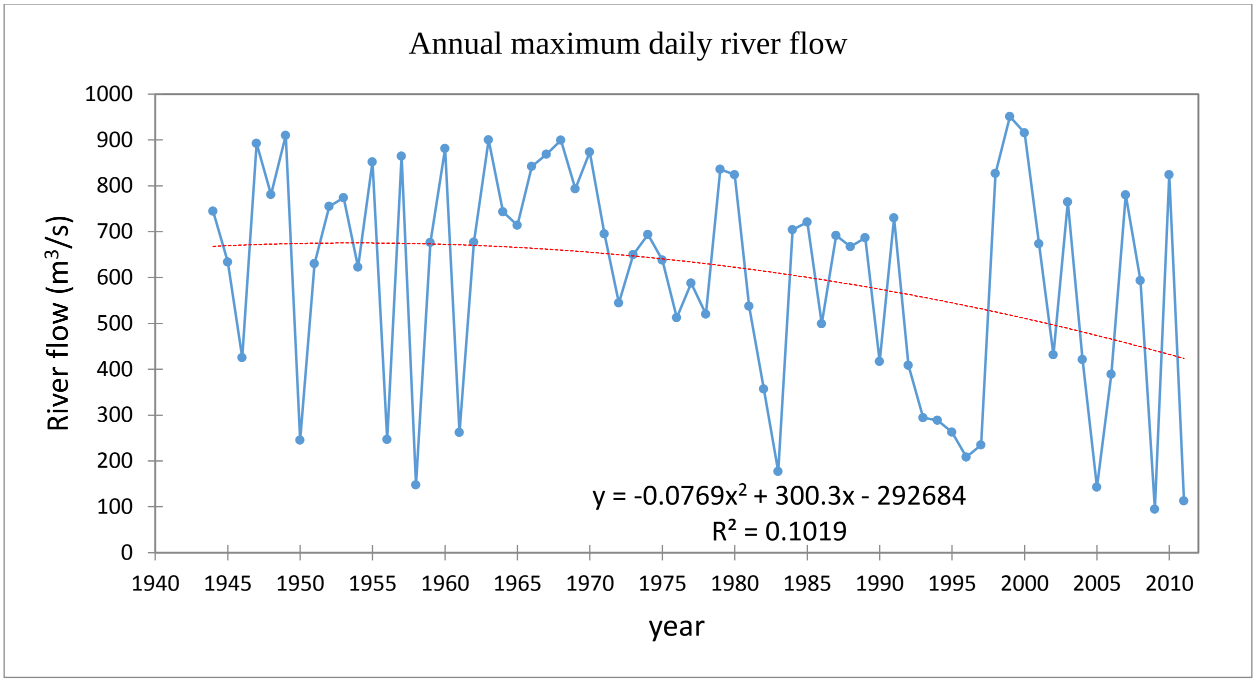

Figure 4.4. Trend analysis of river peak flow at the Athieme Station (1944-2011)

Figure 4.4 presents the pattern of the Mono River flow at Athieme, Benin. The construction of the Nangbeto hydroelectricity dam has effect on the Mono River dynamics at the downstream. The proposed dam of Adjarala, 65 km from the Nangbeto dam in the downstream will likely have further effects on the river flow pattern at the downstream.

Initially, a decrease in the river flow was observed before the construction of the Nangbeto hydro-power dam, but decreased further after the construction of the dam, which seemed normal. However, further decrease in river flow after the construction of the dam is not an evidence of reduction in flood frequency because opening of the dam could lead to destructive flooding at the downstream.

4.4 Estimation of Flood Return Periods using River Peak Flow

In the process of preparedness against disaster, the frequency of occurrence and the magnitude of the disaster are key factors. The results show that the frequency of occurrence of an extreme flood event is inversely related to the magnitude of river flow. The return periods (2-5-10-20-100-200-500-year), are inversely related to their corresponding magnitude. The result of Gumbel distribution (figure 4.6) shows that the devastating flooding in 2010 has a return period of 5 years with a magnitude of 824.4 m^3/s and an exceedance probability of 20% (Appendix II). The return period estimation was statistically tested to be reliable since the coefficient of variation is 49.1%.

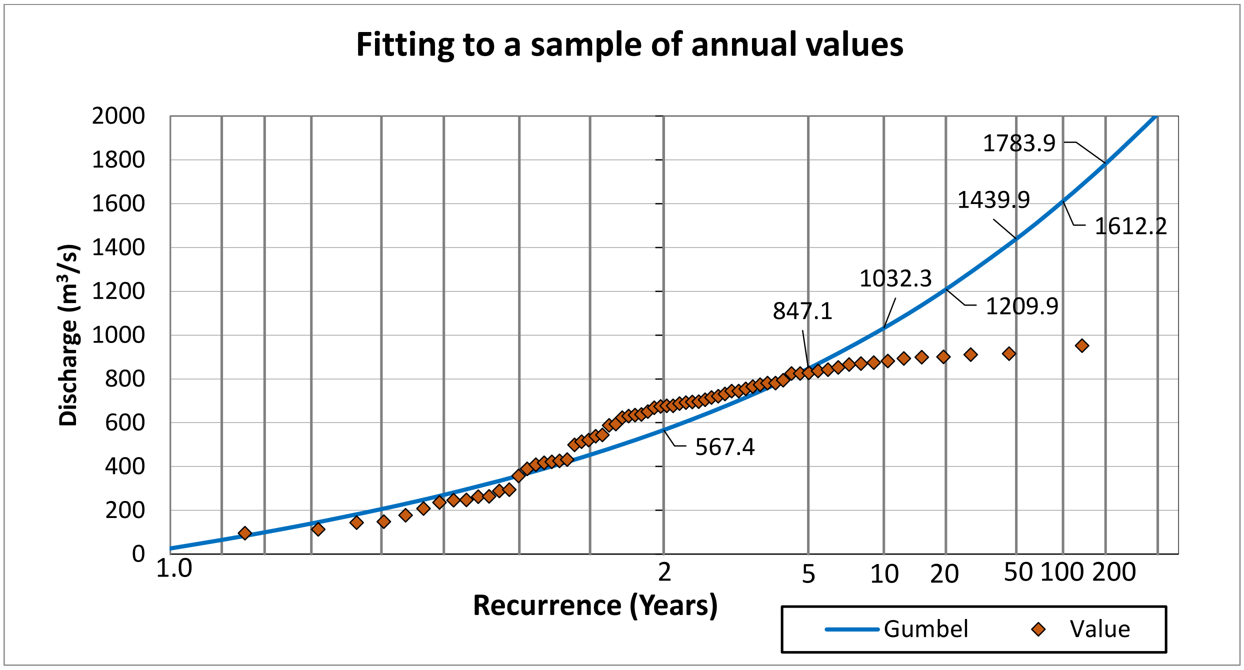

Figure 4.5. Flood return period estimation with Gumbel distribution

For estimating the magnitude of flood in the basin, for instance a 2-year flood, the corresponding values for river flows must be read from figure 4.6. A 5-year flood corresponds to 847.1 m^3/s, while a 100-year flood results into 1612.2 m^3/s (See Appendix III). It should be noted that return periods are inversely related to the probability of occurrence. Flooding with a 2-year return period has a 50% chance of occurring at least once in every 2 years (See Appendix III).

4.5 Result of Flood Hazard Mapping and Analysis

4.5.1 Soil Characteristics

The hydrological drainage characteristic of soil is very important in flood mapping. The more permeable the soil is; the more water can be transmitted through it. A soil with low permeability, such as clay, do not permit much water flow. This could cause "puddling" of water. The soils in the lower part of Mono River Basin are made up of clay (60%) and sandy clay (40%). Areas which are composed primarily of these types of soils are prone to a higher flood risk because the water requires a longer time to drain or infiltrate into the ground (See Appendix VI).

4.5.2 Flow Direction

One of the processes for deriving hydrologic characteristics of a surface is determination of direction flow from every cell in the raster data set. The result of flow direction in the Mono River Basin is presented in figure 4.7 below. There are eight valid output directions relating to the eight adjacent cells into which flow could travel. This approach is commonly referred to as an eight-direction (D8) flow model and follows the results by Jenson and Domingue (1988). The output map is presented in the figure 4.7 below.

