FLOOD ANALYSIS AND SOCIO-ECONOMIC IMPACTS ON HOUSEHOLDS IN NORTHERN BAHR El Ghazal STATE OF SOUTH SUDAN USING GIS AND SWAT MODEL

By

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DECLARATION

This thesis is my original work and it has never been submitted for degree award in any other University.

………………………………………….. Date….………………………

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This thesis has been submitted for degree award with our approval as University of Nairobi Supervisors.

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DEDICATION

I dedicate this work to my late wife Amel Kuol Deng Kuol and to my little Angel my daughter Nima.

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LIST OF ACRONYMS

ARS	US Department of Agriculture - Agricultural Research Service
CCPSSA	Commissariat Chargé de la Protection Socialeet de la Sécurité Alimentaire
CRED	Centre for Research on the Epidemiology of Disasters
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GHACOF	Greater Horn of Africa Climate Outlook Forum
GIS	Geographical Information System
HEC	Hydrologic Engineering Center
HRU	Hydrologic Response Units
HSPF	Hydrological Simulation Program-FORTRAN
HUMUS	The Hydrologic Unit Model for the United States
HYMO	Hydrological Model
IPCC	Inter-governmental Panel on Climate Change
LU/LC	Land Use / Land Cover
NBG	Northern Bahr El Ghazal
NCEP	National Centers for Environment Prediction
NCAR	National Center for Atmospheric Research
NGOs	Non-governmental Organizations
SHE	Systeme Hydrologique European
SPI	The Standardized Precipitation Index
SPSS	Statistical Package for Social Sciences
SSARR	Streamflow Synthesis and Reservoir Regulation
SSNBS	South Sudan National Bureau of Statistics
sq km	Square Kilometer
SWAT	Water and Soil Assessment Tool
USGS	United States Geological Survey
UTM	Universal Transverse Mercator
WGS84	World Geodetic System

ABSTRACT

Flood is one of the facets of hydrometeorological cycle that tend to affect human activities disproportionately and the impacts tends to be more in the under-developed countries as they are relatively more vulnerable to flood events than the developed countries. One of the main elements in flood analysis is precipitation especially when estimated rainfall data from model distribution are verified by existing rain gauge stations data. Modeling of rainfall area-average distribution and assessing the slopes of the flood prone areas to analyze flood events in areas with no observation stations is crucial for disaster warning because rainfall data often obtained from rain gauge networks sometimes do not represent the area of study. In areas lacking meteorological records such as northern Bahr El Gazaal in South Sudan, the use the SWAT Model rainfall output data to investigate flood events after verifying the SWAT rainfall output consistency with the available rain gauges as used in this study is recommended. The main objective of this study was to determine the flood situation in Northern Bahr El Ghazal State of South Sudan using SWAT model and statistical data analysis techniques.

The SWAT model outputs accuracies are determined by the input data set quality such as the spatial and temporal resolution of the input data. In this study, the influence of precipitation data on the hydrological modeling was considered as most significant input data set. The globally gridded high resolution precipitation datasets from NCEP/NCAR, the 30m DEM, 1 km spatial resolution of land use shapefile and 10 km spatial resolution of soil shapefiles were the main input in the SWAT model simulation for the period 1980 to 2013. The double mass curve method was used to verify the SWAT model rainfall data output with the available five rain gauge stations. The Standard Precipitation Index (SPI) was used to determine flood episodes while statistical tests of differences and associations were used to measure impacts at household level.

The SPI values indicated that there occurred excessively humid periods with seven wet cycles starting from 2002 and at least four flooding events occurring in 2007 (2.2 SPI index), 2008 (1.82 SPI index), 2010 (1.62 SPI index) and 2012 (1.49 SPI index) respectively. The abundance of water for flooding were related to trends of increased rainfall events in the last decades and this was in line with what had been reported in other literature that there were indications of increase in the annual rainfall in the area. The surface characteristics of the study area were found to be one of the major factors in floods of Northern Bar El Ghazal. On the socio-economic impacts, it was found that most household had experienced flood and that the most severe flood condition in the last seven years was reported in 2007. Damages to housing units due to flooding were generally the results of poor quality of housing structures. Other flood damages included displacement, health problem, damage to crops and loss of properties. In conclusion, the study established that flooding in Northern Bahr El Gazal tended to cause more damages largely due to topography, soils and location interactions with hydro-climatic inputs and that SWAT model could be a very useful tool in flood management. The recommendation of the study was that simple activities like widening the water channel to accelerate the release of the inundated water be regularly conducted to reduce the flood impacts.

CHAPTER ONE

1.0 INTRODUCTION

1.1Background

Floods are natural phenomena's which occur in almost every country and a flood episode occurs when water masses overspill on lands which normally are not submerged. Broadly, floods major causes can be physical, such as climate factors and anthropogenic activities such as reduction of forest through cutting trees and land use changes. Generally, flood can be caused by two main factors, physical factors which include extended rainfall which last for days, weeks sometimes months of prolonged rainfall causes river banks to overflow due to excessive water. This is one of the key causes of floods in many countries around the world. Among other factors that can contribute to floods snow melt. Factors that have direct impacts on flood behavior and magnitudes are such as influencing river catchments and Land use changes which caused by human. Specifically deforestation leads to an escalation run-off and erosion, therefore decrease in channel capacity as a results of excessive sediment rate (Nott, 2006a). Moreover, floods can occur as a frequent event and on seasonal bases. Heavy seasonal rainfall activity or high water levels in rivers and other large water masses cause the seasonal flood events. When rain falls within a short period onto dry, hard ground such that water fails to penetrate; this causes flash floods. Flooding ranges from small to pools of water over wide areas of land(WMO, 2006).

Human induce impacts on climate change are also considered to be one of the significant factors which cause floods; over the history of the earth, there were considerable changes on climate due to natural reasons, but in recent 50-100 years there have been an acceleration of these changes such as the general warming than ever seen before in records. Presently, (IPCC, 2013) finds that dominant cause of this rapid warming is "extremely likely" due to human activity. On the other hand there are significant challenges imposed on our life style on earth due to climate change. The relatively recent increase of human populations and huge industrial and agricultural revolution which lead to disproportionate activates on deforestation and fossil fuels burning (oil, gas and coal) higher quantities of Greenhouse Gases has been released and at rate that much more exceeding natural processes. This has led to the disruption of atmospheric gases natural balance disrupting the natural balance, generating general trends of increasing earth surface heat-trapping and warming.

Because large-scale distribution of gases are easy done through atmospheric circulations, Because gases are easily distributed through large-scale atmospheric circulation, when the whole planet is trapped by the heat affects this referred as 'global warming' man-made activities are considered to be climate change foremost driving factor. climatic change is also considered being the main contributor to floods in the world (IPCC, 2013).

Floods have many effects; it also considered to be very destructive and of all natural hazards covers wide range. Floods are responsible for deaths, economic devastation, and disease outbreaks. Developing countries communities are more vulnerable to flood hazards particularly the least developing countries, it take many years to elevate their weaknesses and recover their economic growth and social welfare. Therefore, flood is one of the major natural hazard as long as human life and/or property are threaten. Property physical damage is one of the main floods tangible losses. Some impacts are very hard to be placed with monetary figure such as psychological and emotional health problem that people affected by flood could suffer (Nott, 2006). People affected by flood are vulnerable to social impact such as life style changes in addition to culture, community and political systems changes plus health and environmental changes. it also interfere with their aspirations (Mwape, 2009). Floods become disastrous when they cause massive losses to a level that exceeds the affected community to overcome by their own resources (WMO, 2006).

The advance development remote sensing and the GIS techniques has made possible to simulate the functionality of watershed systems by using hydrological models on spatial and physical characteristics bases. These techniques provide powerful integrated tools for land use/land cover (LU/LC) monitoring and observing at regional as well as global scales. The use of (GIS) tools for change detection in watershed is very efficient and effective (Huang *et al*., 2012).The use of hydrological models was hindered by the unavailability of data especially in the developing countries (Fadil, 2011). Many Countries have used the SWAT model around the world and it is applicable for many purposes and it is applicable for a varied range of different environment (Arnold *et al.*, 2005).

Soil and Water Assessment Tool (SWAT) model is a river model which was developed by the department of agriculture and the Agricultural Research Service (ARS), Texas, in USA (Arnold *et al*., 1998).The physically based SWAT model is a continuous time, simulate for long term, lumped parameter as well as deterministic that was originated from agricultural models operate on daily time bases with parameters distributed spatially. Malutta & Kobiyama, 2011 suggested that the SWAT model is very useful tool which can be used flood study. They used the model to analyzed 1983 and 1992 flood events which considered to be were the largest floods in this city in Rio Negrinho city, Santa Catarina state in Brazil. The application of the SWAT model to the precipitation and discharge processes in the Negrinho River Basin the calibration and the validation of the model have shown the NASH 51 and R^2 53 for the model calibration and validation. It can be said that the model performance in the present study is acceptable. The water yield distribution analysis indicates that the larger flood can only be generated when the water yield in the whole parts of the basin is high and/or when the flood discharge dominates the surface flow.

SWAT model was used to simulate hydrology in the Rio Grande/Rio Bravo river basin (598,538 km2) located in parts of the United States and Mexico from 1960 to 1989 Srinivasan, *et al* (1997). The simulated flow rate annual average then compared against actual stream gage of USGS records. The model performance to be evaluates visual time-series plots and statistical techniques were used. Stream flow regression coefficients were of 0.96 and 0.71 at Otowi Bridge and Cochiti respectively. Nevertheless, the Hydrologic Unit Model (HUMUS) project used SWAT model to conduct an analysis at a national-scale level for the United States the quantity and quality of water managing scenarios effects the study demonstrates the usefulness of the application SWAT in flood analysis and prediction. In Kenya, SWAT model was also used to model Sondu river basin hydrology the model indicates that the model has high potential to be applied in African watersheds and points the model input data sets need to be developed in Africa for better and detailed studies on water resources. Spatial data are now increasingly available in virtually continual supply, which are gradually becoming a cost-effective source and can be used under a variety of circumstances. this study emphasize the use of SWAT it suit the study area which lack gauging data specially for discharge for this SWAT model is highly recommended in many published work (Jayakrishnan *et al.*, 2005). The main objective of the present study was to analyze flood events at a basin level.

SWAT model is used for different purposes such as the analysis of rainfall as well as water-yield in basins, the current study used SWAT model for purposes of analyzing flood in Northern Bahr El Ghazal state in South Sudan.

1.2 Statement of the Problem

In South Sudan, floods tend to result in flooding of houses, crop fields, health centers, markets and schools while damaging roads and bridges. This often affects relief services and result in increase in health risk, hunger, poverty and deaths. In Northern Bahr El Ghazal State, flood is one type of natural disaster that cannot be entirely avoided, but it is possible to decrease flood damages and losses. One possible way of reducing flood damages and losses is by providing information on flood which is required for better planning and flood protection. Precipitation could play an important role in analyzing flood events by using measured or rainfall data from model distribution once verified by existing rain gage stations data. Modeling of rainfall area-average distribution and assessing the slopes of the flood prone areas to analyze flood events in areas with no observation stations is crucial for disaster warning because rainfall data often obtained from rain gage networks which sometimes may not cover the study area.

Usually, rainfall data from the nearest gage stations or area-average distribution of rainfall by using hydrological modeling could be used as representative rainfall data for studying or analyzing existing hydrological events such as flood. However, in an unusual conditions such as in case of this study in South Sudan due to the lack of meteorological record stations, instate of considering rainfall data from next country gages which could be very far from the study area watershed, this study used the SWAT Model rainfall output data to investigate flood events in northern Bahr El Ghazal which has no gaging station after its consistency with the available rain gage stations in South Sudan has been verified. This study attempted to use hydrological models to estimate spatial distribution and to analyze floods events in Northern Bahr El Ghazal State. Attempt was made to determine the lands surface characteristics in term of slope, land use and soil types and their effect on flood occurrence as well as the probability of flood occurrence by using model simulated rainfall events, and to determine flood distribution at basin level in order to reduce losses and flood damages.

A flood spell can have an effect on regional and national economic development, with severe social and environmental impacts. There are concerns that current climate changes may intensify floods and droughts. In this context flood risk indicators are an indispensable tool for watershed management, monitoring, risk assessment, and civil protection. In addition, the study used SPI (Standardized Precipitation Index) as identification tool to measure the magnitude these events.

The hydrological model results were compared with the flood impacts at the household levels in Northern Bahr El Ghazal State to assist in rescaling the model to household level hydrological response a holistic hydrological model was created for the study area. The household information was used in the holistic model included the living condition, flood mitigations measures, household preparedness and flood perception in flood prone areas. The household information's were then being coupled with the flood spatial distribution and flood frequency to create the holistic flood model of Northern Bahr El Ghazal State of South Sudan. The results hydrological models were very useful in in describing the flood hazards sources in the Study area.

1.3 Research Questions

The specific questions were:

1. What are the land surface characteristics of Northern Bahr El Ghazal Catchments in term of slopes, Soil types and vegetation cover that affect flood frequency?
2. How suitable SWAT model in estimating floods spatial distribution in Northern Bahr El Ghazal State?
3. What is the flood magnitude base on SPI index?
4. What are the impacts of floods on the households and the coping mechanisms used by the households to reduce flood impacts in Northern Bahr El Ghazal State?

1.4 Objectives

The main objective was to analyze flood in Northern Bahr El Ghazal State in South Sudan by using SWAT hydrological model to simulate the hydrology of the study are basin such as rainfall, water-yield and the surface runoff . The specific objectives were to determine:

1. Flood occurrence based on the simulated rainfall and water-yield of SWAT model on monthly and/yearly time series.
2. Most problematic sub basin with respect to water-yield and surface runoff.
3. Flood impacts of on Households
4. The coping mechanisms used by households to reduce flood impacts.

1.5 Hypothesis

1. The SWAT simulated rainfall and water yield do not provide good approximation of flood occurrence in the study area.
2. The SWAT model water yield estimations do not uniquely identify most problematic sub basins in the study area.
3. Flood frequency and flood inundation have no impact on households in the study area.
4. The coping mechanisms used by the households do effectively reduce flood induced effects in the study area.

1.6 Justification of the Study

Most recently, The Greater Horn of Africa Climate Outlook Forum (GHACOF) in most of its annual reports has reported that South Sudan will experience above normal rains (GHACOF, 2012). Given its geographic location, South Sudan has been affected by an increase in flooding over the recent past. The floods frequency in the South Sudan has increased in the last two decades; 1996, 1997, 2007, 2008, 2010 and 2013 witnessed flood incidences of relatively high intensities (SSMS, 2013).This to a great extend emphasize the investigation of flood and to come up with spatial representation of the flood phenomena in South Sudan, therefore the study attempted to define the most problematic and vulnerable areas to recommend for minimizing these expected above normal rainfall events to reduce the negative impacts of flood in Northern Bahr El Ghazal state.

Interpretation of flood is central to study. The digital models of topographical elevation data form an integral part of geographic information systems (GIS) which is commonly in use for hydrological modeling especially in flood simulation as well as watersheds and drainage networks. The expected output of this study in form of information about the flood areas such as the amount of water-yield, the slope characteristic and it is effect on flood formation and water inundation, and detecting these areas vulnerable to floods will be of great value for decision makers in flood management practices such as assessing and planning to develop an efficient structural and non-structural flood control strategies. Furthermore an appropriate decision support base on effective methodology as well as availability of data were developed in this study to come up with appropriate recommendations based on a scientific facts as a result of detailed analysis. The identification and relationship of the spatial extend to hazard and damage function as trail to reduce human loss and damages of properties were considered to eradicate impacts such as poverty that arising from flood damage.

1.7 Scope and Limitation of the Study

The study focused on analyzing flood in the study area by using hydrological modeling and different techniques such as and Geographical Information System ArcMap10.2 and ArcSWAT was used as tools to run SWAT hydrological model to identify flood spatial extent, watershed characteristic and extract terrain and physical feature of study area. Due lack of robust station data over in the region and in South Sudan in general and to overcome the unavailability of rainfall data due to deterioration of the existing stations because of war SWAT model redistributed rainfall data were used which are originally originated from NCEP/NCAR has been acknowledged in literature as the best available Gridded high resolution precipitation datasets. The NCEP/NCAR Reanalysis data set is a continually updated (1948–present) globally gridded data set that represents the state of the Earth's atmosphere, incorporating observations and numerical weather prediction (NWP) model output from 1948 to present. It is a joint product from the National Centers for Environmental Prediction (NCEP) and the National Center for Atmospheric Research (NCAR).

Before the use of the redistributed NCEP/NCAR rainfall data by SWAT model to analyze flood the SWAT rainfall out put were first validated by using the rainfall station available in South Sudan for validation because the study used only these rainfall and the simulated water-yield data to analyze flood because of the lock of the discharge data in the study area. Discharge data basically used in SWAT model validation but in this study the model has not been validated because there were no discharge observation data; therefore, field work was carried out to validate the findings in this study also the rainfall data was used for more verification of the results. Furthermore, these rainfall data were also used as base for the analysis of the flood events by using the SPI index. The study also covered the flood impact at household level in Northern Bahr El Ghazal State. The variables to be considered are flood frequency, spatial extend of flood, flood inundation, and flood impacts on the community. The main limitation of the study due to the lack of any discharge data calibration and validation were not done, but comparing the field work survey data to validate SWAT output such as surface water level and water-yield level were done. The study was limited to Northern Bahr El Ghazal State and the area covered by the SWAT model delineations.

1.8 Operational Definitions

Flood mitigation: Represents developing flood management and sustainable development models, by paying more attention for flood prediction to reduce lost rather than focusing on emergency relief delivery after flood catastrophes aftermath.

Flood risk reduction: Is the process of eliminating both the source of the hazard and the vulnerable conditions when possible.

Flood: Is when land which normally not covered by water is submerged by water.

Geographic Information Systems (GIS): Is a tool based on a computer used for analyzing, storing as well as manipulating geographic information to visualize them in a map.

Preparedness: Is when the government use its built knowledge developed capacities, in addition to the collaborative work of the organizations which are professional in recovery response to effectively enable the community to anticipate, response and recover from an impact or imminent or current event or hazardous condition.

Remote Sensing: Means the sensing of the Earth's surface from space by making use of the properties of electromagnetic waves emitted, reflected or diffracted by the sensed objects, for the purpose of improving natural resources management, land use and the protection of the environment."

Resilience: Is the capacity of a system, society or community that is exposed to hazardous event to able to resist, absorb, withstand and recover from the hazard effects in an efficient time manner, including restoration and preservation of the community essential basic function and structures.

Response: The provision of emergency services and public assistance during or immediately after a disaster in order to save lives reduces health impacts, ensure public safety and meet the basic subsistence needs of the people affected.

Watershed: Is a landform (basin-like) defined by descended highpoints and ridgelines into lower elevations and stream valleys. When it rains or/ snow watershed conveys water "shed" from the land. Every drop of water is taken into soils, creeks, groundwater, and streams to larger rivers and ultimately the sea.

CHAPTER TWO

2.0 LITERATURE REVIEW AND CONCEPTUAL FRAMEWORK

2.1 The Global Disasters

Natural disasters continue to happen and impact on people all over the world. Centre for Research on the Epidemiology of Disasters (CRED, 2013) the collected data through the emergency event database (EM-DAT) concluded that there is an exponential increase of natural disaster from 1900-2011 (see figure 2.1).

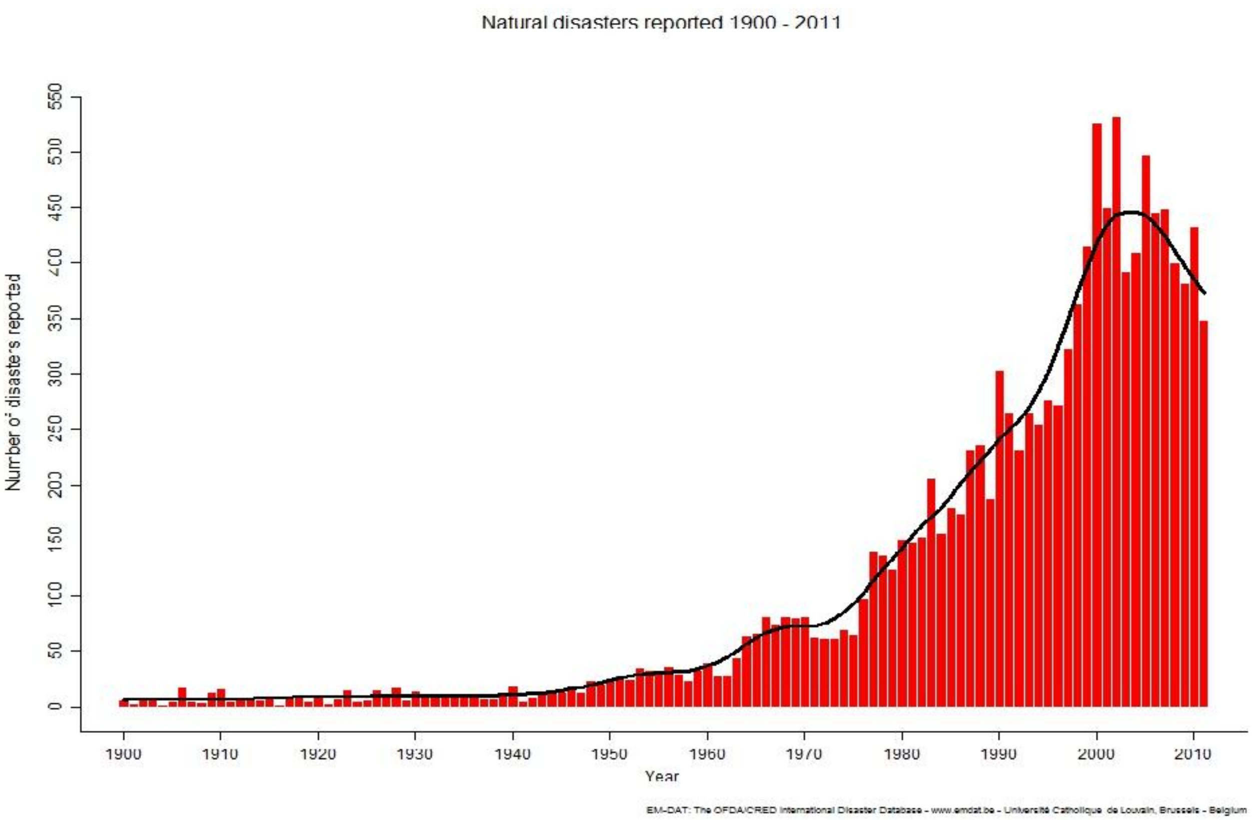


Figure 2.1: Natural Disaster Reports 1900-2011 (CRED, 2013)

Source: CRED 2013

As from 1975, the global occurrence of disaster rose from about 75 to over 400 a year. For instance, the number of hydro-meteorological (weather-related events) disasters went up by more than 100 percent in 2004 to range between 200 in 2006(UN/ISDR, 2008).

Reports from World Meteorological Organization (WMO) For instance, indicate more than 17 million human being in more than 80 countries has suffered from hardship in the last decade. Nevertheless, (UNESCO, 2010) reported that about 3,000 people died in addition to nearly forty billion US dollars is the estimated amount of the property damage. The rise of the disaster occurrence especially flood was attributed to the increasing number of climate relate disasters. In the period of 2000 to 2007, people who were affected by disasters were almost about 230 million or more around the world. The factors that led to increase in disaster losses were increased weather events such as climate change related along with population growth and degradation of the environment (Global Humanitarian Forum, 2009). However, the increase in the population growth is one of the main factors that lead to environmental degradation through anthropogenic activity as one of the major causes of flood disasters around the world. See Appendix (I) The rise in flood among other natural disasters.

The Working Group I in their report to the Intergovernmental Panel on Climate Change (IPCC), projected that the will be an increase of about 1.4 C^0 and 5.8 C^0 of the global average of the surface air temperature as from 1990 to 2100 (Houghton JT *et al.*, 2001). As more scientific evidence and proves, increasingly global warming certainty seen as a reality. Therefore, climate system changes should be adopted at different levels (Adger, 1999). There are more evidence prove that climate change is the potential reason to cause an increase in hazards related to floods in many regions of the world. Particularly, the El Niño/La Niña phenomena, or likely weather extremes may be intensify (Penning-Rowsell, 1996). Flood risk was predicted as one of the widespread adverse effects of human (Ahmad *et al.*, 2001). Recent studies of climatic modeling shows that some areas will witness an increase in precipitation predominantly monsoonal regions accompanied by changes on extreme events frequency and intensity(Few, 2003a). Evidence from empirical studies showing changes in flood frequency due to climatic change therefore exist and such evidence inform the present research objectives in investigating flood. Weather data collected in the northern hemisphere at more than six thousand weather stations from 1951 to 1999 has been analyzed and the outputs were compared with numerous climate models scientists have found that man-made carbon dioxide emissions have caused warming which has increased the intensity of precipitation episodes from 1-to 5 days long across many countries. Finally, by feeding in the rainfall values using some models flooding potential was assessed (Min *et al.*, 2011).