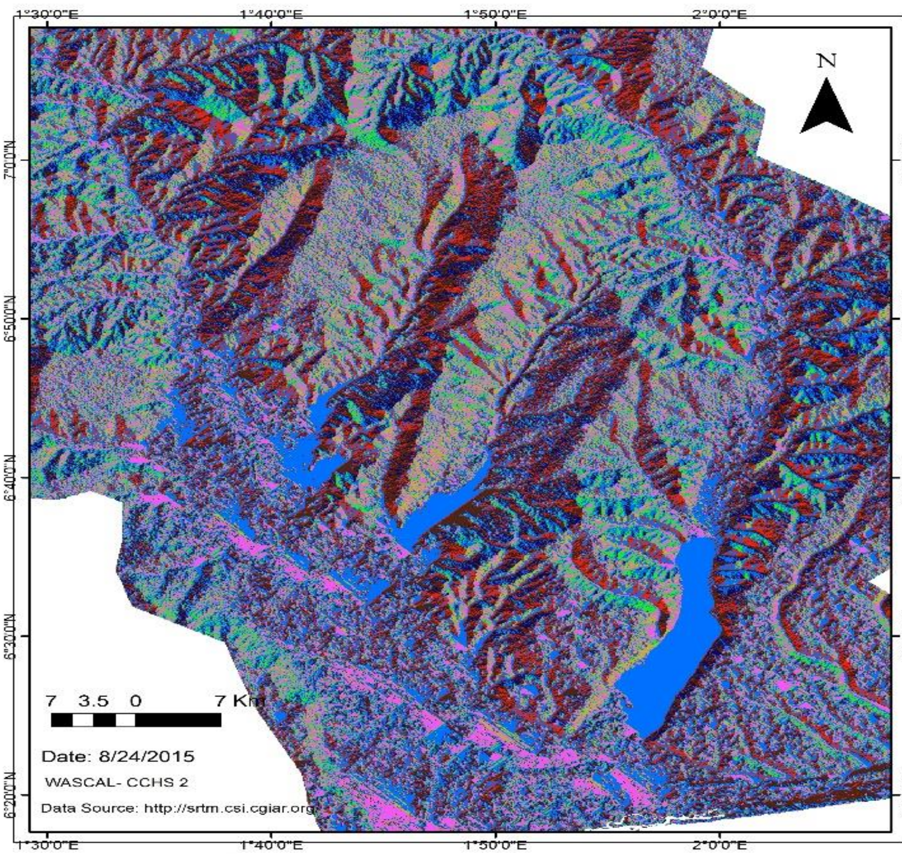

Figure 4.6. Flow direction in the lower basin of Mono River

Source: Author of the study

4.5.3 Results of flow accumulation and stream network

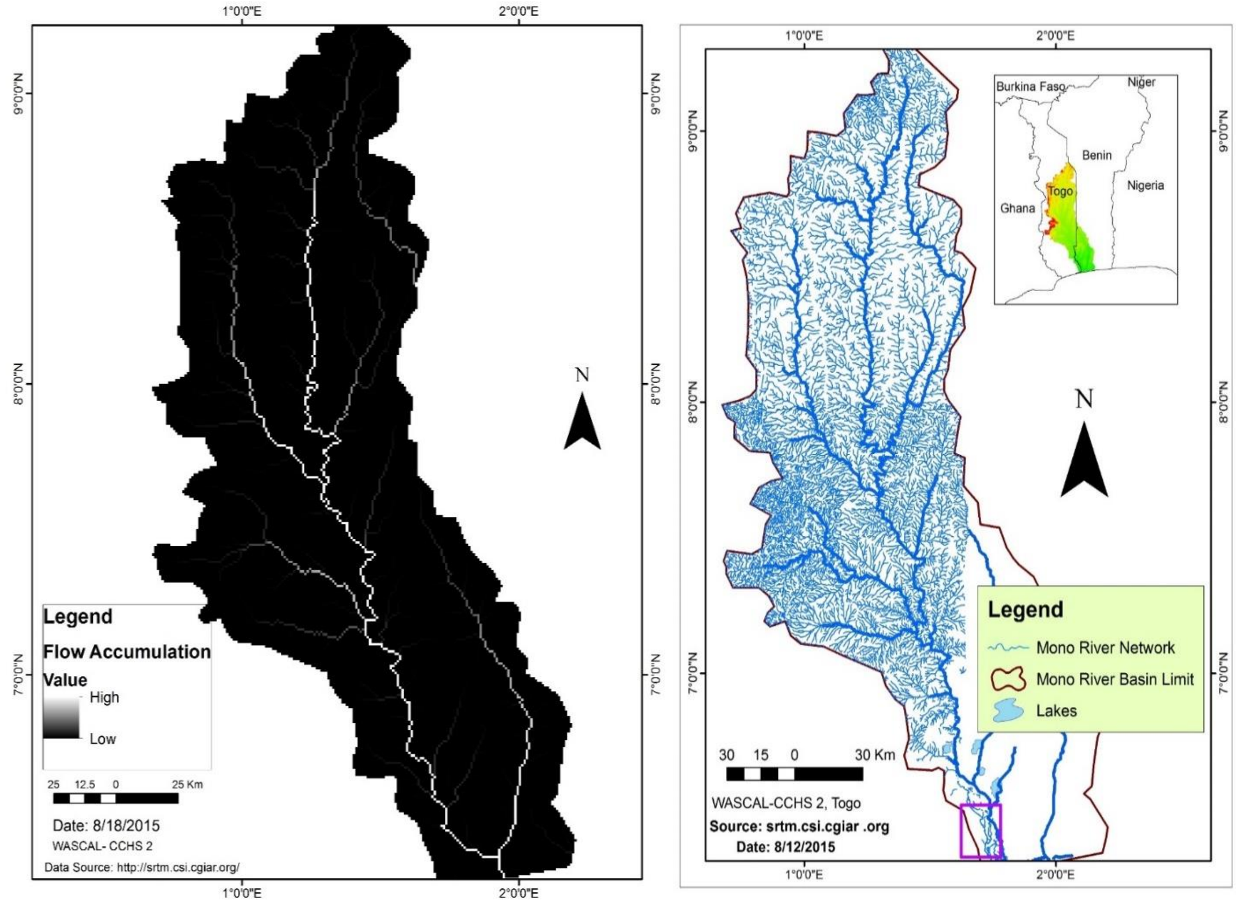

Figure 4.7. Flow accumulation (Left figure) and drainage network (right figure)

Source: Author of the study

Flow accumulation shows the cells within the study area where water accumulates as it flows downwards. Thus, settlements around these cells will receive much water during an event of rainfall or any sudden release of water. Flow accumulation in its simplest form is the number of upslope cells that flow into each cell. By applying a threshold value to the results of the flow accumulation tool, using either the Condition or Set Null tools, a stream network was delineated. The output results are presented in figure 4.8.

4.5.4 Stream Buffer zone

In trying to find the places that were within 500m zone around the active water channels, a single buffer zone was created and the output map is given in (Appendix VII). Interestingly, it was identified that most of the communities in the lower basin of Mono River in Togo are within a 500- meter buffer zone. Proximity to water body is an exposure factor that could increase the susceptibility of a community. Agbanakin, Togbavi, Azime Dossou and Adame are found within 100 m buffer.

4.5.5 Elevation

The elevation of the entire Basin was estimated and further zoomed-in to the study area. The output maps that were generated are presented in figure 4.9.

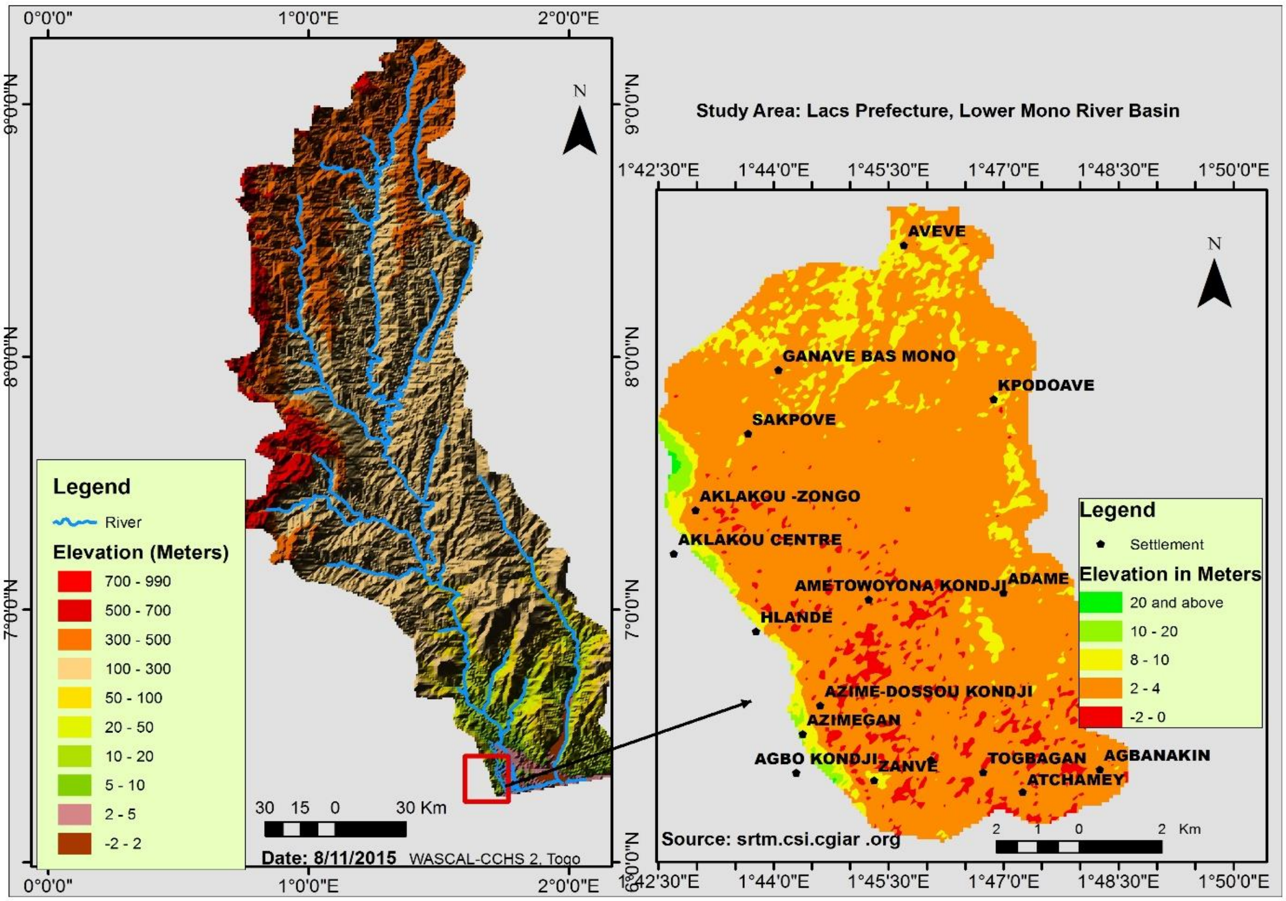

Figure 4.8. Elevation of the entire Mono River Basin (Left) and the study area (right)

Source: Author of the study

The highest value of elevation in the entire basin is 990 meters, while the lowest value is -2 meters below sea level (Figure 4.9). Zooming in to the lower part of the Basin, the study area, the lowest elevation is -2 m below sea level. Some communities like Agbanakin, Togbavi, and Azime-Dossou have elevation, which ranges from zero (0 m) to 4 m above sea-level, while communities such as

Aveve, Adame and Kpodoave are located between 4 m and 8 m above sea level. Elevation plays a major role in flood vulnerability and risk analysis. This is linked to the fact that places with lower elevation stand a higher chance of being inundated with a given clay soil and land cover type (Forkuo and Mensah, 2012).

4.5.6 Slope angle

The slope of an area can either be represented in degrees or percentage rise. In this study, the slope angle is displayed in degrees. The resultant map is presented in figure 4.10 below.