According to (UNESCO, 2010) factors such as epitomized environmental degradation posed by deforestation along with biodiversity loss, reduction in water supply as well as desertification lead to an increase the risks of disasters related to climate change such as flash flood which sometimes leads to land-slides. These socio-economic factors such as land use changes are the main drivers to floods and landslides. Anthropogenic factors such as changes on the drainage systems, Grassland to arable farming schemes and soil top layer changes can increase runoff and occurrence of flooding. Also, decreases in vegetation in the ridged slopes can cause an increase in landslide and flood activities. On the other hand, extended floodwater inundation in flood zone areas increases the potential of soil degradation and susceptible to landslides.

Flash floods are expected to be among the highest to increase amongst environmental-related disasters. Among all the disasters related to environmental changes flash floods considered to be having the higher probability to increase in the coming decades. Flash floods are also referred to as of all natural disasters the most destructive. Their catastrophic consequences includes financial losses, houses and agricultural lands destruction, casualties, losses on livestock and loss of human lives. Nevertheless, great damages to the infrastructures such as public services utilities (road, bridges, electricity, transportations and communications, etc.), and enormous landslides. This also prompts this study to examine the flood impact and the spatial distribution of floods by using Hydrological modeling such as Soil and Water Assessment tool (SWAT)to estimate flood so that household in South Sudan be to prepare to flood with the increased level of flood phenomena.

2.1.1 Impacts of Natural Disasters

According to (Noji, 1997), among all the 20th century greatest disasters, the death toll of floods is four out of 65 with 194,000 deaths and hurricanes16 and (499,000) deaths, Earthquakes 28 and 450,000 deaths. Volcanic eruptions among the other significant hazards of the natural disasters with 9 and 9,000 deaths, landslides and 5,000 deaths, and tsunamis 3 and 5,000 deaths. There is variation based on the country for example developing countries such as Asia, Africa, and countries of South America accounting of number of lives lost from 1966 to 1990 are in the top 20th position. Subsequently natural disasters took of about 58,000 lives each year and another 225 million people were affected. Furthermore, natural hazards cause to of about 100,000 loss of lives in every year. In worldwide, by the year 2050 the natural disaster annual cost is projected to go beyond $300 billion per annum(SEI, IUCN, 2001), if climate change impact such as flood and it has not been opposed with aggressive measures of disaster reduction, natural environmental hazards such as flood in particular can cause deaths, economic devastation, and disease outbreaks can go largely unobserved. Flash floods which is very common around world, in African countries in specific they are caused by intensive rainfall which relatively has short duration. In the last 40 years there is significant increase in flash floods frequency and magnitude evidentially as a result of global climate change sensed around the globe.

Some of the main factors which are aggravating and intensifying flooding in most of the countries are related to some technical planning reasons for instance, inadequate land use planning, bad zoning, others are related to inappropriate agricultural activates such as plugging up and down a hill rather than along the contours), deforestation etc. Factors related to populations pressures such as planning of human settlement on flood plains. These factors in most of the countries are behind flooding to be as such tragedies and disastrous (UNESCO, 2010).

Flood can be caused by either one of the following: mainly when rivers overflow, seasonal prolonged rainfall, rainstorm and reservoirs or dam break. Other factors includes rainwater accumulation in relatively low lying areas with inadequate storm drainage or high water table and /or seawater intrusion during cyclones or tidal surge on to land. Convictional storms may cause flash flood over small basins while seasonal semi-predictable rains which cover wide geographical areas can cause an increase on the annual monsoonal floods in some tropical areas. The flood onset speed, duration and magnitude could be then influenced by topography, soil and vegetation types as well as river channel and land use and/or urbanization. Urbanization in particular worsen flood by accelerating flood onset speed and duration also by reducing the ground surface permeability which leads runoff rates to increase as a result flooding could take different form from steady water logging off ground to a catastrophic flood events that overwhelm the coping mechanisms and create disasters. Low-lying flood plain inundation nearby major rivers can be both long in duration and widespread. The case of the river system of the Ganges–Brahmaputra–Megna in Bangladesh is so dramatic where 110 million people are vulnerable. On southern Asia’s floodplain most river system are prone to flood but settlements in small river basins and along low-lying shorelines are at a great risks as subject to sudden flash floods where storm surges associated with cyclones with several meters depth that can produce by sea flooding(Few, 2003).

2.1.2 Flood Disasters

During last year's flood disasters created widespread environmental socio-economics destructions in many countries around the world. Floods resulted in natural landscape reshaping, waterways and reservoirs sedimentations, lakes ecosystems disruption, drinking water contamination, invading houses with mudflows, embankments and terraces failure, farmlands and roadways dislodged with eroded materials, properties damage as well as severe damage to the sewerage water, telephone lines and power station (Bou *et al*., 2006)(Bou Kheir, Cerdan and Abdallah, 2006). Albergel *et al.*, (2004) reported that between 1994 and 2002 three floods events arisen the sedimentation of Kamech dam in Tunisia for about 50%.

Furthermore, flood disasters has led to many casualties both injuries and deaths, socio-demographic modifications (people shifting from place to another), socio-politics deviations (political disruption as a result of social activism). Floods also result in long-term impacts which are difficult to assess because they develop after long period of time such as psychosocial stress which includes emotional signs for example anxiety, despair, and sorrow. Besides, effects on behavior such as changes in appetite and sleeplessness, ritual behavioral changes and substance exploitation. In general, observed effects were in most cases minor and temporary. Psychiatric attention found to be required by few victims of the disaster but the majority need crises counseling instate of mental health treatment especially if their usual social support links of friends, relatives, neighbors and workmates remain largely undamaged. Yet, there is a portion of population that will have need of special care and active outreach. These include children, elderly people, and people with previous mental illness, minorities groups, and families who lost their loved once in the disaster. Although, special attention should be also given to the emergency staffs because they often work without rest for long hours and they usually witnessed terrible sights, also organization workers because they involve in emotional discussions that can be considered as a sign of weakness(Rubin, 1985).

The direct socio-economic losses caused by flooding disaster which considered as damage of properties can be referred as asset value loss measured as cost of repair or replacement. Whereas instant economic damages refer to all cost to fix assets, capital, and the costs of the finished and semi-finished goods as well as raw materials and spare parts. These also include complete or partial destruction of physical structures, buildings, furniture, equipment or machineries, transportation and storage facilities as well as damage to farmland soils, irrigation and drainage works such as dams and etc. In case of agriculture, the destruction of crops which are ready to be harvested is considered to be a direct damage. Indirect damage of economic refers to flow of goods destruction such as products that will not be manufactured and of services that will not be delivered when flooding disaster hits.

The period of time to cover from a flooding disaster begins instantaneously afterward the disaster and may last a number of months or years, conditional to the characteristics of the flooding disaster. Secondary economic effects are the impacts of the flooding disaster on the performance of the country overall measured by the most substantial macroeconomic variables. The changes estimated in these variables complement the estimated of direct and indirect costs caused by the disaster, although they cannot be added to express the total expense of loss imposed (Lindell *et al*., 2003).

On top of the flowing water physical threat, flood events can cause an increased risk of water-borne pathogens as well as insect infections and snakebite. On the other hand, the spread of the contaminated waste water by floods may lead to disease outbreaks, drinking water supply infection in addition to inundation of water in low lying lands which creates mosquitos' breeding ground which can cause malaria outbreak. For example, floods of 2000 in Mozambique, has led to the infection of drinking water in the capital (Maputo) caused by the interference of sewerage systems triggering outbreak of dysentery and cholera. Another study of flood hazards in Manila, Philippines, reported that flooded people are more likely vulnerable to diseases such as respiratory infections, gastro-intestinal illnesses and allergies of skin, children most likely to be at risk. Concluded that the environmental health problems such as poor sanitation systems, blockage of the drainage system channels by damping of solid waste greatly increase the infections (Few 2003 et al).

Outbreak of malaria and typhoid are also very common in tropical regions after flood events.
There are more than 300 million people live in flood affected areas in India and Bangladesh according to estimates (Nott, 2006). Other studies argue flood events of a lower magnitude but more frequent can still results in severe destruction and disturbance by damaging crops which can

lead to food scarcities, disrupting access to services by damaging infrastructure, business activities suspension nevertheless intensifying health risks at home and local environment. Moreover, as long as floodwaters are persistence that means people may continue to suffer from these hazards for prolonged period of time. In Most of developing countries inhabitants of low-income do not have a choice of moving somewhere else when waters recede. Even during extreme flood events, they normally don’t move far away from their former and homes. And in many cases displaced people were accommodated in local schools such as Mozambique devastating flood in 2000 (Few, 2003). The thesis investigated the impact of floods on the community in Northern Bahr El Ghazal during the last years.

2.1.3 Regional Flood Disasters

Algeria flash floods 2001 reported to be the most overwhelming in the last four decades according to (UNESCO, 2010). There were over 700 peoples lost their lives and more than 300 people were injured, more than 1,600 people were reported missing, more than one thousand houses were totally damaged about fifty schools and many bridges were demolished. The estimated total of the damage cost was over $250 m. In Morocco December 2001, about 15 people lost their lives when serious flood hit the country. The damaged caused was estimated at about $1.75 m, and dozens of peoples were left without homes. Muscat, Oman in April 2003, about 14 people died by major floods causing severe damage to the properties, power stations and removal of trees from their roots.

In Mauritania August 2007 more than 3,000 people have been forced to leave their houses when Titane town was totally flooded, the water level was about two meters height. This flooding incidence has been reported as the worst in term of intensity and the areas has been covered in the region in the last 50 years. Many people have lost their lives and many others reported sustained serious injuries as a result of falling walls and the speedy crossing water. A dam breakdown has been reported as a result of the heavy rains destroying more than one thousand date palm trees.

The total cost of the damage of the schools, health facilities as well as other infrastructures have been estimated in billions according to reports by IRIN news 9 August 2007. Before people could recover from early August flood events hundreds of families have been affected by more heavy rainstorms at the end of the same month of August 2007 Gorgol and Assaba of the southern region reported by WFP and CCPSSA. In September 2009 a huge population displacements occurred in the cities of Rosso, Nouakchott and Kaédi as a result of a serious flash floods provisional shelters have been provided to more than three thousand people in the higher ground 7 km north Rosso city Around 3700 people have been camping in provisional shelters 7 kilometers north of Rosso city of Mauritania.

Yemen Floods, in the city of Taiz $2.7 m have been estimated as an average annual damage of flood events mostly destruction of properties and houses and shops missing stocks. Heavy rains October 2008 in Yemen one of the very disastrous rainstorms covered nearly all the provinces in Yemen took a life of more than 180 people an estimate of 20,000 people were left without shelter. Furthermore, more than two thousands houses were totally destroyed in addition to that destruction of power, water and phone lines as well as roads. The government of Yemen has failed to send aid immediately to these most horrible hit areas. However, when governmental help is not completely successful, the impact of such kind of serious flood events usually last for a long period of time. Because the reconstruction and the rehabilitation require a lot of funds and takes a long time to be completed. Also September 2009 in Tunisia southern regions, flash flood caused by heavy rains have took lives of about 17 people. Majority of the victims killed as a result of houses roofs and walls collapse. Others were drafted away by floodwaters which was more than six feet in some areas. Saudi Arabia’s floods events in November 2009 after very heavy rains the number of losses were estimated to about 150 individuals. Many victims have died while in their cars, either by crashing or drowning of the vehicles. There are many consequences such as the high recovery and relief costs which may seriously impact the development activities and the infrastructure rehabilitation, and in many cases the economy of the damage areas become fragile. On the other hand authorities may face public dissatisfaction or loss of trust in case the government response to such serious flood events in not effective in terms of relief operations.

Torrential downpours combined with flows from high rivers can lead to a severe flooding. Although, gauging with accurate reading at high flows is challenging. As in the case of flood flows in Lebanon which rise and fall in a short times, and most of the time contain amounts of sediment and fragments such as trees, boulders etc. Ali River floods in 1955, which have covered an area of about 400 square Km in Lebanon killing over 10 people and over 200 head of cattle in addition to houses and bridges destructions .Huge damages occurred in the inner rural areas of Zghorta and

Koura in Lebanon. Moreover in coastal in the city of Tripoli (Lebanon second largest city), where the river lies with many branches, over damages 100 km^2 were damaged, over 400 peoples were killed and about 200 families were homeless as well as citrus trees of thousands of acres were devastated, numbers of the city bridges have collapse.

Post the flood events, debris and sediments of about 1.5 m thick have accumulated in several markets as well as in the houses, and about 200 000 m^3 of sediments have been deposited in the river mouth has built a delta. In Libya, October 2002, heavy rains resulted in a severe flood caused extensive materials losses in many areas of the country.

Huge amounts of water of about 7,495,600 m3 were stored in Wadi al-Njeim dam and nearly 5,495,000 million m3 were held in QadiKaam dam. On 4 June 2002 the dam Dam of Zaizon located in Syria southwest part collapsed Zaizon village has been swept away, and additional four additional Syrian villages namely Al-Ziyara, Quarqoor, Tal-Wast and Msheek, were hit caused death to at least 21people in addition about 251 houses were damaged and the dam as totally destroyed (UNESCO, 2010).

Heavy rains followed by flash flood in Djibouti in April 2004 at least 114 people were killed in the bank of Ambouli river. Furthermore, houses iron roofs have been lifted the wind which was extremely strong and telephone pole were completely blown an estimate of about 10,000 people have lost their shelters and their properties. Somalia December 2006, was hit by the most devastated flooding in the recent history about, reported about 350,000 people alongside the riverine areas were either displaced inundated or otherwise extremely have been affected by the flooding catastrophes. The latter in the South and Central areas such as Juba Valley, Gedo, Hiran and Shabelle Valley Region the entire communities have been displaced, the villages were flooded, the granaries destroyed, roads were cut off, irrigation and flood structures damaged and thousands hectares of farmland were fully inundated.

Last not least, the town of Ghardaia in Algeria, October 2008, a massive rainstorm caused a seasonal river to flood of about 8 meters, this serious flooding caused death to about 29 people, at least 84persons were injured, and demolished around six hundred households including the UNESCO Heritage Site. A devastating flash floods in July and August 2007, have hit many parts Sudan including Darfur in the western part of Sudan and many cities in the southern part of Sudan

(Currently the Republic of South Sudan). In the modern history of Sudan this was the worst in living memory over 150,000 houses were partially or totally destroyed, at least 750,000 people were left without homes need shelters. Besides, around 365,000 people directly have been affected, leaving behind more than 64 dead and at least 335 people injured. The following highlights have been reported by the United Nations (UN, 2007b) (i) The destruction of at least 257 schools, over 56,000 children were left without basic education; (ii) Damage to 96,000 acres of crop , at least 12,000 livestock and around 16,000 chicken and (iii) outbreaks of waterborne disease continue in Some cities such as Gedaref and Kassala has suffered a severe waterborne disease outbreak resulting in a death of at least one person every two to three weeks on average (UNESCO, 2010).

2.3 Hydrological Modeling

Since the Stanford Watershed Model was developed (Crawford, 1966) it has marked the beginning of several models such as operational, lumped/conceptual models. For instance, SSARR by (Rockwood *et al.*, 1972), the Sacramento model by Burnash *et al.*, (1973), also (Williams *et al.*, 1973) established the HYMO hydrological model. Sugawara *et al*., (1976) developed the tank model, in 1981 the Hydrologic Engineering Center the first HEC-1 model was advanced. These models have used various equations to express their process at different stages of the model based on simplified laws of hydraulics and were others described by algebraic empirical equations, recently conceptual models to measure the various dynamics that contributes to the direct runoff have combined many techniques such as replenishment depletion and redistribution of the soil moisture. Soil moisture probability distribution has been used to develop many model from theories such as the model of ARNO (Todini, 2002), the TOPMODEL which has used the topographic index by (Moore *et al.*, 1981) and further developed by Beven *et al*., 1984 and (Zhao, 1984).

A new class of hydrological modeling which has been based mass conservation, energy in addition to momentum. These include models such as SHE by Abbott *et al*., (1986), IDHM developed by Beven *et al.*, (1987). Moreover, models such as FORTRAN developed by the Hydrological Simulation Program-FORTRAN (HSPF) which was under the sponsorship of the EPA (Johansen *et al.*, 1984) this model was very useful in hydrologic simulation and the processes of the water quality in both natural and man-made systems. HEC-1 is an example for model developed to simulate runoff of short-term by the US Army Corps of Engineers in 1981.

The most modern computer hardware and software advances such as the advanced debugging tools as in the GIS spatial analysis tool in addition to the high speed and the large system storages has made it possible for the simulations of the large areas large-area. In the past the development of a scale basin model was challenging in many ways because to get reasonable results when the management scenarios of a given land this requires systems which are computationally efficient that the capability of land management scenarios which gives reasonable results requires computationally efficient provided with sophisticated inputs can allow significant spatial detail in continuous time.

It is important that land use changes, stream flow as well as the sediment yield must be reflected by such models. Many of the available models are limited by the spatial scale which in general the output does not association adequately with land use management to assess the management approaches. They are in most cases models of single-event (Arnold *et al.*, 2005).

2.3.1 SWAT Model

The river basin SWAT model (Soil and Water Assessment Tool) which was develop by US Agriculture Department and Agricultural Research Services (ARS), Arnold *et al.,* (1998). The model which originated from agricultural models it operates on daily time steps and its parameters are spatially distributed. It is physically based, with a continuous time as well as lumped parameterized, deterministic and simulate long term physical processes. (Arnold *et al.*, 1995; Santhi *et al.*, 2001). SWAT model integrates features from several ARS models and is a direct extension to the Simulator for Water Resources in Rural Basins (SWRRB) model (Williams *et al*., 1985).

Various models have significantly contributed to SWAT model development such as (Chemicals, Runoff, and Erosion from Agricultural Management Systems) known as CREAMS (Knisel, 1980), the (Groundwater Loading Effects on Agricultural Management Systems) GLEAMS (Leonard *et al*., 1987), and the (Erosion-Productivity Impact Calculator) EPIC (Williams *et al.*, 1984). hydrological model SWAT attends to describe transformations of the numerous physical such as the alteration of the different forms of precipitation into runoff as well as to evapotranspiration (ET) and surface and lateral runoff (Arnold *et al*., 1998; Neitsch *et al.*, 2002; Arnold *et al.*, 2005).

The model computational ability and the continuous simulation capabilities over long periods of time make it unique. The weather, hydrology and soil temperature as well as plant growth parameters and land management are among the main components of the model. Basically, SWAT model divides the watershed into various sub-basins, which in the other hand are subdivided into several Hydrologic Response Units (HRUs) that homogeneous in term of soil characteristics, land use and have similar management practices. The percentages represented by the HRUs in the sub-basins area are not spatially characterized within the model simulation.

Conversely, the watershed can be divided into sub-basins based on the dominant characteristics of that particular sub-basin such as soil type, land use and the management's practices. Four storage volumes determine the water balance in each of the HRUs in the watershed includes from 0 to 2 meters snow and soil profile, accordingly from 2 to 20 meters represent shallow aquifer, and above 20 meters are considered deep aquifer. The loads of each HRU in the watershed such as of the flow, sediment, nutrient, and pesticide are then summed and channeled through streams, water pools, and/or reservoirs to outlet of the watershed (Neitsch *et al.*, 2002).

2.3.2 SWAT Model Data Quality

The quality of the input data may to certain levels affects the precision of the model prediction of total area of the delineated. For instance, the resolution quality of the DEM data which known as the Digital Elevation model is considered to be one of the key inputs of the model SWAT. The other fundamental input data is used to run the SWAT model include soil and land use/land cover data are required for the watershed delineation and to further divide the watershed into sub-watersheds according to its hydrologic response units (HRUs). The Digital Elevation Model (DEM) resolution quality is the most important input parameter to develop a well SWAT model (Gassman *et al.*, 2007). DEM affects the classification and the delineation of the watershed and stream network as well as the sub-basin in SWAT model. The effects also can extend to level whereby the HRUs and number of the sub-basin may be reduced. Also large errors in number of predicted streams and the sub-basin classification subsequently large error in the delineated watershed (Chaubey *et al.*, 2005).

2.3.3 Previous Applications of SWAT Model

SWAT model was developed as an operational model to assist the managers of the water resource in evaluating water supplies as well as non-point causes of pollution on the large river basins. The key objectives of the develop model were to sustain a continuous simulation time, basin erosion tractability, management of climate impacts and water quality monitoring. The model used to simulate the hydrologic major components and their interactions in simply and accurate way as possible. The hydrology and channel routine flood monitoring considers to be among the main component considered in SWAT model in the uplands (Arnold *et al.*, 2005).

SWAT model was used by (Srinivasan *et al.*, 1997) in the upper part of the Seco Greek Basin of about (114 km2) in Texas to simulate water transport .The delineation subdivided the watershed into 37 sub-basins and the rangeland was found to be the pre-dominate land use in the area. SWAT simulated monthly stream flow was compared measured monthly for a period of 20 months. The study reported that there were consistent correlations over the predicted surface runoff in the different seasons of the year. The model validation and calibration by comparing the measured values with the simulated values Nash-Sutcliffe $R^2 = 0.86$ and the predicted average monthly flow was only 12% lower than observed flow.

Stream-flow volume predictions by using SWAT of was tested by (Rosenthal *et al.*, 1995) for Colorado Lower River basin (8927 km2) in the city of Texas, USA. A geographic information system\ (GIS)-hydrologic model link was used to aid in forming input files. The input files were aided by the use of ArcGIS system to be linked to the hydrological model, then four stream gaging stations were used to simulate stream flow for nine years 60 watersheds were included in the location. The model was not calibrated and the model very closely simulated the monthly stream-flow, the regression coefficient was of 0.75 but during the extreme events the model underestimated the stream-flow. On other hand, the precipitation intensity was high and scattered, when excluding the two events the relationship of the regression decreased to 0.66, but with an increase of the slope to 0.87 and which is very significant.

The SWAT model was evaluated by (Bingner *et al.,* 1996) on Goodwin watershed in Greek with a (21.31 km2) area over 10 years period in Northern Mississippi. Each Stream measuring stations in the watershed were representative of at least one or two outlet in the sub-basin. The watershed land use was largely pasture and agricultural fields. The computed Nash-Sutcliffe values R^2 were around .080 between the observed monthly flow valuated the SWAT model using the Goodwin Creek Watershed (21.31 km2) located in northern Mississippi over a 10-year period. The watershed contained in-stream measuring stations, each representing an outlet of one or more sub-basins. The land use of the watershed was primarily pasture and cultivated field. The Nash-Sutcliffe coefficients, R^2, values computed were all around 0.80 of the monthly observed and the simulated monthly flow excluding only one station, which was in forest predominately.

Another study was carried in in Central Kentucky with a karst geology SWAT result close agreement of the measured stream flow and the simulated data of SWAT demonstrating the model can be an effective tool describing the monthly runoff for relatively small watershed (Spruill *et al.*, 2000). Meanwhile in many regions around the world SWAT model was found to be flexible and applicable for simulation purposes on various environmental conditions on a wide range (Arnold and Fohrer, 2005).

2.4 The Conceptual Framework

Scientific research on flood including hydrological network systems and flood analysis plays a major role in flood disaster management at all the stages especially the pre-flood stage. The core works since most of the flood managing practices are depending on flood information. Flood prediction must recognize the end-user such as the community and the other stakeholders who participate in the different stages of flood management. Using geo-database for flood rainfall prediction and remote sensing such as DEM data as a main input data for SWAT model to help in investigate the floods and to map the floods spatial distribution to obtain thematic hazard maps which has the potential to assist in reducing loses and damages of floods. The floods physical impacts could be prevented by modifying the hazard occurrence through the management of the watershed which can be done effectively through the planning of the land use and flood zoning, and also in operations design & maintenance of flood defenses and drainage system when there is knowledge about flood frequency analysis and flood distribution.

Flood frequency plays a vital role in providing estimates of recurrence of floods which is used in designing structures such as dams, bridges, culverts, levees, highways, sewage disposal plants, waterworks and industrial buildings . In order to evaluate the optimum design specification for hydraulic structures, and to prevent over-designing or under designing flood frequency analysis is required. Hence, increase community of Northern Bahr El Ghazal readiness and resilience.