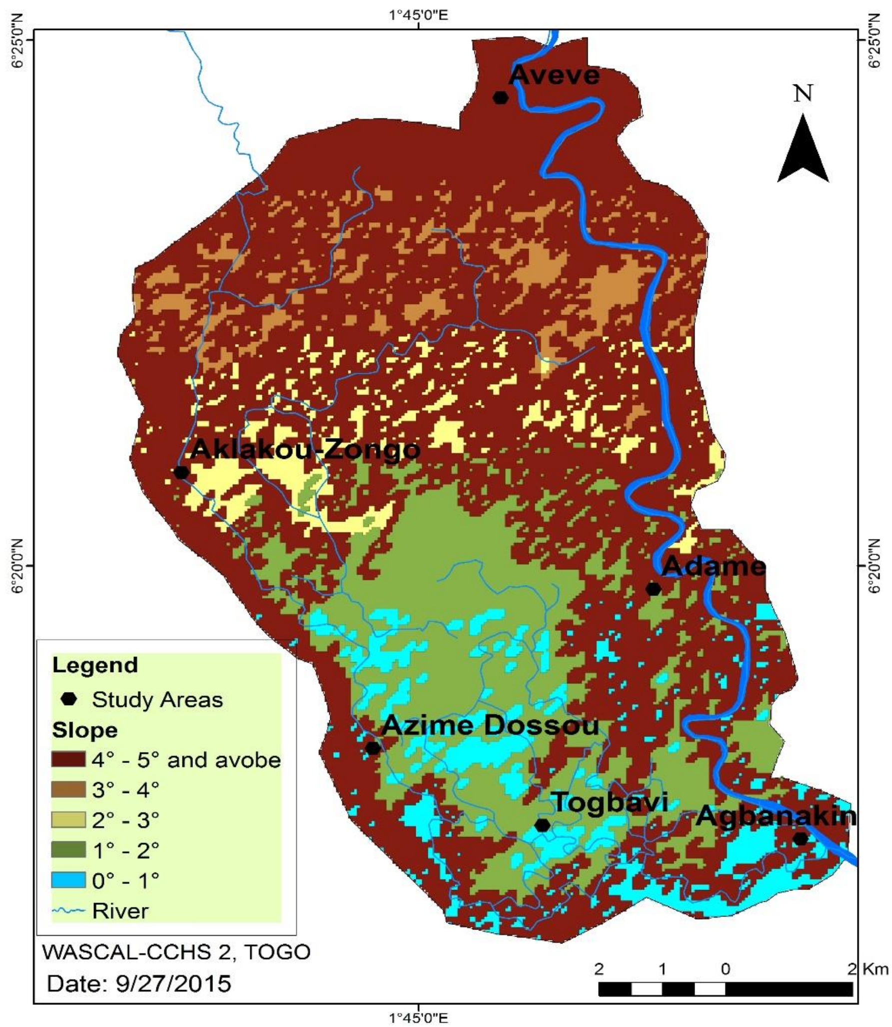

Figure 4.9. Slope Angle in the lower Mono River Basin in Togo

Source: Author of the study

As shown in figure 4.10, slope angle plays a major role in flood characteristics of an area. It shows a change in the elevation and steepness of an elevation. This influences the surface flow of water, flow accumulation and duration of floodwater at place. In figure 4.10, areas with slope angle of 0^0 to 2^0 have flat slope, while areas with slope angle between 3^0 and 4^0 have very gentle slope. Places that stand a higher risk of flood hazard are represented on the map in figure 4.10 from deep blue colour to deep red.

4.5.7 Result of land use/land cover classification

The result of land cover and land use classification using 2010 Landsat 7 ETM+ image is presented in figure 4.11 below.

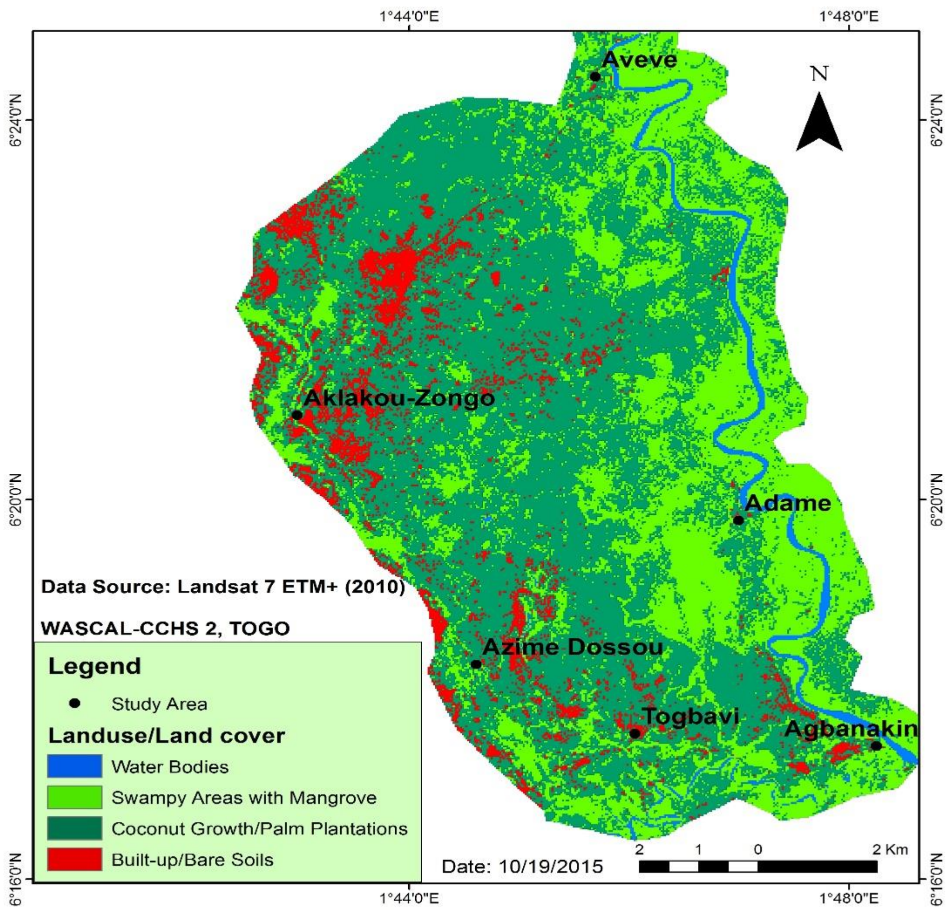

Figure 4.10. Land use/Land Cover Classification using 2010 Landsat 7 ETM+ image (30 m; Path/Row: 198/52)

Source: Author of the study

The resultant map of the image classification showed four major land use and land cover classifications in the area. Built-up areas/bare soils, coconut and palm plantations, swampy areas, with scattered mangroves were the resultant classes. It should therefore be noted that most of the roofs of the building were made of thatch and palm branches and therefore gave a reflectance that is similar to that of bare soils. Mangroves are effective in controlling flooding in an area. Bare soils and built-up areas tend to increase surface runoff when the given slope is gentle or steep, thereby reducing the rate of infiltration of surface water.

4.5.8 Flood Hazard Map

The flood hazard map for the Lower Mono River Basin is presented in figure 4.12 below.

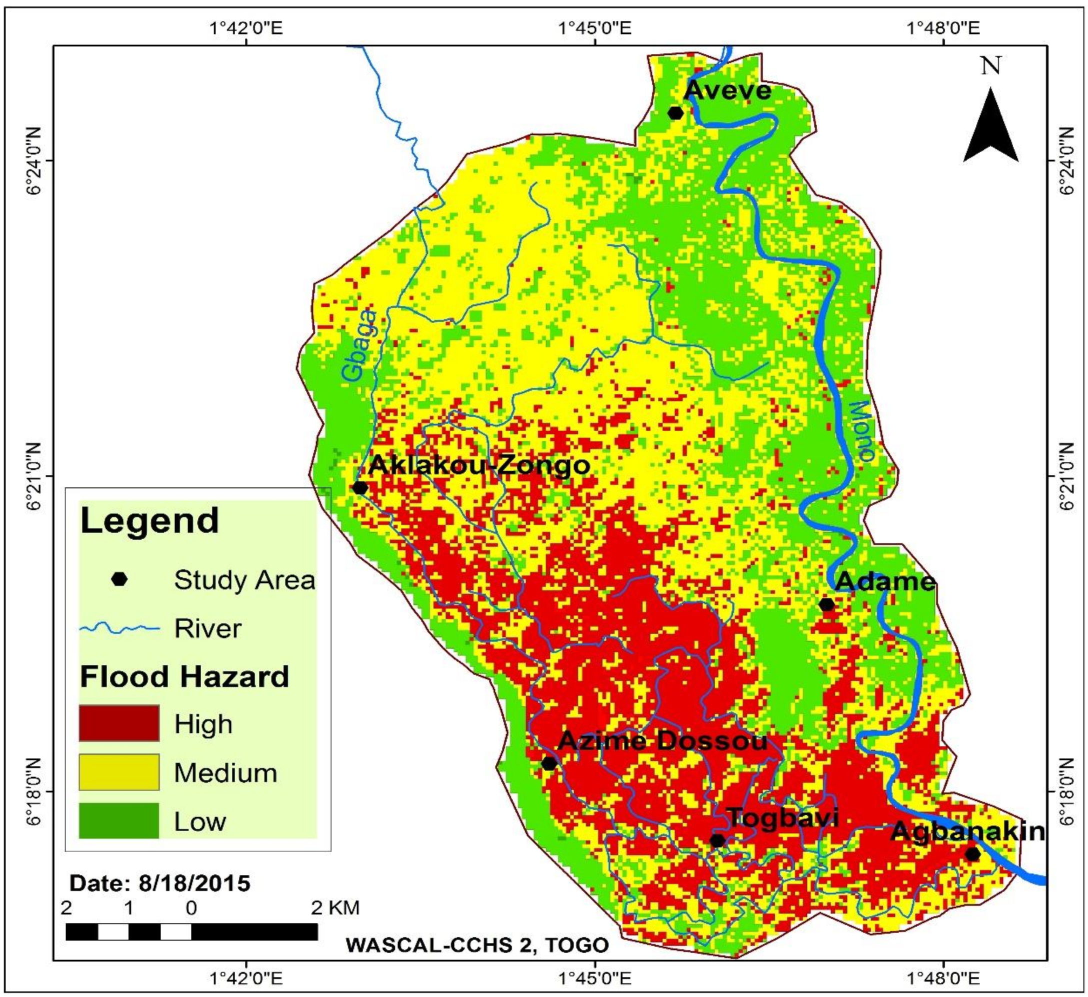

Figure 4.11. Flood hazard map of the lower Mono River Basin (Lacs district)
Source: Author of the study

It is observed in figure 4.12 that elevation, slope angle and soil structure are crucial in flood hazard mapping. The map revealed that areas with low elevation, flat slope angles and clayey soil are located in flood risk zones. It could be deduced from the map that Aklakou-Zongo is located 16 km by road from the main channel of Mono River at Adame but due to its lower elevation, it stands a high risk of flood hazard. All communities in the study area are located in floodplain but face different levels of flood hazard. Aveve and Adame are located very close to the main channel of the Mono River but stand lower chances of flood hazard due to their relative higher elevation and gentle slope angles. Communities such as Agbanakin, Togbavi, Atchamey and Azime-Dossou are all prone to high level of flood hazard.

4.5.9 Community's perception on the causative factors of Flooding

The communities were interviewed on the causative factors of flooding and the various results are given figure 4.13 below.