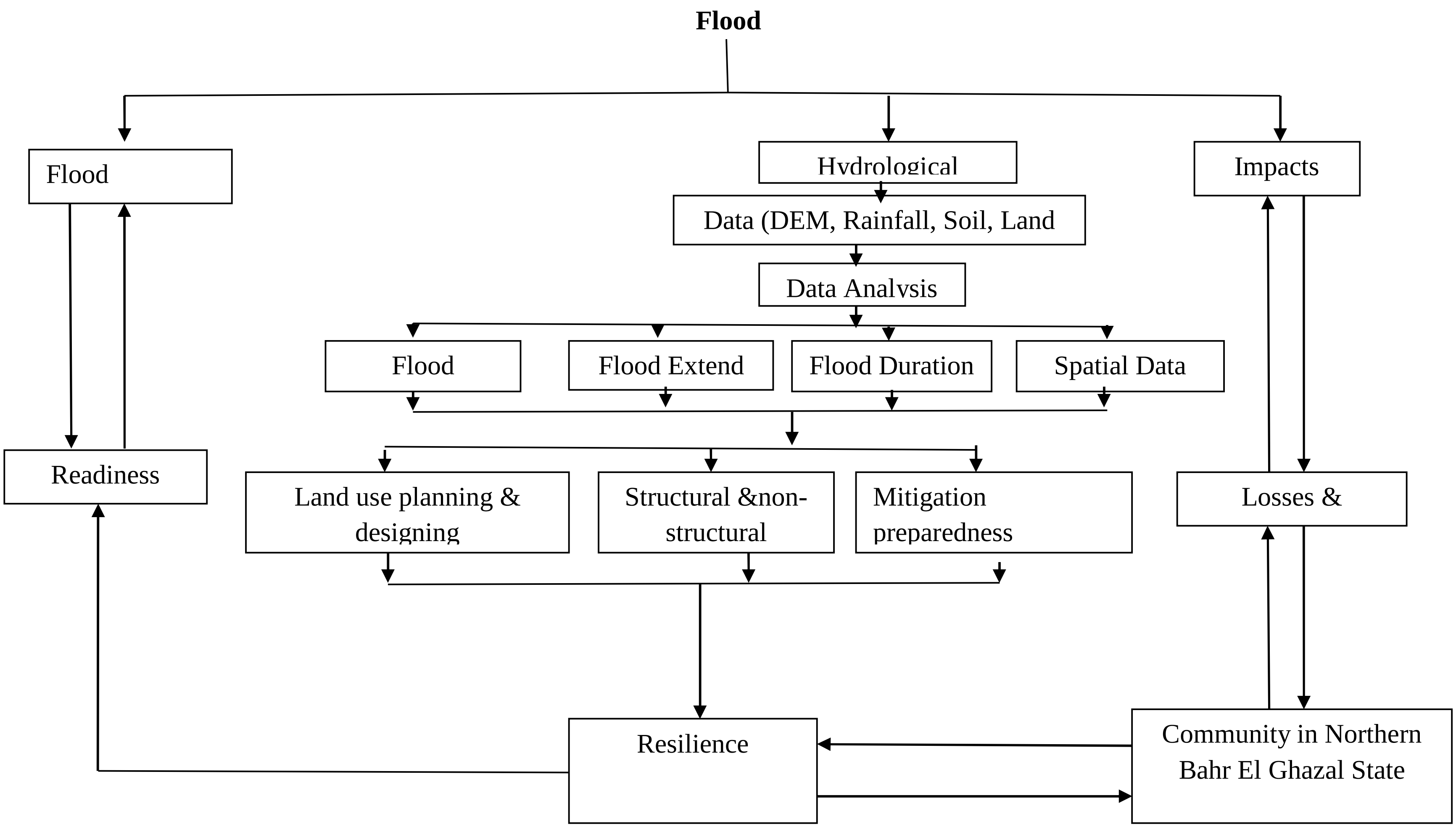


Figure 2.2: Conceptual Framework

Source: Compiled by Researcher, 2016

CHAPTER THREE

3.0 STUDY AREA

3.1 Location

The Northern Bahr El Ghazal is located in the northwestern part of South Sudan between latitude 06°52'37" N, longitude 031°18'.25" E, therefore within the tropical climate zone. It is bordering Republic of Sudan from the south, Western Bahr El Ghazal state to the west and south and Warrap State and Abyei region to the east. The name of the study area comes from the river Bahr El Ghazal. This location lies approximately 800 kilometers (500 mi), by road, northwest Juba the capital of South Sudan. Northern Bahr El Ghazal state covers an area of approximately 30,453.30km^2(11,758 sq mi) it mad of five counties as follows: Aweil North, Aweil East, Aweil West and Aweil South with Aweil town as the capital of the state.

3.2 Geology and Soils

South Sudan geology ranges from Precambrian crystalline basement rocks to quaternary unconsolidated alluvial deposits significant period of erosion during the Paleozoic and Mesozoic removed the majority of sedimentary cover deposited on crystalline basements during these times. Northern Bah El Ghazal State formed of unconsolidated sedimentary deposits Nile Alluvium wadi fill and swamp deposits , consist of well sorted silt and clay can be up to 60 m. The study area lies on in fertile land which can be very useful for agricultural purposes. It characterizes by loamy soils, clay as well as rocky soils which can be suitable for growing a variety of crops such as maize, sorghum, groundnuts, sesame, beans, okra, potatoes, cassava, water melons and tomatoes. Cassava which requires relatively simple land preparation practices. The soil temperature can be very convenient for cultivating fruit trees for instance mangos. The area conditions also considered ideal Pawpaw trees rapid growth.

3.3 Topography

The topography is flat and is prone to flooding, although the study area itself surrounding plains. The city lies close to the confluence The River Kuom flows from Central Africa through Western and Northern Bahr El Ghazal to Unity state and into the White Nile, the River Lol flows through Northern Bahr El Ghazal and crosses Gogrial West, The River Kiir from Darfur crosses Northern Bahr El Ghazal heading to Abyei region. The average elevation of the city of area is about 425 meters (1,394 ft.) above sea level.

3.4 Climate

The Study area characterizes by two seasons in a year savanna and tropical climates. Wet season are generally from April to late October the heavy rainfall experienced normally in May, June, July, August in addition to September. The dry season begins from December to March yearly. The study area catchment which is not gauged assumed to be varies between typical rainfall over the upper catchment is not well gauged, but it is assumed to varies between 1200 to1600 mm/yr, maximum and about 400mm/yr to 900 mm/yr minimum. The study area temperatures goes up to 36 C^0 in September and experience winter temperatures of the Northern hemisphere as from November to beginning of February.

3.5 Hydrology

The northern Bahr El Ghazal state can be sub-divided into three hydrologic zones based on groundwater heights and these are lowland, midland and highland zones respectively. The low lands are characterized by high water table and flooding in the rainy season from May to November. Hydrologic characteristic of mid-lands is that of availability of water throughout the year and the area is not prone to floods. The fertile highlands are have low water table and no access to water in the dry season.

There are three main rivers draining Northern Bah El Ghazal and these are river Kuom flowing from Central Africa through Western and Northern Bahr El Ghazal to Unity state and into the White Nile; river Lol flowing through Northern Bahr El Ghazal, across Gogrial West where it is called Akon’s River; river Kiir flowing from Darfur through Northern Bahr El Ghazal heading to Abyei region. There are several seasonal rivers in all counties of Northern Bahr El Ghazal which are sources of drinking water and livelihood.

3.6 Vegetation

The vegetation cover of the study area is largely of the savannah type characterized by grassland and woodland, tropical forest can be found in some parts as well. The lulu trees and acacia woodland are very common in the area in addition to the mahogany tress which are full of natural resources used as timbers and for other wood products. It is commonly used by local population for bee keeping, charcoal, wild fruits and oil that is produced from the of lulu tree.

3.7 Demographic

According to South Sudan National Bureau of Statistics the census conducted in 2008 population of Northern Bahr El Ghazal State are 720,898 of which 19% of the population was under the age of 5, and 53% under the age of 18 the average household has 6 members. This is marginally smaller than the average household in South Sudan which has 7 members, In Northern Bahr El Ghazal State the density of the population due to some studies is defined as 24people per square kilometer, which is approximately higher than the average of South Sudan which is 13 people per square km. Northern Bahr El Ghazal State is considered to be among the highest population density with 92% in comparison to the other 10 States forming the Republic of South Sudan. Out of the five counties forming NBGS Aweil East County has higher population density; Aweil South County comes in the second place. This requires more service establishment as returnees from different Regions of North Sudan are coming back after the peace agreements has been signed in 2005. Source: South Sudan National Bureau of Statistics- SSNBS 2016. According to reports by both U.N organizations and government officials, nearly 95 % of the population in South Sudan depends on their livelihoods on “climate-sensitive” activities such as agriculture and forestry because of the civil war which has increased the anthropogenic activities such as tree-cutting reporting that approximately 11 million people depends on charcoal on cooking due to lack of electricity supply.

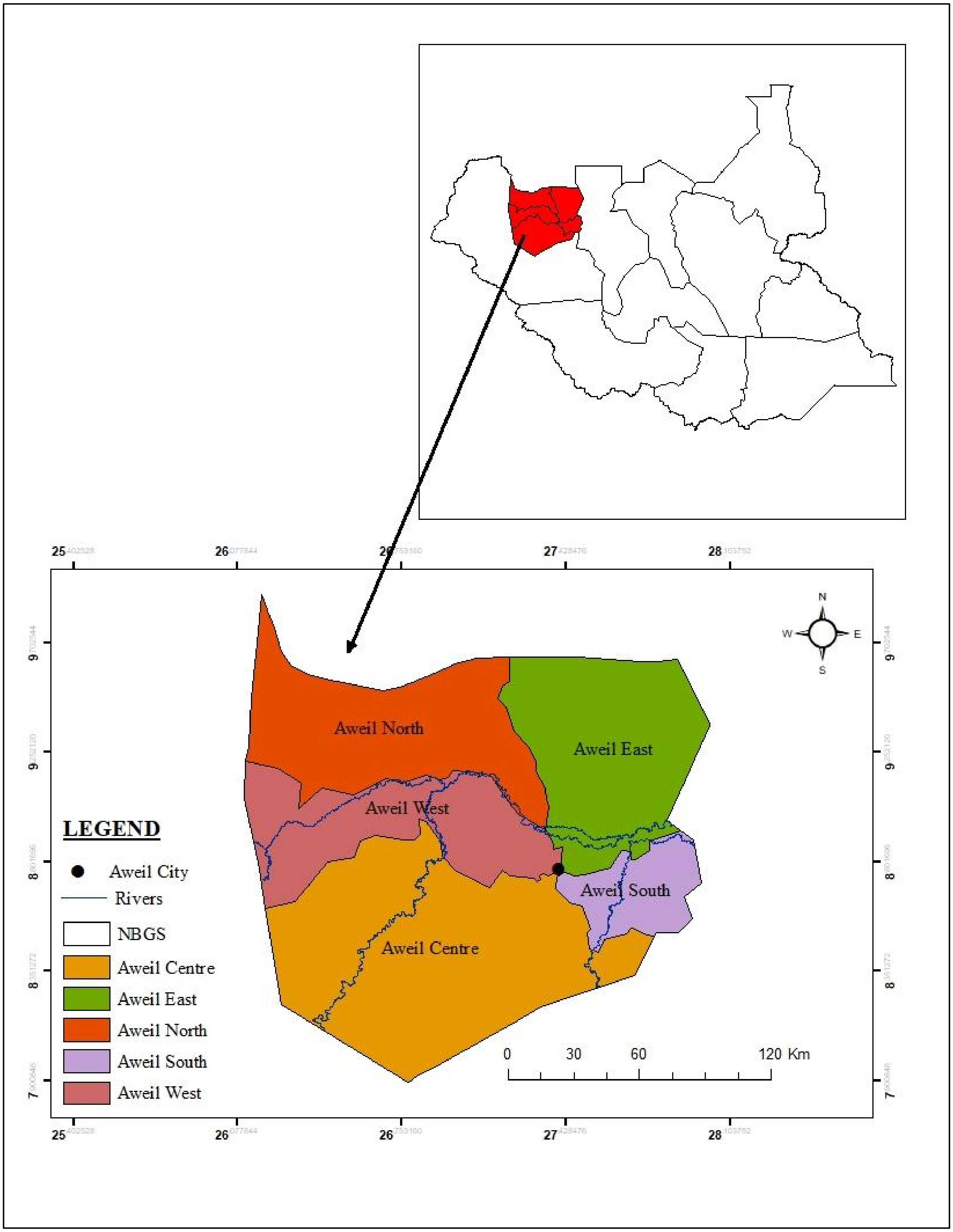


Figure 3.1: The Study Area

CHAPTER FOUR

4.0 METHODOLOGY

4.1 Research Design

This study of flood analysis and the socio-economic impacts of flood in Northern Bahr El Ghazal were based on a sample survey of the river catchment processes using basin interaction design. The flood frequency was based on an input-output design taking into account processes in the hydrologic flow system while socio-economic study was based on flood-human interactions design. The main study platform was the spatial analysis model which is a good tool for soil and water assessment referred to as SWAT model which has components that account inputs, processes and outputs in the hydrologic cycle.

In this study Soil and water assessment tool (SWAT) was used, the input variables included terrain data which is Digital Elevation Model (DEM) to simulate the slope, land use data (a proxy for socio-economic activities), soil data (to carter for water balance) and to create the Hydrologic Response Units (HRU) within the sub-basins, and weather data (to complete the hydrologic loop). These input variables were in spatial format either as grid (raster data) or vector data.

A GIS tool ArcMap was employed to capture and joins the input data and variables in a format SWAT could use in the simulation process. The processes in any watershed include: interceptions, evapotranspiration, percolation, return flow, lateral flow, surface flow, water yield and sediment yield within each hydrologic Response units within the watershed. The outputs of concern in this study are the water yields from the sub-basins as well as the surface flow which collectively represents the potential flood water.

The SWAT output for Rainfall as well as the water yields were subjected to frequency analysis such as (Weibull) model in the time series analysis procedure to estimate flood frequency. The socio-economic impacts were estimated using impact models (spatial regression model).

4.2 Types and Sources of Data

To address the study questions and to meet the stated objectives, there was need for primary and secondary data both were used. The primary data were on household's information on households' bio-data to crosscheck flood vulnerability, flood frequency, flood severity and flood magnitude to characterize flood episodes in Northern Bahr El Ghazal State, as well flood related Morbidity and Mortality in flood prone areas to assist flood impact on health, also flood effect, damages and losses due to flood at households' level and the associated environment to estimate the cost of flood at the household level, never the less knowledge of flood to check the community awareness on flood as an hazard, finally information on flood preparedness to identify the coping mechanisms and flood adoption to estimate capacity to response to a flood episode also were required. The required information on the specified variables was collected through field survey conducted in Northern Bahr El Ghazal State at the household level in South Sudan.

Secondary data were mainly for simulation of hydrologic response in the Northern Bahr El Ghazal watershed and they included spatial information on terrain which was sourced as a digital elevation model (DEM) from USGS Earth Explorer database. The terrain information was required to estimate the slope, flow direction as well as flow accumulation and eventually drainage basin delineation. Soil information was available in shapefile form and was required in the estimation of soil moisture carrying capacity, soil water percolation as well as soil moisture surplus and soil moisture deficit, all in the overall soil moisture balance computation. The soil data was sourced from FAO Agro-geodatabase.

The land use information was necessary as an interface between soil and the atmosphere in the form of interceptions, drip inputs and evapotranspiration as an output in the hydrologic cycle. The land use data in this study was originated from FAO Agro-geodatabase. The input process in the hydrologic flow system design needed the weather data in the form of precipitation and this was represented by rainfall data. The Global gridded high resolution precipitation data was used from (NCEP/NCAR) database for the rainfall data. All the spatial data (grid data or vector data) were projected (UTM WGS84 Northern Zone 35), a prerequisite for SWAT basin delineation and simulation.

Table 4.1: Datasets for the Watershed Drainage Flow Simulation

Dataset	Source
Digital elevation data (DEM)	USGS Earth Explorer geo-database
Soil Data	FAO Agro-geo-database
Land Cover Data	FAO Agro-geo-database
Gridded high resolution precipitation datasets	National Centers for Environment Prediction/National Center for Atmospheric Research (NCEP/NCAR)

Source: Researcher, 2016

4.3 Data Collection

4.3.1 Pilot Survey

Pilot survey was conducted at the beginning of the study (September 2014) to familiarize the researcher with the study area especially in term of susceptibility to flood hazards and to identify the relative background information to the study. The survey was conducted across local government areas and the special report from the Non-government Organizations (NGOs) on flood, with regard to rainfall, stream flow, floods events their frequency, severity and magnitude as well as to identify the suitable communities (sample frame) that was used in the main primary data collection exercise in Northern Bahr El Ghazal state. The survey was also used to check the whether the instruments would provide the required data or would require some adjustments to be effective in field.

February 2015 to April 2015 another pilot survey was conducted on the availability of spatial data in South Sudan but it was discovered that they could only be found as part of the global spatial database available across the internet at various websites and in various formats. The existence of spatial data in various formats indicated the need for format transformation before using them in SWAT model. The spatial data that were to be source from the global data bases through the internet included the terrain data (DEM), Soil and the Land use data. The survey also indicated that the weather data available from weather stations in South Sudan would not be appropriate in SWAT Model simulation and there was therefore need to seek weather data in grid formats as available from (NCEP) and (NCAR). The DEM sources were many but the pilot survey identified that the ASTER 30m resolution was the best quality for Northern Bahr El Ghazal and that there was need for at least six layers (Scenes).

The land use and soil data for South Sudan were found to be only available as part of the old Sudan and would therefore require geo-processing procedure to fit through clipping.

The resulting pilot survey data were used in identifying the target populations and in the estimation of appropriate sample size. It was established that there were five administrative units within Northern Bahr El Ghazal State that could be used to stratify the sampling zones but there were no precise data on households. This necessitated the use of spatial sampling based on remote sensed images of the Northern Bahr El Ghazal State. For this reason, the Northern Bahr El Ghazal surface represented the spatial sampling frame and housing units that could be identified constituted the sampling elements. The only 104 housing units could be clearly identified within the flood prone area which was the area of interest and therefore represented the target sample size to be entered in the sampling procedure taking into the account the administrative strata.

4.3.2 Target Population and Sample Size

The 104 housing units that were identified on the spatial image of Northern Bahr El Ghazal represented the households sampling frame within the surface areas. The identified housing units were all assigned geographic location values which were entered in the GPS receiver to be used later through the GOTO (Find) function to locate the individual units during the field survey. All the 104 units were included in the survey but distributed equally across the four administrative strata using the spatial sampling function in ArcGIS (Table 4.2). In each of the households selected, all the heads of the households' constituted both the target population as well as the survey sample size (104).

Table 4.2: Sample Distribution

Stratum	Households targeted
NBGS North	26
NBGS West	26
NBGS South	26
NBGS East	26
Total	**104**

The terrain data (DEM) for South Sudan as available in ASTER spatial database constituted the target terrain data population from which the sample terrain data were derived based on the geographic location values and this resulted in six DEM layers. The six layers provided a near complete spatial coverage of Northern Bahr El Ghazal State. The six DEM layers were mosaicked and then geo-clipped using the shapefile of Northern Bahr El Ghazal State to create a DEM sample for the SWAT hydrologic analysis (Figure 4.1).

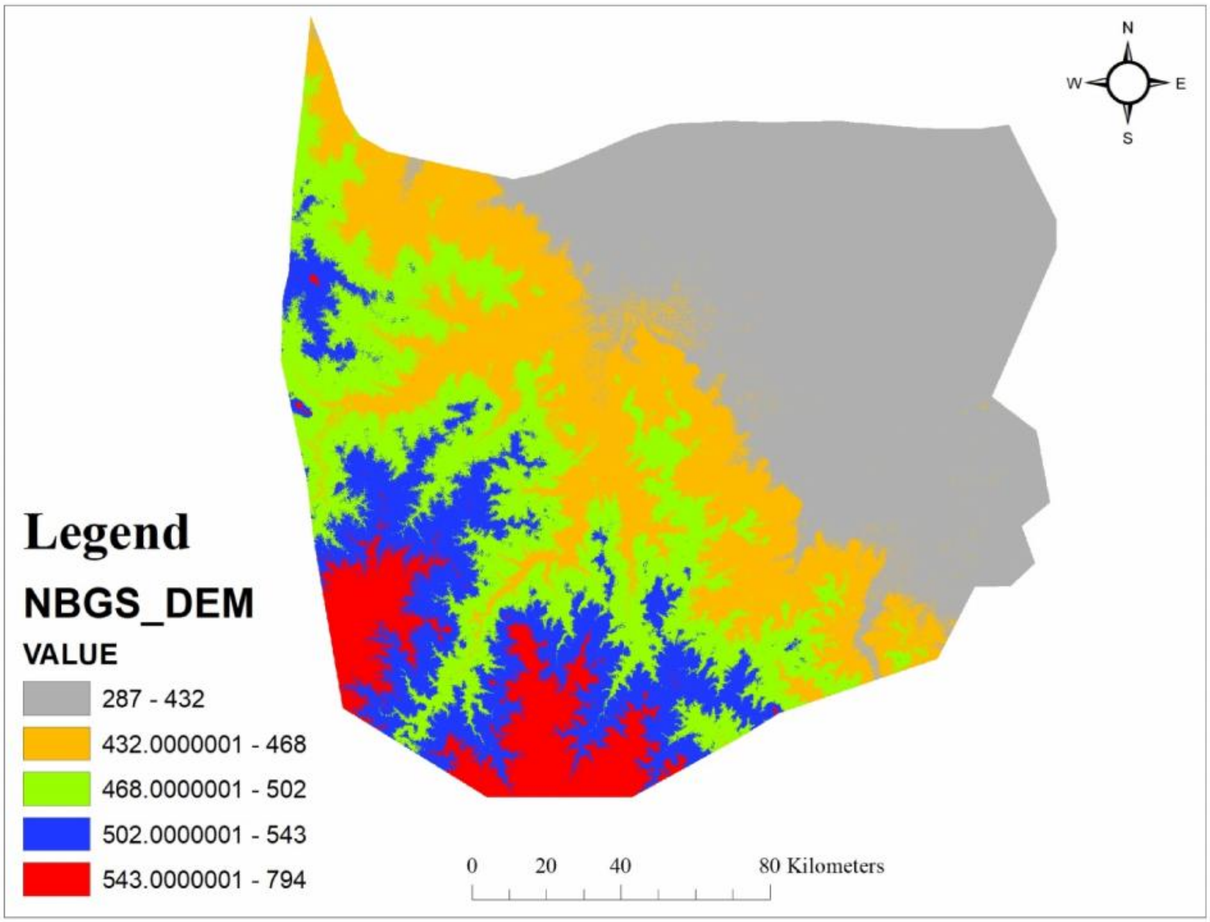
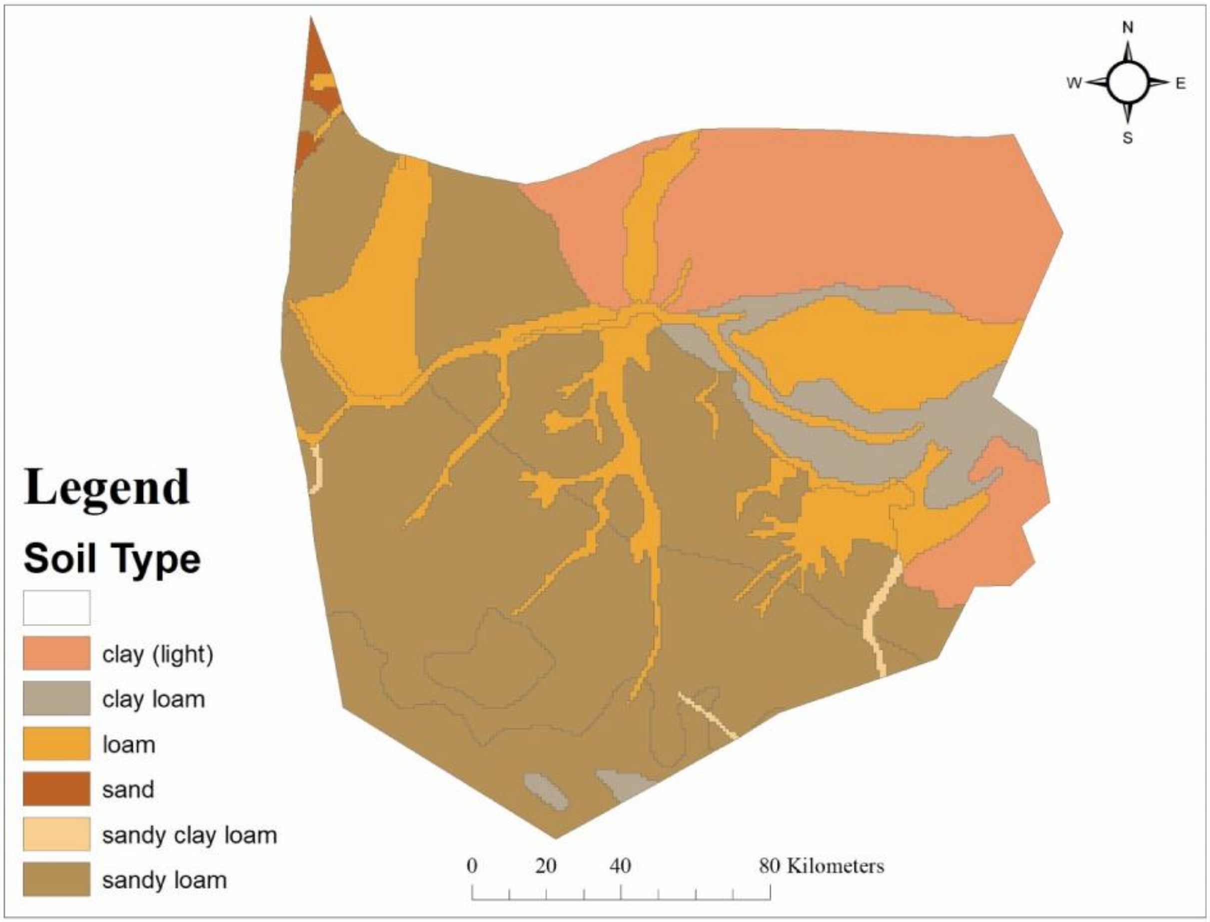


Figure 4.1 Digital Elevation Model Map (DEM) of Northern Bahr El Ghazal State
Source Modified from USGS, 2016

Soil data which was available as the Sudan Soil map (Geospatial soil database from FAO Sudan, 2003) represented the Soil population while the portion representing South Sudan constituted the soil target population (Figure 4.2) from which soil sample data for Northern Bahr El Ghazal was drawn using the administrative shapefile as the delimiting tool.