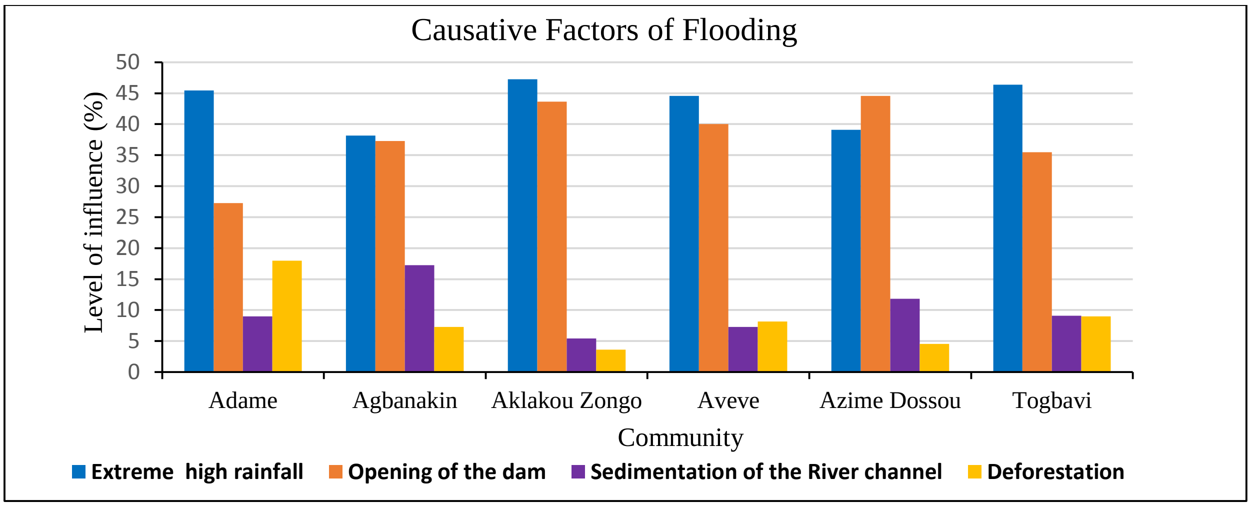

Figure 4.12. Perception of communities on the causes of flooding

As indicated in some of the rainfall stations, some communities perceived that the main cause of flooding in the lower part of the basin is extreme high rainfall. The next probable causative factor was the opening of the Nangbeto dam in the middle course of the river. It is indicated in figure 4.13 that 5 out of the 6 communities agreed that average annual rainfall has decreased over the past 30 years with a higher variability. In contrast, it is visible in figure 4.13 that deforestation has the least influence on the causes of flooding in the lower basin. This is contrary to the findings of

Kundu *et al.* (2011), in Nyando River basin in Kenya where deforestation was the major cause of flooding. *"Each time they open the dam at Nangbeto, we suffer from flooding at the downstream here but I might say that the main underlying factor is extreme high rainfall with the reason that rainfall is the main source of water in the lakes and rivers"*, said a teacher, in an interview at Aveve during field work.

4.6 Flood Exposure Mapping

Flood exposure map of the selected communities in the Lower Mono River Basin is given in figure 4.14 below.

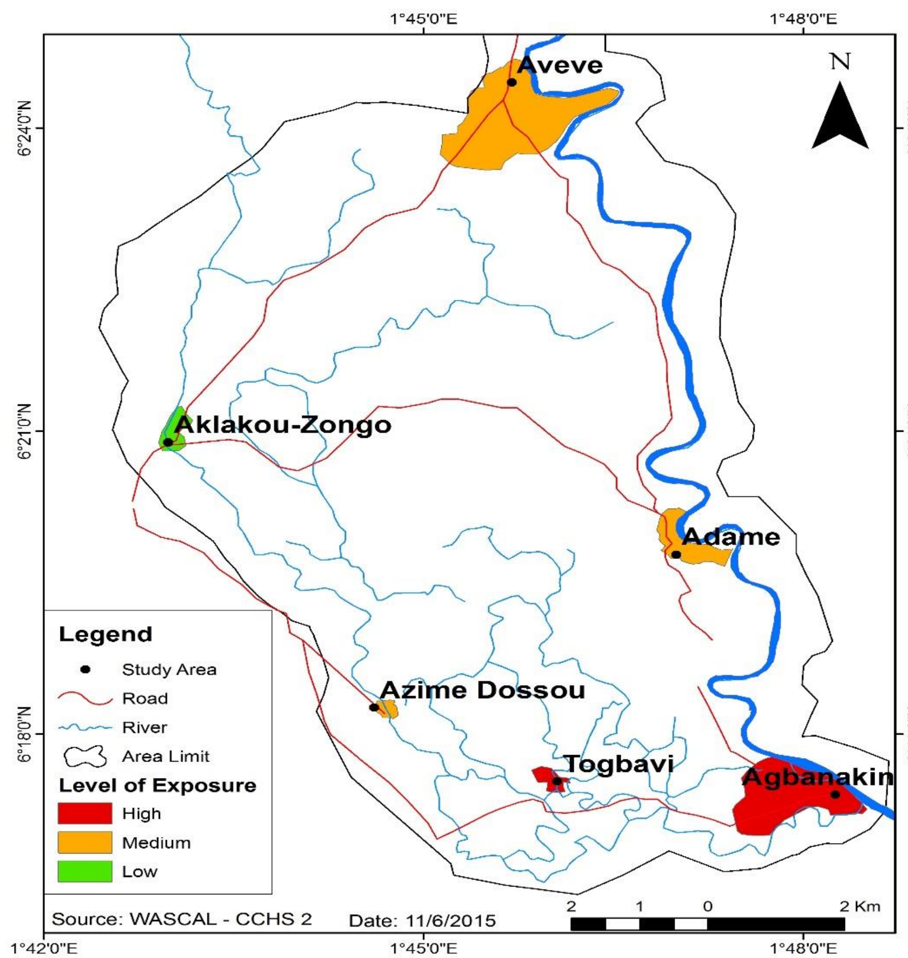

Figure 4.13. Flood exposure map for selected communities

It is clear from figure 4.14 that Agbanakin and Togbavi are highly exposed to flooding as compared with Aveve and Aklakou-Zongo (See Appendix IV).

4.7 Results of flood vulnerability mapping

4.7.1 Floodwater depth of the 2010 flood (measurement taken on the walls, trees)

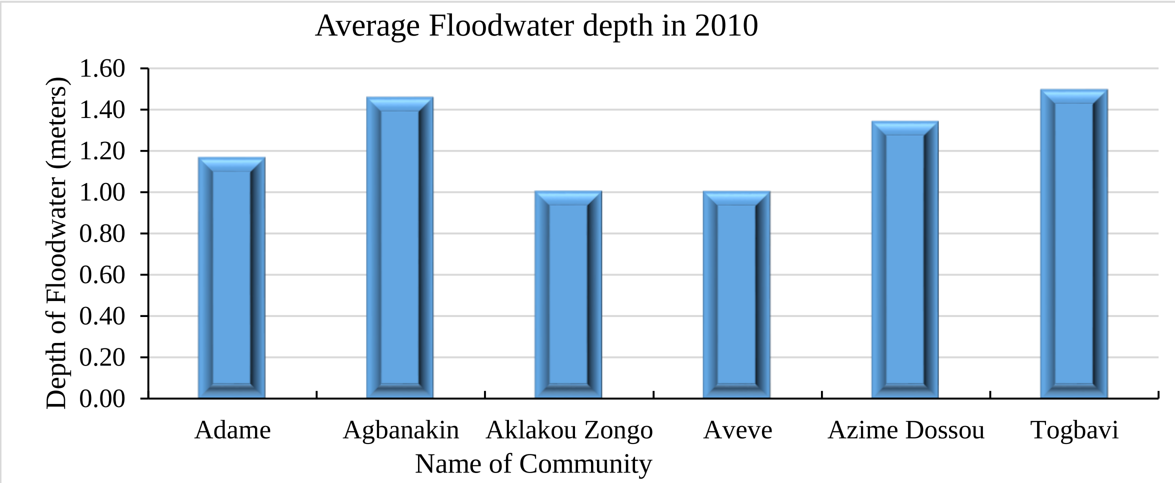

Figure 4.14. Floodwater depth in the communities during the 2010 flood event in the lower Mono basin, Togo

Obviously, it is visible from figure 4.15 that the highest floodwater level of 1.5 m and 1.45 m was recorded at Togbavi and Agbanakin. This confirms the fact that the areas have relatively lower elevation, flat slope angles and clay soil (60%), which do not permit rapid infiltration of water. The lowest floodwater depth was 1.01 m, which was recorded at Aveve and Aklakou-Zongo. Deeper floodwater increases the vulnerability of communities and pose great challenge to human security.

4.7.2 Flood duration

Table 4.2. Flood duration in the lower Mono River Basin in Togo (2010 flood)

Name of Community	Flood Duration (Days)
Aveve	40-46
Aklakou-Zongo	40-50
Adame	50-60
Azime Dossou	80-90
Agbanakin	90-95
Togbavi	90-95

As characterised by the 2010 flood disaster, table 4.2 shows that it took at least more than a month for floodwater to retreat in study area. In communities like Togbavi and Agbanakin, it took about three months (90-95 days) for the floodwater to retreat. The slope angle and soil structure of the place were other factors for longer floodwater duration in the communities. Longer flood durations led to the destruction of buildings and farmlands, denied access to major roads, buildings and field crops, restricted movement of people (school children and flood victims) and led to an outbreak of disease such as malaria. This is threat to health and food security.

(A), An abandoned house at Azime Dossou due to flooding. (B), Measuring floodwater height at Agbanakin

Photo by Adjaho Kouami, June, 2015

4.7.3 Flood vulnerability map

Flood vulnerability map of the selected communities are given the in figure 4.16 below.

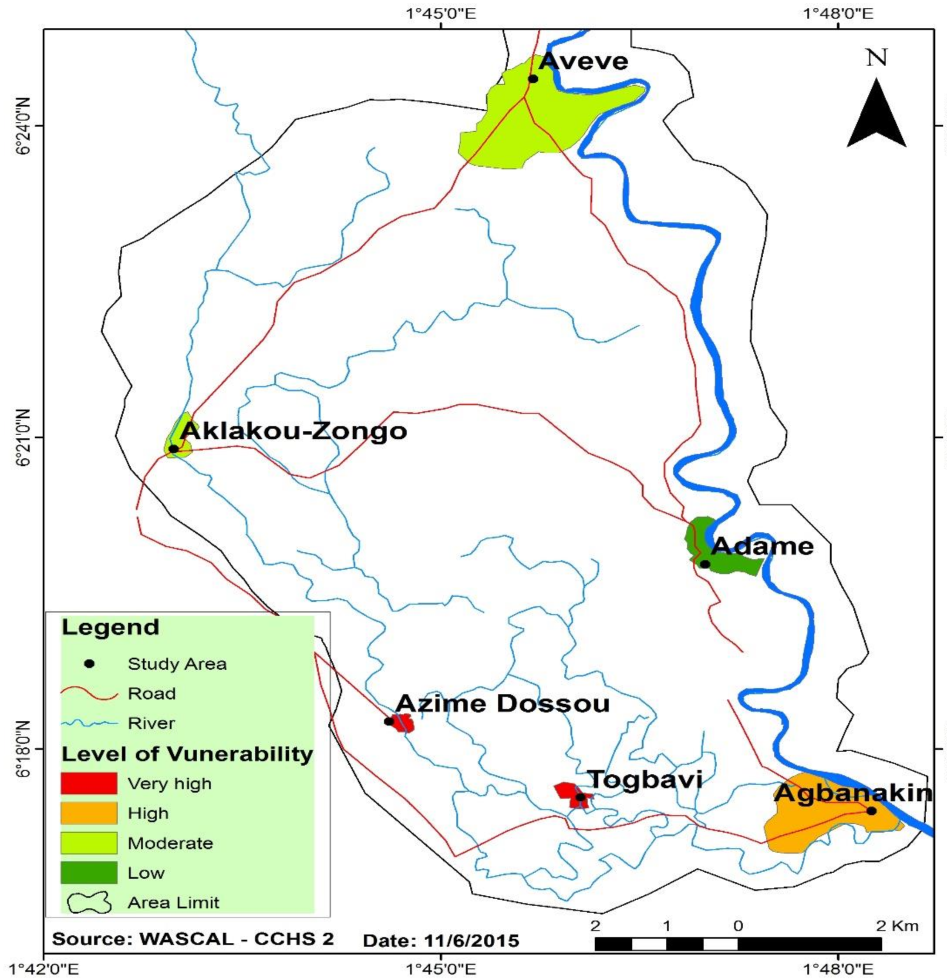

Figure 4.15. Flood vulnerability map of the lower part of Mono River Basin Togo.

More importantly, vulnerability of a place is dynamic in both space and time and also on the scale of measurement. In figure 4.16, it is obvious that Azime Dossou and Togbavi are highly vulnerable, while Adame is the least vulnerable among the selected communities. The high vulnerability of the two communities is partly explained by the fact that 98% of the building were made of mud and bricks supported with “Bamboo sticks”, and roofed with either thatch or palm branches. As confirmed by UNDP (2006), vulnerability is a complex concept and its outcome could not be predicted through a mere mental mapping. The spatial proximity of the communities from active water channels did not really explain their vulnerability to flood disaster but the use of social and economic indicators helped reveal the underlying factors of vulnerability.

4.8 Capacity and measure to anticipate, cope and recover in a flood event

The results of the capacity measures of the selected communities are presented in figure 4.17 below.

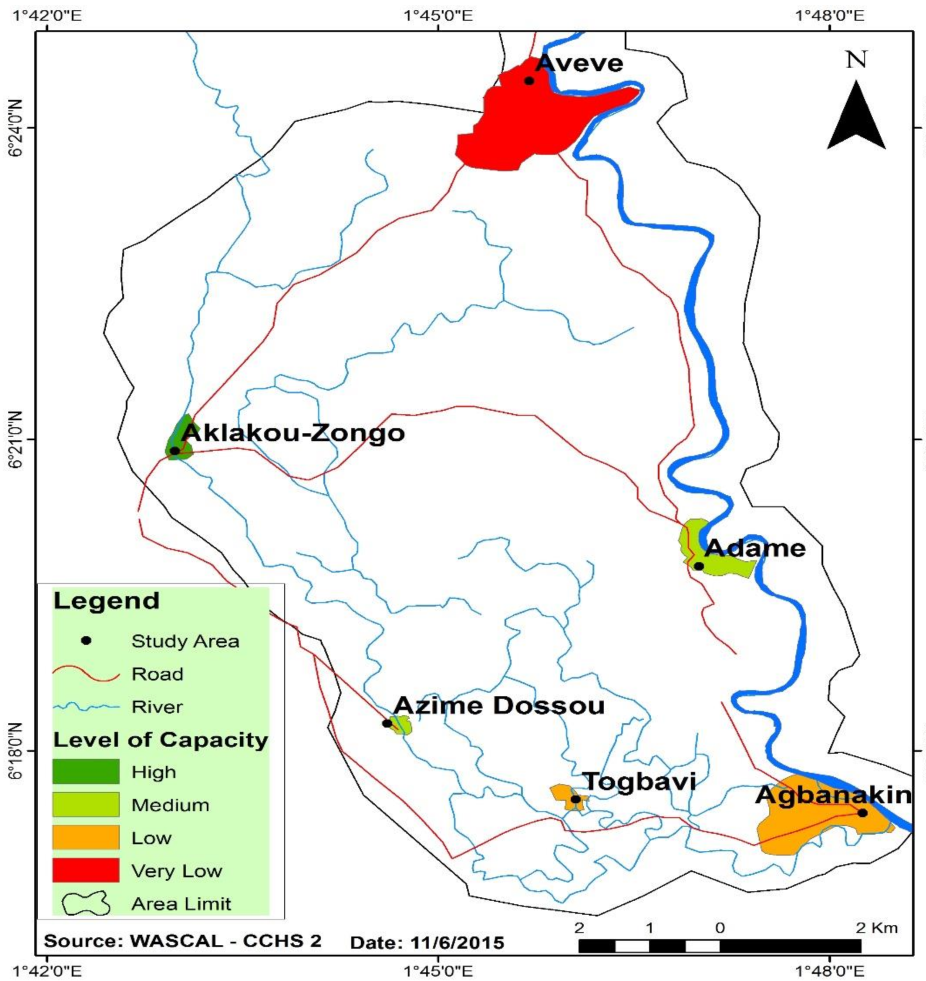

Figure 4.16. The level of capacity measures to face flood disaster

Undoubtedly, the capacity of social-ecological systems to anticipate, cope and bounce back well is very crucial to face hydro-meteorological hazards. The capacity assessment considered availability of flood disaster training programs, early warning systems and availability of evacuation facilities among others. Figure 4.17 shows that Aklakou-Zongo has the highest capacity to face flooding while Aveve has a very low capacity to anticipate, cope and recover from flooding. Agbanakin and Togbavi also emerged with low capacity to face flood disaster. This is partly explained by the fact that they do not have a "Balise", a flood early warning system, to alert them of an oncoming flood unless they receive telephone calls from the Togo Red Cross Team.

Contrarily, Azime Dossou and Adame happened to be more exposed than Aveve but the results of field survey indicate that they are well aware of flood hazard and are prepared to face flood disaster. Also, the results of field survey reveals that the communities have some local indicators, which serve as early warning system.

4.9 Indicators identified by the communities for flood hazard anticipation

Capacity to anticipate, cope and recover from a disaster is very crucial in disaster management. The communities have identified some local indicators, which serve as a flood early warning system. A few of the local indicators are presented in table 4.3

Table 4.3. Local indicators identified as flood early warning system (%)

Local indicator	Agbanakin	Aveve	Adame	Aklakou	Azime Dossou	Togbavi
Birds chg. dir. of movm't.	29	21	23	37	34	25
Frog croaks	55	59	64	47	51	58
Ants begin to carry their eggs	10	9	9	11	11	10
Snails climbing trees	6	11	4	5	4	7
Total	100	100	100	100	100	100

Local knowledge has been in existence since antiquity but not given the required attention in scientific studies. In this era of increasing disasters, it is very important to integrate it into empirical studies. From table 4.3, all the communities have identified frog croaks as the most common and relatively reliable indicator of flooding. The croaking of the frogs signifies that there is going to be a heavy rainfall, which might lead to flooding. Also, birds such as swans change their direction of movement with respect to heavy rainfall. When ants begin carrying their eggs, it is a prediction of heavy rainfall and served as a local indicator of flooding. It was again identified that when snails are observed climbing trees, it is a sign of flooding but this was not widely used in all the communities.

4.10 Flood Risk Mapping and Analysis.

The various levels of flood risk in the Lower Mono River Basin in Togo are presented in figure 4.18 below.

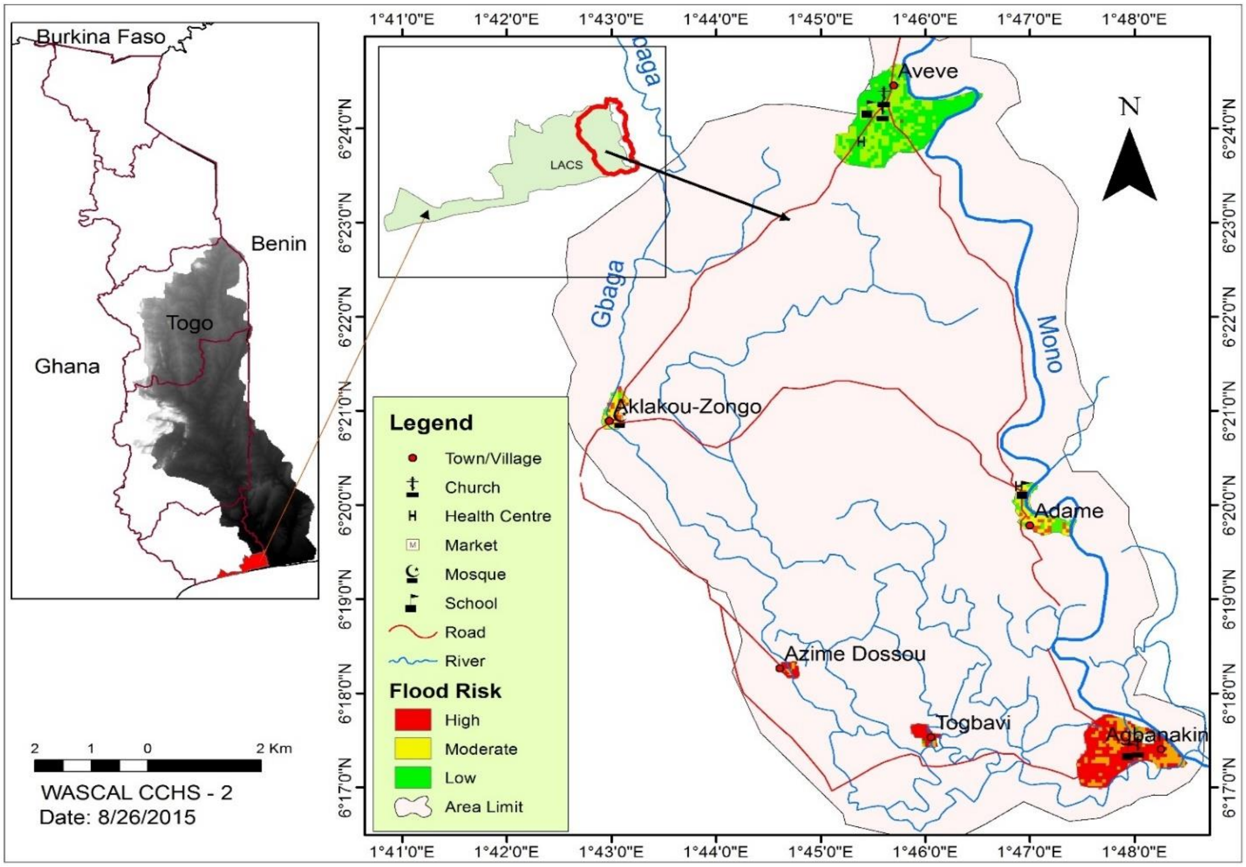

Figure 4.17. Flood risk map of the lower Mono River Basin in Lacs district, Togo.