Source: Modified from FAO Soil Database, 2003

Figure 4.2: Soils of South Sudan.

The data for the Land Use/Land Cover target population used was for the FAO land use/land cover database for Sudan (figure 4.3) from which Land use /Land cover sample data of the Northern Bahr El Ghazal was later clipped by using the study area shapefile.

Source: Modified from FAO Landuse/ Landcover Database, 2003

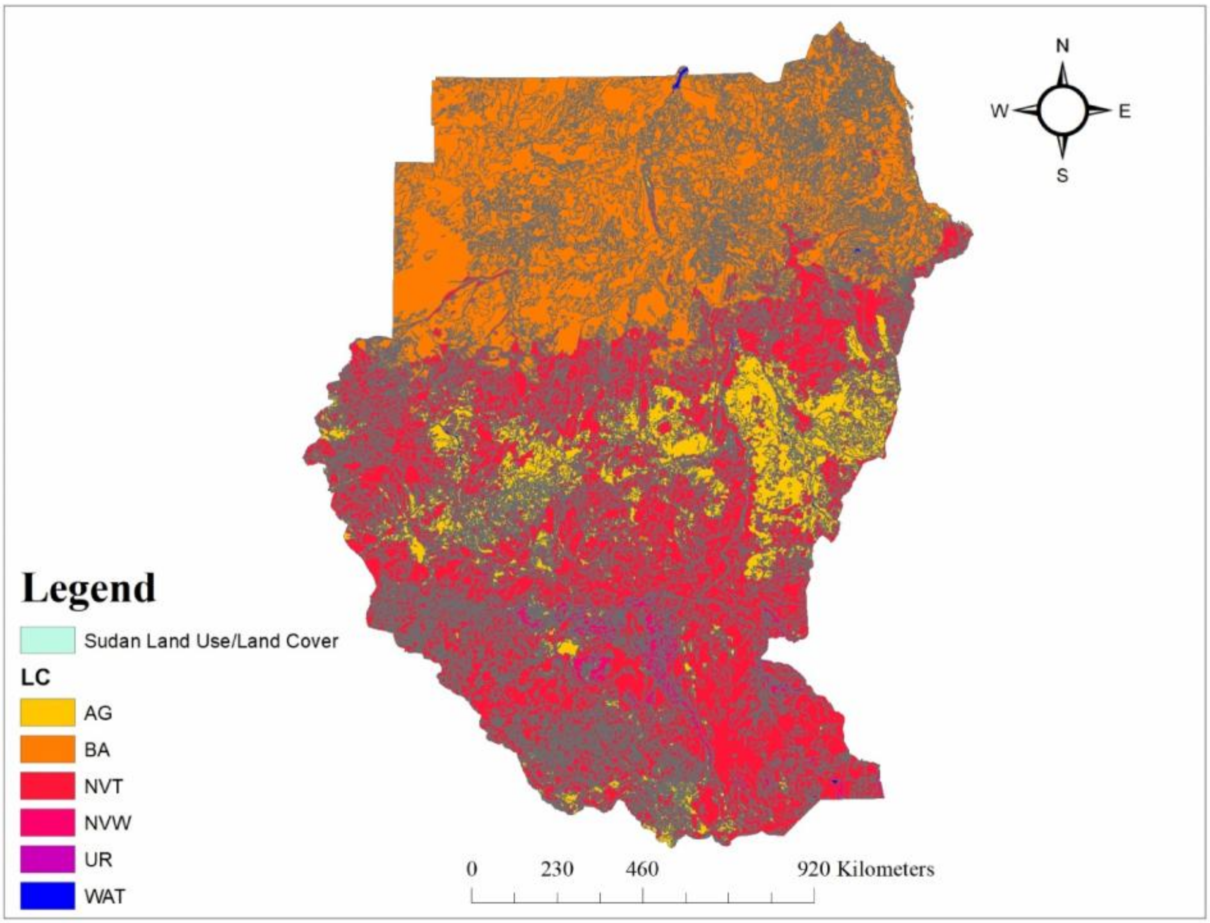


Figure 4.3: Land use/Land cover of Sudan

The target population for the weather data required in the SWAT simulation were the Rainfall, Temperature, Relative Humidity, Solar Radiation and Wind) was the globally gridded high resolution Climatic datasets for South Sudan from (NCEP/NCAR) of the US database for 33 years. From the weather target population, a sample of gridded high resolution weather data representing 49 point within Northern Bahr El Ghazal or without but representatives of Northern Bahr El Ghazal catchment was drawn as guided by the geographic location of longitudes 26.0156 W, 28.3557 E and latitudes 10.0987 N, 7.8090 S (starting from 01/01/1980 to 31/12/2013).

4.4 Data Collection Instruments

Firstly, the questionnaire was used to collect information on the flood related socio-economic characteristics of communities in Northern Bahr El Ghazal State of South Sudan. It was designed in a structured way guided by the study questions, objectives and hypothesis. The questionnaire structures were nine parts dealing with households bio-data, flood frequency severity and magnitude, flood and population morbidity and mortality, flood effects on the households, community knowledge on flood, households flood preparedness and households flood adaptation mechanisms.

The questionnaire was designed to be administered by the researcher or research assistants using personal interviews for quality control to ensure data integrity. The questions on the questionnaire were either open ended or closed resulting in a semi structured format that could provide as much as information as possible from community perspectives on flood but in a control manner so as to get the right information for the stated study problems.

The questionnaire was designed to target the heads of the households who could be the head of the family or any mature person available in the households but must have been ≥18 years and therefore able to make a decision affecting the whole household. The location of the households was considered important in the study and the questionnaire was designed to capture the location of the households within Northern Bahr El Ghazal State. Location was to be used to estimate the spatial vulnerability of households to flood.

Secondly, Laptop Computer, since the SWAT model requires inputs of landscape physical parameters to be computationally efficient, there was need to have Computer with graphic user interface with large RAM, fast processor and large secondary storage (Hard disk), as well as internet connection to collectively represent spatial data collection instrument and as well as a processing tool in hydrologic simulation.

The spatial data collected using the internet included the DEM data, the soil, land use/land-cover and the weather data. The downloaded data required a geo-information system interface and this was provided by ArcGIS and SWAT where the SWAT was integrated in the ArcGIS as ArcSWAT extension.

Thirdly, GPS Receiver, the Global Position System known as (GPS) was used to locate the 104 housing units which had been identified on the remote sense image during the pilot survey. The location of each housing unit was used to trace it using the GOTO function of the receiver and this was done until the entire 104 units were visited. The already visited units were then captured as a waypoint in the GPS and in case of need to revisit could easily be retrieved.

Fourthly, Camera Pictorial recording of flood related features in Northern Bahr El Ghazal was carried out using digital camera for easy transfer to digital files to be used analysis procedure and in result discussions. Pictorial features captured included: crop fields affected recently by flood during the field survey. The crop fields which were affected by the floods were used to crosscheck the information on flood effects on household livelihood provided in the households' questionnaire.

Physical damages were pictorially recorded to give indication on the potential vulnerability of households and their membership to flood and also to give some indication on capacity to adapt. The particular physical damages captured included: houses destruction, damages to traditional pit latrines therefore potential effects on community health. Schools infrastructures were damaged and therefore there is potential disruption of learning activities and damages on communications linkages such as road and bridges.

Finally, SWAT Software, it was used as an instrument in estimating flood occurrence Northern Bahr El Ghazal catchment. The software allowed the Digital Elevation Model (DEM) data to be use in approximating slope flow accumulation, flow direction basin delineation and stream network definition in terms of individual streams, streams outlets, sub-basin and the longest stream reach in the catchment.

To estimate hydrologic response unit in the catchment SWAT allowed the overlay of digital elevation model for slope definition, land use grid data for hydrologic processes specifications and Soil spatial data (shape files) for interventions input-output processes in the water balance specification. The overlay of the three spatial data sets in SWAT allows the hydrological response units (HRU) in the whole water catchment to be identified.

The HRU contributions in the catchments output could only be specified if the catchment inputs could be added. And SWAT allows the weather data in the form of daily grid high resolution weather data (Rainfall, Temperature, Relative Humidity, Solar radiation and Wind). These weather inputs together with the defined HRUs were used in SWAT to simulate the variance hydrological outputs that was necessary in estimating flood frequency in Northern Bahr El Ghazal State of South Sudan.

4.5 Data Collection Procedure

To get the field survey data from 104 households as specified in the sample size and the study first stratified the Northern Bahr El Ghazal into four strata (Northern NBGS, Western NBGS, Southern NBGS and Eastern NBGS). Each Stratum was assigned 26 housing units as already identified on the remote sensed image. The GPS receiver was then used to trace each of the 26 housing units in each stratum by keying in their geographic locations and using the GOTO function. At about 20m -50m from the units, the enumerator was alerted by the receiver and on reaching the unit, the GOTO function was switched off. This was repeated for each stratum 26 units until all the 104 housing units were covered.

At each housing unit, the enumerator introduced the objectives of the study and sought out the head of the household as the potential respondent. With the help of research assistants who in all cases could speak the Dinka language and were familiar with the locals, the enumerator conducted the interview if the time and the locations were convenient to the respondent. Because of general low literacy level in the study area and since the questionnaire was in English there was need to carry out personal interviews to avoid misrepresentations of facts and avoid language difficulties.

This procedure was repeated throughout the study area resulting in slow returns but with quality assurance required in answering the research questions and meeting the research objectives. At each point of the field interview the enumerator was to keenly observed the immediate environment for any signs of flood effects and record the observation sheet and take relevant photographs to be used in corroborating the responses on the questionnaires

The study opted to use DEM data from ASTER because of the good quality therefore useful in the delineation of the basin and stream network definition. The available ASTER 30m resolution DEM were first sampled for quality within the identified geographic boundaries and the suitable ones were then assigned numbers which were used in ordering the downloads for easy mosaicking. The resulting mosaic was then geo-clipped to fit the Northern Bahr El Ghazal surface. The resulting image was then saved as the DEM data file for study area to be used as an input data in the SWAT model process.

The soil data and the land use/land cover data which are important components of SWAT model HRU definition process were identified given the pilot survey information and then selected on the basis of their attribute table quality. The attributes were needed in the model to define the hydrological responses units that are required in the simulation given weather inputs. The download of the soil and land use data from the FAO geo-database required the identification of the country and the download location. The results were data spatial data files for HRU definition in SWAT.

The weather data were first ordered by requesting the NCAR was done by sending an email request after selecting the location of the study area, the weather data type and the period on the website of the NCEP/NCAR then the data where downloaded after a notification from the NCEP/NCAR that the data are ready for download.

4.6 Data Processing and Analyses

4.6.1 Data Processing

The primary data collected from Northern Bahr El Ghazal State were scrutinized (data cleaning) for completeness, then the data were coded, and converted to digital format through data entry using SPSS data editor interface. Simple frequency tabulation was used to check each variable response for extremes, wrong entry or missing entry. The resulting information was then saved as a field data file to be used in the analysis procedure.

The downloaded spatial data sets required various transformations to be ready for use in the ArcGIS and ArcSWAT interfaces. The first step was to create the shape file of Northern Bahr El Ghazal State from the South Sudan Shapefile by geo-clipping in ArcGIS geo-processing clip tool. The clipped shapefile was then projected using ArcGIS data management project feature tool from decimal degrees surface to UTM WSG 1984 Northern Zone 35 and the result was a projected North Bahr El Ghazal shapefile.

The downloaded DEM data was prepared for use in ArcSWAT by first creating a mosaic of the six layers (scenes) using the ArcGIS data management raster data set tool and by using the spatial analyst tool in ArcGIS toolbar under hydrology tool the DEM was then filled and sinked in a surface raster to remove small imperfections in the data to clear the DEM data. The mosaic was then clipped to fit the study area surface using Northern Bahr El Ghazal Shapefile which was already created. Then DEM for Northern Bahr El Ghazal was projected to WGS 1984 UTM Zone 35N by using the raster projection tool in ArcGIS data management. The projected map was saved in the spatial data file to be used in the delineation of the watershed d in ArcSWAT which is an interface extension in the ArcGIS to use it in SWAT model. The soil data that cover whole of South Sudan was projected to the same coordinated system of the DEM data, the soil data plus the land use data were all projected then converted into Raster data as a prerequisite for the SWAT model. The soil data and the land use data were then saved in the spatial data file to be used for the land use/soil/slope definition for the Hydrological Response Units definition in the SWAT model.