Source: Author of the study

Flood risk mapping is an important step in flood disaster risk reduction as outlined by the Sendai Framework for Disaster Risk Reduction (2015-2030). The risk map for the study area (figure 4.18) shows that Azime Dossou, Togbavi and Agbanakin are likely the riskier communities. However, Azime Dossou community proved to have some level of capacity to face flood disaster but its level of risk was due to other underlying factors such as vulnerability, hazard and its exposure. Transect walk on the field confirmed that the three communities in the southern part of area are located in a low-lying swamp (1 – 2 m) above sea level. The three communities are surrounded by Gbaga and other tributaries of Mono River.

Moreover, Aklakou-Zongo is about 16 km by road from the Mono River at Adame, which is usually the limit of floodwater. This is partly explained by the fact that the elevation of Aklakou-Zongo is 2 meters above sea level, while the elevation of the main channel of Mono at Adame is 5 meters above sea level. "*Whenever the Mono River floods, the limit of the water is Aklakou-Zongo. We could go to Aklakou only by canoe and it is not all of us who have the capacity to own a canoe. During the last major flood in 2010, Aklakou-Zongo was evacuation centre for some of us",* said a flood victim during a pre-field visit to Adame.

Aveve and Adame appeared to be at a flood lower risk. This is explained by the topographical characteristics of the places. It was revealed that they are found on gentle slopes and comparably located 5 m to 8 m above sea level, although they are sited very close to the active channel of the Mono River.

Furthermore, it should be noted that accumulation of sediments in the channel of the river through erosion from upstream and deposition at the downstream reduces the channel depth and also hinders the smooth flow of water. As a result, a little increase in the volume of water compels the river to overflow its banks. This is affecting the dynamics of the river and the risk profile of the surrounding villages.

4.10.1 Impacts of flood disaster on rural communities

It is important to accept the fact that impact of a disaster affects those who have low capacity to cope and recover. Communities in the lower part of the Mono River Basin suffer from the impacts of flooding due to several internal factors such as poverty, wrong siting of building, construction of building with low quality materials, and bad roads, among others. It was identified that no cases of death were recorded over the past 10 years in communities but the economic and physical impacts were recorded each time flooding occurred. The details of the various impacts of flooding are given in figure 4.20 below.

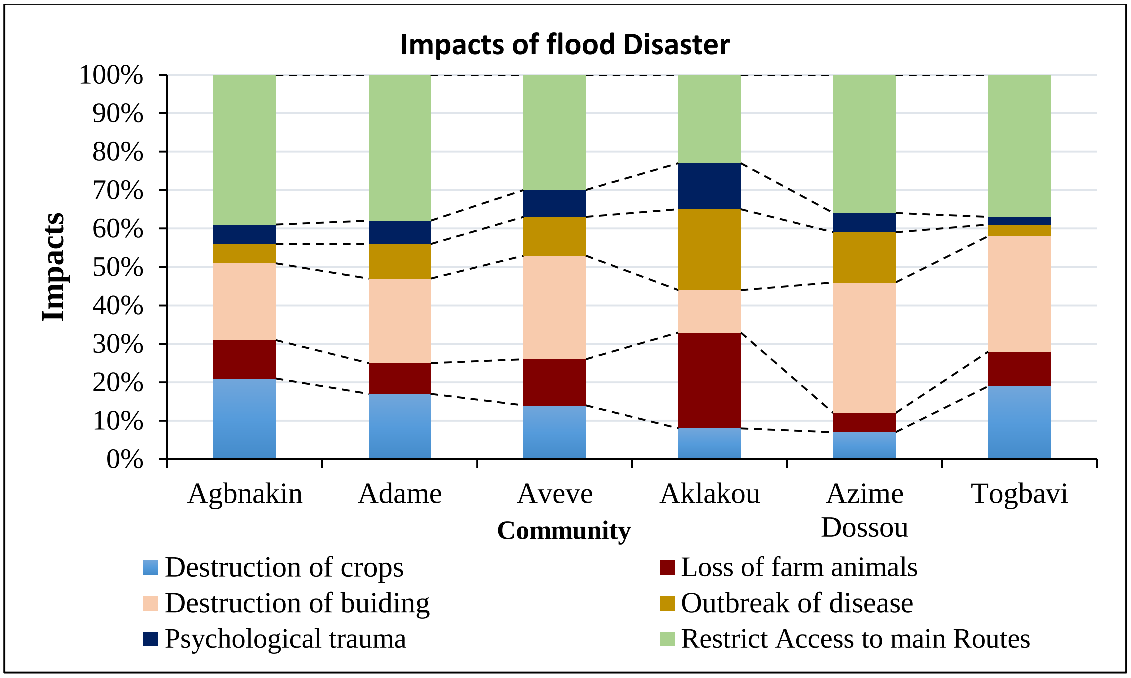

Figure 4.18. Impacts of flood disaster in the communities

Obviously, flood disaster risk has gained worldwide attention because of its commonness and destructive nature. Results of fieldwork show that the worst hit of flooding in the communities over the past 10 years was destruction of building, food crops and restriction of movement. During flooding, peoples' movements are restricted in that they cannot go to the market and children cannot go to school as well. The associated secondary impacts of flooding in the communities were lost of livelihood, outbreak of diseases and pollution of drinking water. All these effects were found to have contributed to the already existing high level of poverty. "*My house and my farm were destroyed due to flooding in 2010 and since then, I have not been able to recover fully. My neighbours were equally affected"*, said a flood victim in an interview during fieldwork at Togbavi.

4.10.2 Communities' perception on climate change and flood occurrence

In West Africa, the impacts of climate change are well felt mostly among rural poor who depend directly on nature through rain-fed agriculture. The increasing variability in extreme climate variables such as temperature and rainfall often result in uncertainties but most local communities have fair knowledge of this variability. Through field survey, interviews and focus group discussion, it was found that 70% of the people in the communities are aware that climate is changing and there has been a change in the rainfall pattern over the past 30 years. It was also found that the average annual rainfall is decreasing and the rainfall pattern is marked by high variability. This variability affects their cropping patterns and other livelihood activities. It was again found that the average recurrence interval of flooding varied between 4 and 5 years but since 2007, flood occurrence is almost on yearly basis.

Focus Group Discussion at Agbanakin (A) and Aveve (B)

(Source. Fieldwork, 2015)

4.10.3 Positive impact of flooding

Interestingly, while humanitarian organizations, governments and other institutions are putting strategies forward to save lives and property during flood hazard, it should be brought to light that flooding could have some positive impacts at times. In Togbavi, 60% of the people are of the view that flood occurrence leads to an increase in fish catch. This is favourable when the flood duration is long enough to sustain the breeding of fishes. Also, at Azime-Dossou, 20% of the people agreed that flooding leads to increase in fish catch, especially when the retreat of the floodwater is progressive but at times the negative impacts are too severe. In contrast, at Agbanakin, Aveve, Adame and Aklakou-Zongo, there are no positive impacts of flooding.

4.10.4 Community-based flood risk factors

Members of each of the selected communities were asked during the focus group discussion to list the flood risk factors that were relevant in their communities and rank them according to their level of influence on flooding. The rank of 1 was given to the most important factors, while the rank of 7 was given to the least important factors. The results are given in table 4.4 below.

Table 4.4. Community's perception on flood risk factors

Agbanakin	Adame	Aveve	Aklakou	Azime Dossou	Togbavi	Rank
Elevation	Proximity to active water channel	No access to financial aid	Elevation	Surrounded by water	Elevation	1
Proximity to active water channel	No access to financial aid	Proximity to active water channel	Poor building materials	Elevation	Surrounded by water	2
Poor building materials	Poor building materials	Poor building materials	Proximity to active water channel	Poor building materials	No disaster mgmt. plan	3
No access to Meteo. data	No flood mgmt. committee	No "Balise"	No flood mgmt. committee	No flood mgmt. committee	Poor building materials	4
No flood mgmt. committee	No disaster mgmt. plan	No flood mgmt. committee	No access to financial aid	No access to Meteo. data.	No means of evacuation	5
No "Balise"	Elevation		No disaster mgmt. plan	No means of evacuation	No access to financial aid	6
Poor drainage system of the River						7

Source: Fieldwork, 2015

4.10.5 Flood disaster preparedness

As part of assessing the level of flood disaster risk in the selected communities, preparation in terms of physical and economic arrangements before and during flood disaster is very crucial. It was found that at Togbavi and Aklakou-Zongo, the foundations of building are strengthened against flood hazard. Similarly, at Agbanakin, food stuffs are gathered and kept at safer places before the occurrence of flood hazard. Farm animals are also quarantined at relatively higher and safer grounds.

Again, it was found that communities such as Azime Dossou and Togbavi are completely surrounded by Gbaga, a tributary of Mono River and they have only one canoe each for evacuation. This means that children below 6 years and the elderly above 65 years stand a higher risk since they may not have enough strength and may need the assistance of others, while average depth of floodwater is 1.3 m.

4.10.6 Communities' role in flood hazard reduction

In disaster risk reduction, capacity at national, regional and local levels is very important. Local efforts in the form of projects or communal labour towards flood disaster risk reduction was assessed in the selected communities through focus group discussion. The results revealed that there is no project at community level to help reduce the risk of flood disaster. At Agbanakin, a communal labour is organized at times to help dredge some parts of a tributary of Mono River but such activities are not found in other communities.

Dredging of a stream at Agbanakin to allow smooth flow of water

Photo by Joshua NTAJAL, 2014

4.10.7 Institutional role in flood disaster reduction

As enshrined in the Sendai Framework for Action (2015 – 2030), every stage of disaster risk reduction has some required actions. Humanitarian organizations and relief institutions carry out some of the activities. In the communities at hand, the main disaster relief body is Togo Red Cross. Provision of early warning systems and evacuation facilities are some of the things provided by the Togo Red Cross during the last major flooding in 2010 in the area. Regarding rapid response and recovery processes, the police and the military are also dispatched to help save lives. At Agbanakin, Togbavi and Azime Dossou, relief items such as mats, clothing, food and internally displaced persons' camps (IDPs) were provided by Red Cross during the 2010-flooding event. In addition to the basic items mentioned, Togbavi and Azime Dossou were provided with a canoe each for evacuation process. "Balise", an early warning system, was installed at Azime Dossou and Atchamey, a nearby community by the Togolese and the German Red Cross.

More importantly, in each of the communities, the local Red Cross team had formed focal points and ladies' club called "Mothers Club" under the local coaches. They serve as intermediaries between the national coordinator and the communities for dissemination of early warning information against flood hazard; they are equally charged with the responsibility of saving lives during disaster.

In summary, all the communities are exposed to flood hazard while the capacities to anticipate, cope and recover are low. The results of risk analysis indicate that elevation of a community above sea level is a very important indicator of flood risk because communities that are located 4 meters below sea level at a given slope angle of less than 3^0 are mostly exposed to flood risk.

CHAPTER V: Conclusion and Policy Recommendations

5.1 Conclusion

In the upper part of the Mono River Basin, rainfall has decreased significantly over the past 30 years at Sokode, while an insignificant increase at Sotouboua station was observed. In the middle section of the basin, at Atakpame, there has been a slight increase in rainfall but a decrease in rainfall was observed at Kougnowou. The study demonstrated an insignificant increase in rainfall at the lower section of the basin.

Also, communities in the lower part of the Mono River Basin stand the chance of being frequently affected by a 2-year and a 5-year floods with corresponding magnitudes of 847 m^3/s and 567.4 m^3/s. The magnitudes of a 2-year and 5-year flood are relatively lower than that of a 100-year flood (1612.2 m^3/s), which seemed statistically impossible. The 2010 flooding, which hit most part of the country, has a return period of 5 years with a magnitude of 847 m^3/s and an exceedance probability of 20%.

It was found that the communities (Azime Dossou, Agbanakin and Togbavi) that are located in the lower altitude areas are more exposed to flood hazard than Aveve and Adame that are located on relatively higher elevations (4-8 m above sea level). Again, Aveve community had very low capacity measures to face flood; however, Agbanakin, Togbavi and Azime Dossou are highly at flood risk as compared to Aveve and Aklakou-Zongo. It should therefore be noted that the source of flood risk is not only climate change but also the regulation of the Nangbeto dam and the social economic factors of the communities.

Risk and vulnerability are very complex and dynamic phenomena. Developing mitigation strategies therefore, need a collective effort from the communities, institutions, organizations and governments. The following recommendations were suggested towards flood disaster risk reduction at the community level.

- Each of the communities could own a rice farm, community forest, palm nut and coconut plantation. This would help reduce the issue of unemployment and poverty.
- A positive attitude towards early warning systems is an effective means of reducing disaster risk in the lower basin.

At the institutional level, the following recommendations could be considered to help reduce flood disaster risk in the Lower Mono River Basin:

- collaboration among disaster relief organizations is very crucial. This will help in reducing duplication and strengthen the mitigation strategies.
- designing and location of early warning systems should be properly done. For instance, the Balise at Azime Dossou is not well sited because it was placed at 1m above sea level. Therefore, by the time the water level was at green (Normal flow), it was already entering people's rooms. It is proper to install "Balise" at hydrographic zero.

At the governmental level, a further enquiry could be carried out in order to identify which communities are ready to relocate. Relocation is a good strategy to reduce the exposure of the communities to flood disaster. Sensitizing the communities and training the people to equip them with the needed skills should precede the relocation activity. This is because relocation may lead to changing of livelihood activities.

LIMITATIONS

One of the limitations of this study was inadequate data such as flood history maps and facility maps. Remote sensing data was not readily available for the study area. The poor resolution of the satellite images and cloud cover of over 20% posed greater challenges to image classification hence changes in the land use and land cover in the entire basin was not achieved.

Comprehensive analysis on resilience and adaptation capacities are very important in the development of flood disaster management but was not covered in this study. Further studies could be carried out on the resilience and adaptive capacity measures of the communities for integrated policy formulation.

Hydrological modelling of the Mono River was also not done due to the proposed Adjarala dam on the Mono River. This is because the construction of the dam could likely change the hydrological parameters of the river. Further studies could be done after the construction of the dam.

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APPENDICES

APPENDIX I. Results of the Mann-Kendall test for Rainfall and River flow

Station	M-Kendell (S)	Kendell's tau	Sen's slope	P-value (two - tailed)	Alpha	Test interpretation
Atakpame	61.000	0.068	2.16	0.532	0.05	Accept H0
Sokode	-314.000	-0.220	-4.523	0.020	0.05	Reject H0
Sotouboua	117.000	0.346	1.579	0.173	0.05	Accept H0
Tabligbo	95.000	0.105	1.907	0.327	0.05	Accept H0
Kougnowou	-40.000	-0.092	-2.471	0.486	0.05	Accept H0
Aklakou	33.000	0.076	3.31	0.572	0.05	Accept H0
Athieme*	-498.000	-0.219	-3.94	0.009	0.05	Reject H0

Note: (*) = Mono River flow at Athieme, Benin

APPENDIX II. Statistical summary of rainfall time series

Station name	Minimum	Maximum	Mean	Std. deviation
Sokode	872.400	2087.000	1332.765	231.722
Sotouboua	863.500	1661.400	1310.712	194.790
Aklakou	396.800	1531.000	815.948	262.512
Atakpame	767.300	1850.100	1338.400	250.342
Tabligbo	674.000	1341.500	1018.135	176.243
Kougnowou	895.850	1679.500	1318.765	199.811

Appendix III. Flood frequency estimation by Gumbel’s exponential distribution

Exceedance prob. (%)	Recurrence	Std. Normal Variate	Gumbel Estimates (m^3/s)
50.0	2	0.000	567.4
33.3	3	0.430	699.7
20.0	5	0.841	847.1
10.0	10	1.282	1032.3
5.0	20	1.645	1209.9
2.0	50	2.054	1439.9
1.0	100	2.327	1612.2
0.5	200	2.576	1783.9
0.2	500	2.879	2010.4
0.1	1000	3.091	2181.6
0.0	2000	3.291	2352.7
0.0	10000	3.719	2749.9

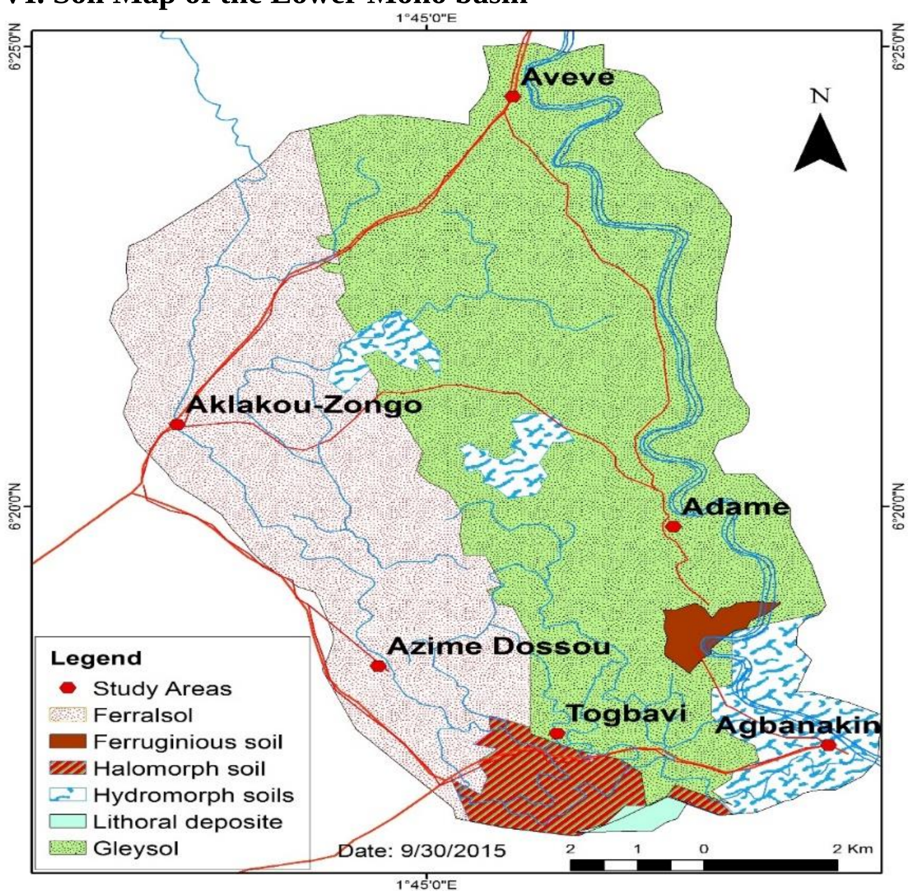
APPENDIX IV. Results of the normalized indicators used for flood risk studies

Indicator name	Agbanakin	Aveve	Adame	Aklakou- Zongo	Azime Dossou	Togbavi
E1	1.0	1.0	0.0	1.0	0.0	0.0
E2	0.8	0.0	0.2	0.0	0.9	1.0
E3	0.9	0.0	0.3	0.4	0.7	1.0
E4	0.4	1.0	0.1	0.0	0.1	0.1
E6	0.5	0.1	0.9	0.0	1.0	1.0
V1	0.2	0.1	0.3	0.4	0.0	1.0
V2	0.3	0.2	0.0	0.5	0.9	1.0
V3	0.0	0.2	0.4	0.9	1.0	1.0
V4	1.0	0.0	1.0	0.9	1.0	1.0
V5	0.8	1.0	0.0	0.3	1.0	0.8
V6	0.0	0.4	0.6	1.0	0.9	0.9
V7	1.0	0.2	0.2	0.0	0.0	0.1
V8	0.8	0.0	0.8	1.0	1.0	1.0
V9	1.0	0.8	0.2	0.0	0.3	0.1
V10	0.5	0.1	0.3	0.6	1.0	0.0
V11	0.0	0.6	0.9	1.0	1.0	0.8
V12	0.9	1.0	0.7	0.0	1.2	1.2
V13	1.0	0.7	0.3	0.0	0.0	0.0
V14	0.0	1.0	0.4	0.5	0.1	0.2
C1	0.4	0.0	0.4	1.0	0.2	0.8
C2	0.0	0.3	0.1	0.6	0.9	1.0
C3	0.7	0.0	0.7	0.9	1.0	1.0
C4	0.0	0.2	0.3	1.0	0.1	0.1
C5	0.8	0.0	1.0	1.0	1.0	1.0
C6	0.0	0.0	0.0	0.0	0.0	0.0
C7	0.0	0.2	0.9	0.7	1.0	1.0
C8	0.0	0.6	0.8	1.0	1.0	1.0
C9	0.0	0.0	0.0	0.0	0.0	0.0

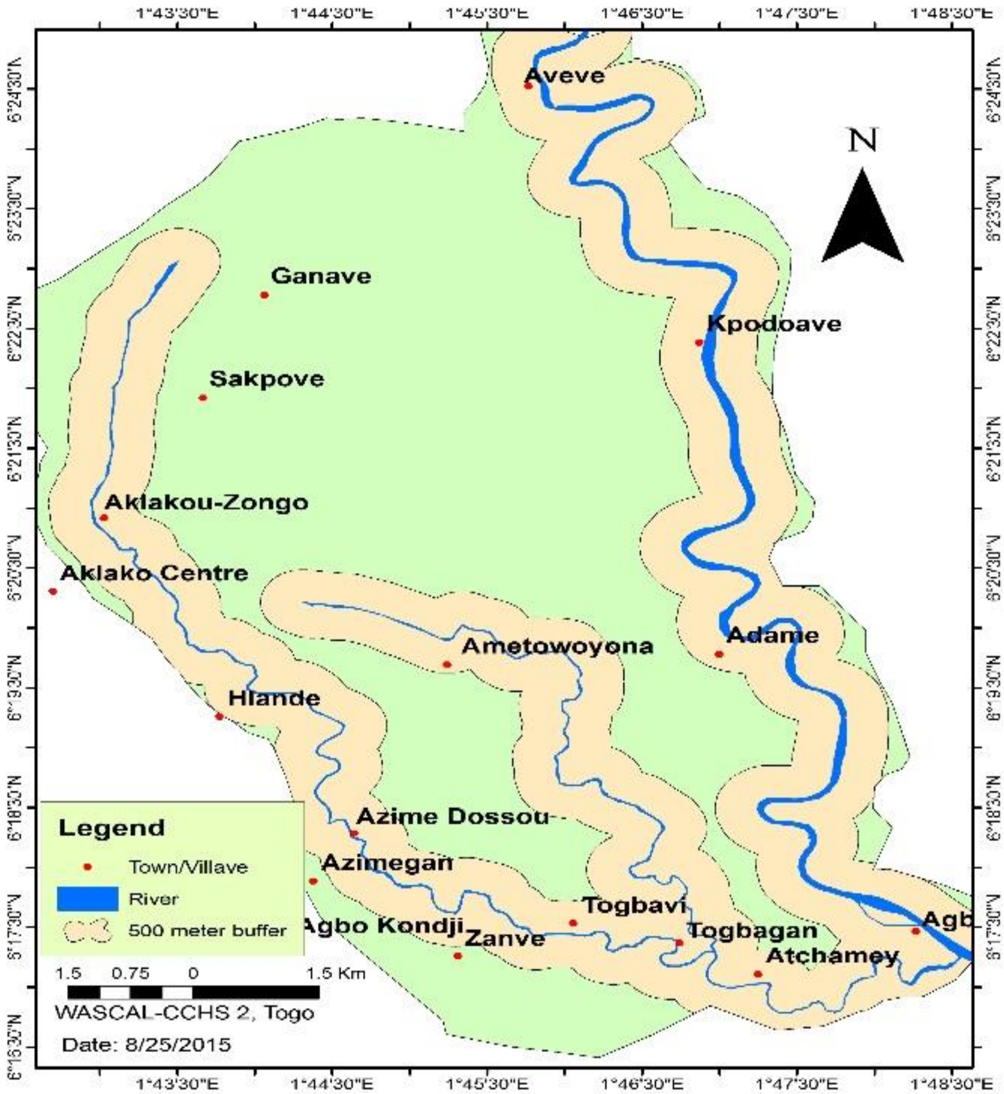
APPENDIX V. Creation of flood risk map using weighted overlay analysis in ArcGIS (10.1)

Data layer	Percentage of influence	Value	Scale Value
Hazard	33.1	1	5
		2	4
		3	2
		4	3
Exposure	32.30	1	3
		2	4
		3	5
Vulnerability	23.12	1	1
		2	3
		3	4
		4	
Capacity Measures	11.48	1	5
		2	4
		3	3
		4	2
	100.00		

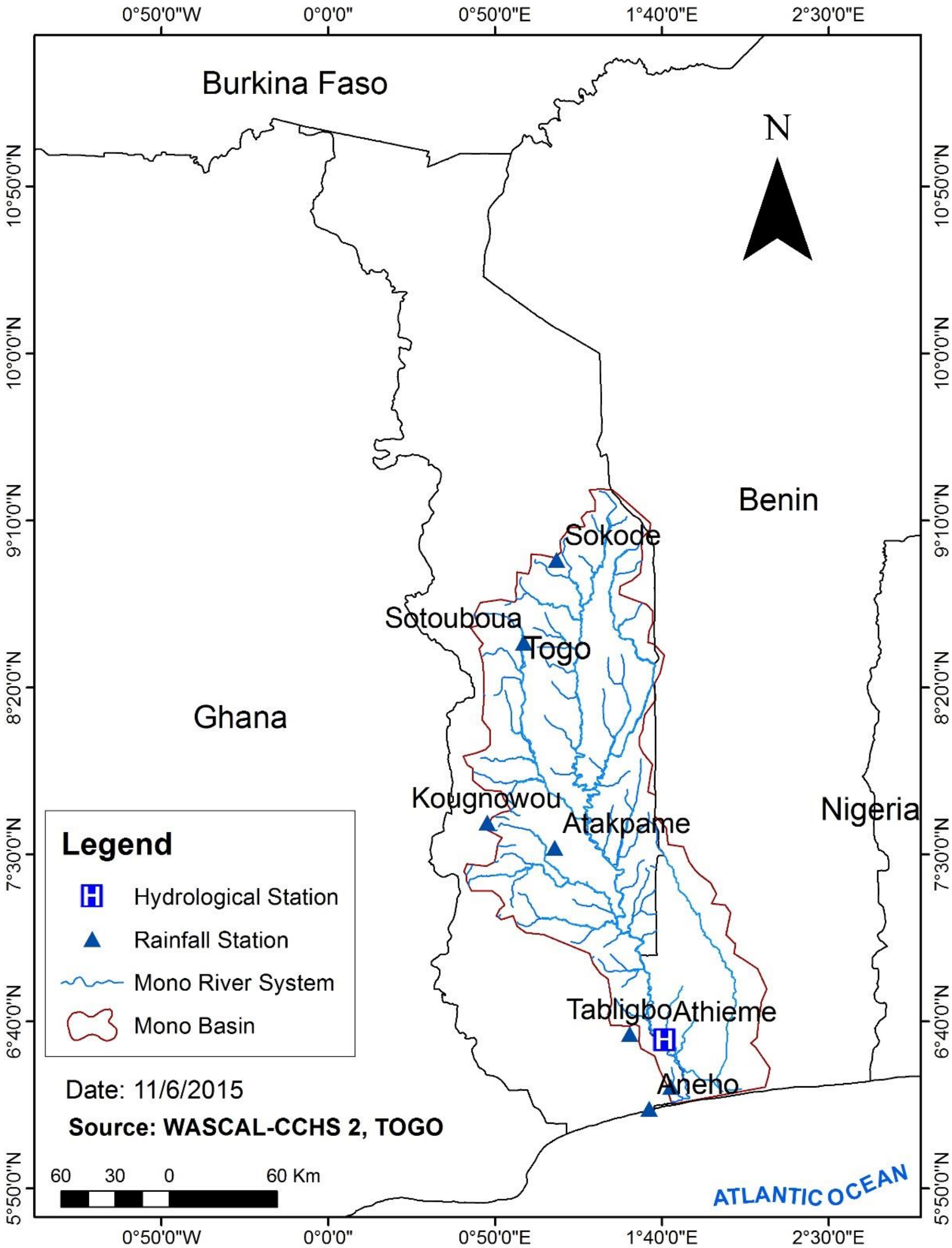
APPENDIX VI. Soil Map of the Lower Mono basin



Appendix VII. Stream Buffer Zone (500m)



APPENDIX VIII. Map of Togo showing the Mono River Basin and the selected rainfall stations



Appendix IX. Interview Guide

University of Lomé, Togo

Faculty of Arts and Humanities

Master of Science Degree Research Program

WASCAL

West African Science Service Centre on Climate Change and Adapted Land Use

This interview guide is designed strictly for academic purpose. You are assured of total confidentiality and anonymity. Your views are very important for this study.

Topic: Flood Disaster Risk Mapping in the Lower Mono River Basin in Togo

<u>Interview Guide</u>

1. What is your level of education? a). None [ ] b). primary [ ] secondary [ ] c). tertiary [ ]

2. What is the major occupation of people in this locality? a). Farming [ ] b). fishing [ ] c). petty trading [ ] d). other [ ] …..please specify……………………………………………………

3. Do you have an alternative source of livelihood? If yes, please specify

4. What is your average monthly income?

…………………………………………………………………

5. Is the daily expenditure of your household greater than CFA 500? Give your reason

……………………………………………………………………………………………………

6. How many people are under your care?

…………………………………………………………………………………………………….

7. What building materials was your house made of? …………………………………………………

8. What roofing materials did you use to roof your house? …………………………………………

9. Will you say that climate has changed over the past 30 years?

a. Yes [ ] b. No [ ] …………….Please give your reason

10. Do you think that the amount of rainfall has increased over the past 30 years?

11. What do you think are the causes of flooding in your locality?

a. Extreme high rainfall [ ] b. Opening of Nangbeto dam [ ] 3. Sedimentation of the river [ ]

12. Do you think the frequency of occurrence of flooding has increased over the past 30 years? If yes please explain…………………………………………………………………………

13. Flood duration (what is the average number of days floodwater stays in the area?)

a. 20-30 [ ] b). 31-40 [ ] c). 41-50 [ ] d). 51-60 [ ] e). 61- 70 [ ] f). 70- 90 [ ]

14. How were you affected by the impacts of flooding?

15. Do floods often affect your household field crops? If yes how?

16. How far (in km) is your farmland from a water body?..

17. Why do you think your community was or is more affected than any other communities?

18. How do you deal with flood occurrences and the effects?

19. What are the good impacts of flooding in your area?

……………………………………………………………………………………………

20. What will you say is the worst impact of flood in your community?....................................

21. Do you have access to early warning system? a). Yes [ ] b. No [ ]

22. What local early warning system have you identified? ……………………………………….

23. Do you have access to meteorological data? a). Yes [ ] b. No [ ]

24. Do you have access to health service? a). Yes [ ] b. No [ ]

25. Is your community aware of flood disaster?

26. Do you have access to financial aid to face flood disaster?

27. Do you have means of evacuation? What evacuation facilities are available in your community? ………………………………………………………………………..

28. Have you been trained to deal with flood hazards before the arrival of relief organizations?

29. Which relief organizations assisted you to deal with flood disaster?

……………………………………………………………………….

30. Is there a flood disaster management program in the Lacs District?

31. How do you think the community can help itself in managing floods?

Other activities carried out on the field

1. Estimate the distance of houses and farmlands from water bodies
2. Observe the Mono River dynamics (level of water at different times)
3. Take coordinates of important points and elements (with a GPS)
4. Measure the depth of floodwater as indicated on the walls of building, trees etc.
5. Assess the availability of early warning systems
6. Observe the physical infrastructure (building codes & roads, Health centers, Markets)
7. Observe the soil types in all the communities
8. Observe land cover types and land use in the area
9. Observe drainage systems