SWAT Model Set Up: The SWAT model is a computational model it is parameters are spatially distributed. The DEM is used for and the drainage network information, all the sub-basins are defined in the model. With the land use, vegetation cover, soil type and slope information the model then divides the watershed into various Hydrologic Response Units (HRU). Consequently the surface flow estimation for each HRU is much more accurate and contributes to a better description of water balance which is expressed as:

$$SW_t = SW_0 + \sum_{i=0}^{t} (R_{day} - Q_{surf} - E_a - W_{seep} - Q_{gw}) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

Where SW_t is the final amount of soil water (mm); SW is the initial amount of soil water (mm) on t time (days); is the daily precipitation (mm); q_i is the surface flow (mm); ET is the actual evapotranspiration (mm); $q_{lat.i}$ is the lateral flow (mm); $q_{ret.i}$ is the return flow (mm); and i is the time step (days). The surface flow is calculated with the Curve Number method (CN). The lateral and return flows are calculated in subroutines. The actual evapotranspiration is calculated from the potential evapotranspiration determined with the Penman-Monteith method. Then, the water yield (or river discharge) is calculated:

$$Q = q_i + q_{lat.i} + q_{ret.i} - Tloss_i - pond \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

where $TLoss_i$ is the rate of water loss from reach by transmission through the streambed; and *pond* is the water storage in ponds.

The watershed computation requires the following input files to run the model; the DEM which is the elevation, land cover which details all the types of the vegetation cover type and the land use, soil layers which includes the different soil types, and climate data which consists of the precipitation daily values, temperature minimum and maximum, solar radiation, relative air humidity and finally the wind speed. ArcSWAT tool was used to aid the map information of SWAT model and the to model the surface, among other things, the DEM data was used in the creation of the stream network as well as the sub-basins and also utilized to delineate the watershed boundaries using the elevation details or the terrain data and also used to calculate the parameters for each sub-basin. Then, the Land use in addition to the soil maps and the slope were reclassified and overlaid to generate the HRU which are then analyzed for each sub-basin based on the threshold value assigned for land use. The watershed were subdivided into areas based on the soil and the slope and characterizing by a unique land use and soil combinations that enabled the model to reflect differences in evapotranspiration and other hydrologic conditions for different land covers/crops and soils. The land use and the soil threshold were used as an input data to extract the spatial details to be included into the HRU creation in ArcSWAT.

Then, these thresholds are applied to each sub-basin and function to control the size and number of HRUs created. The watershed division into sub-basins enables the model to reflect differences in evapotranspiration for the various land covers and soils. For each HRU the runoff is predicted separate and routed to obtain the total runoff for the watershed. Then to define the values of the precipitation, solar radiation, minimum and maximum temperature, and humidity and wind speed to complete the model data set required during the period from 1980 to 2013 the period of the study design, the globally gridded high resolution data for precipitation from (NCEP/NCAR) for the SWAT model were used. The threshold levels set for defining the HRU‘s depend on the project goal and the amount of detail desired by the modeler. The default SWAT-threshold values for land use, soil and terrain slope, which are 20%, 10% and 10%, respectively, are sufficient for most applications and have also been used in this study. With this approach, 164 HRUs were obtained for the totality of the Northern Bahr El Ghazal State watershed. This increases accuracy and gives a much better physical description of the water balance.

4.6.2 Primary Data Analysis

The primary data as identified in (4.1) which were coded earlier were entered into the Statistical Package for Social Sciences (SPSS). SPSS was used in statistical analysis of primary data because of its flexibility and ease when handling data that has both quantitative and qualitative aspects. The first step in primary data analysis involved using exploratory (descriptive) statistical tools for accurate description of the sample data distribution tendencies. The procedure used to measure distribution tendency was frequency analysis to provide information on occurrences. The occurrences were measured in terms of numbers and as percentages in a frequency distribution table. Some of the results in the frequency tables were converted into visual representations using graphing techniques as summary tools.

The results of frequency measures were then subjected to non-parametric measures to test for differences and associations in which the Chi Square statistical test. The Chi-statistics was specified by the expression:

$$\chi^2 = \frac{\sum (O - E)^2}{E} \quad \text{..............................(3)}$$

This was used to assess the effect of flood duration on the type of to flood impact episodes and the type of flood impact at household’s level. P-values of 0.05 or less was considered to be significant and hypothesis test was stated. Results were presented using tables and graphs.

4.6.3 Probability of Exceedance Estimation

The first step to run a frequency analysis was by ranking the rainfall data from maximum to minimum. After the ranking of the rainfall data, an assigning of a rank serial number (r) going from 1 to n (the observations number) is given. Next the probability was determined by assigning rainfall depths to each probability. The data were ranked in descending order by sitting the highest value followed by the lowest value, therefore probability can be an estimated as of the probability that when the equivalent rainfall depth will be exceeded. Whereas the probability of non-exceedance is when ranking data from the lowest to the highest value. Therefore the probabilities are estimations of cumulative probabilities formed by summing the probabilities of occurrence of all events greater then (probability of exceedance) or less than (probability of non-exceedance) some given rainfall depth. Since these probabilities are unknown the probabilities of exceedance have to be estimated by one or another method. Several methods are in used but in this study the Weibull Method was used for the reason that it was theoretically better sounded easy to use. The probabilities were the plotting positions of the ranked rainfall data in the probability plot.

Weibull (Weibull, 1939) = $\frac{r}{(n+1)}100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (4)$

4.6.4 Double Mass Analysis

The model of the double-mass curve was used for cumulative of simulated rainfall against the cumulative of the other stations available in the South Sudan during the same period were plot as a straight line with the assumption that as long as the data are proportional; the slope of the line will represent the constant of proportionality between the quantities. A break in the slope of e double-mass curve means that a change in the constant of proportionality between the two variables has occurred or perhaps that the proportionality is not a constant at all rates of cumulative.

4.6.5 Standardized Precipitation Index (SPI)

The SPI is defined as the number of standard deviations deviates from the long-term mean of the cumulative precipitation at a given timescale. For any location the SPI calculation is based on the desired period (timescale) usually 1, 3 or 6 and 12 or 24 months) of the long-term precipitation record. Then, gamma probability distribution is used for fitting this long-term record.

Subsequently, the cumulative probability calculated from the Gamma distribution will be transformed to the equivalent cumulative probability of the standard normal distribution (zero mean and unit standard deviation), with the resulting z value being the SPI (McKee *et al*., 1993). When SPI is normalized, wetter and drier climates can be represented in the same way; therefore, wet periods can also be monitored using the SPI. Zero SPI indicates that there was no deviation from the rainfall mean value at the analysis period chosen time scale. And precipitation is above average when SPI values are positive and a negative value of SPI indicate below average precipitation. Accordingly, SPI values ranging from −1 to +1 state a normal precipitation regime and values of SPI ranging from +1 to +1.5 are moderately wet and +1.5 to +2.0 are associated very wet episodes, respectively, SPI values exceeding +2 are representative of extremely wet episodes, and SPI ranges with a negative sign represent moderately dry, very dry and extremely dry spells (Mckee, Doesken and Kleist, 1993) used the classification system shown in the SPI value table below (Table 3.3) to define flood and drought intensities resulting from the SPI.

Table 4.3: SPI values

2.0+	extremely wet
1.5 to 1.99	very wet
1.0 to 1.49	moderately wet
-.99 to .99	near normal
-1.0 to -1.49	moderately dry
-1.5 to -1.99	severely dry
-2 and less	extremely dry

The analysis was performed using monthly precipitation data from SWAT simulated rainfall data where NCEP high resolution gridded data were used as input rainfall data for SWAT model because the study area is characterized by no rainfall data availability and to insure it is more than likely that the data sets would only have 90% or even 85% complete records. The Standardized Precipitation Index (SPI) was calculated for 3 and 6 months' time scales. The SPI was determined using monthly precipitation data from SWAT model which was adjusted to a Gamma probability distribution, a necessary condition for SPI calculation (Mckee, Doesken and Kleist, 1993) Gamma distribution is well explained in the literature (Wu *et al.*, 2005) and is described by the following equation:

$$G(x) = \frac{1}{\beta\,\Gamma(\alpha)} \int^{x} x^{\alpha-1} e^{-x/\beta} dx \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where

G(x) - cumulative probability

β - Scale parameter

α- Shape parameter

x - Random variable (monthly precipitation)

Γ (α) -gamma function

Parameters α and β are estimated by

$$a = \tfrac{1}{4A}\left[1 + 1 + \tfrac{4A}{3}\right] \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (6)$$

And

$$= \frac{\bar{x}}{a} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where

$$A = 1n(x) - \sum \frac{(1n(x))}{n} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (8)$$

n - The number of observations.

4.7 Flood Spatial Distribution

To show the most problematic sub-basin with respect to water-yield across the sub-basins in the study area which could be referred as flooded sub-basin, ArcMap and ArcSWAT were employed to visualize the spatial distribution of the water-yield simulated by SWAT model. The averages of the water-yield in each sub-basin for all the period of the simulation were used to show the sub-basins with the highest level of water-yield to be regarded as most flooded based on the level of the average amount of the water-yield in that sub-basin during the total period of the simulation.

First after running the swat model after successful setting of the model the output data file then has been saved in the database, then from the output data file was extracted and by the use of the pivot table the data was analyzed in an excel worksheet. Pivot tables functionality were used to sort, count, and averaging the water yield in the sub-basins to create another table to display the summarized average of the water yield for every sub-basin for the all watershed sub-basins. The average water-yield for every sub-basin has been plotted by using join table function in ArcMap to represent the average water-yield distribution for each sub-basin to show the highest sub-basin in term of water yield will be referred as the most problematic sub-basins in term of flood.

CHAPTER FIVE

5.0 RESULTS AND DISCUSSIONS

5.1 Introduction

The results and discussions were aim that reflecting the outcomes of the methodology sections in terms of the research questions, objectives and the hypotheses. The presentation topics include analysis of flood events, flood distribution and flood impacts. These topics are presented and discussed in this thesis in terms of the SWAT analyses outcomes and the socio-economic data analyses outcomes.

The objectives of this chapter were to present and discuss the results in such a way that the flood impact analysis and its distribution were clearly captured in the Northern Bahr El Ghazal drainage system and in terms of socio-economic conditions in an integrated manner. This integrated approach took into account the flood policy gaps and the literature gaps.

5.2 Simulated Flood Situation in Northern Bahr El Ghazal: SWAT Outcomes

5.2.1 Land Surface Characteristics and Flooding: The delineations of the Northern Bahr El Ghazal State watershed identified 164 HRU from 56 sub-basins therefore 56 reaches (Streams) within an area of 30,453.30km.sq. Potentially there could have been more reaches therefore more sub-basins but this was limited by the 30m spatial resolution of the DEM used in the delineation of the Northern Bahr El Ghazal watershed. Collectively the DEM, the land use, and the soil when used together with the daily rainfall indicated there were 56 streams covered by delineated into 56 sub-basins and 164 HRU. The parameters for each sub-basin were calculated based on surface topography provided by the DEM of the elevation model.

Table 5.1: Land use Types by Areal Coverage in Northern Bahr El Ghazal

Land Use	SWAT code	Area (km2)	% of total area
Forest-Deciduous	FRSD	6269.03	71.87
Agricultural Land-Row Crops	AGRR	2197.34	25.19
Hay	HAY	256.47	2.94

As it was observed in Table 4.1 and Figure 5.1 in a big portion of the watershed is covered with Forest-Deciduous and Agricultural Land-Row Crops, which accounts for 71.87and 25.19% of the respective watershed area. The land use classes in Table 5.1 only resulted after the HRU definition thus indicating that only three soil types affected hydrological responses in the study area. The soil types of watershed is presented in Table 4.2 and Figure 4.2, it was shown that there are three main soil types were identified in the study area watershed. The dominant soil type in the watersheds is the Sandy Loam soil type. The detail parameter values are presented in Appendix I.

Table 5.2: Soil Type

Study Area	**Area (km^2)**	**% of total area**
Clay	1150.64	5.34
Loam	3338.53	15.02
Sandy Loam	17167.13	79.64

Table 5.3: Slope Classes

Study Area	Area (km^2)	% of total area
Slope< 10%	18921.62	87.78
Slope 10-20%	2635.14	12.22

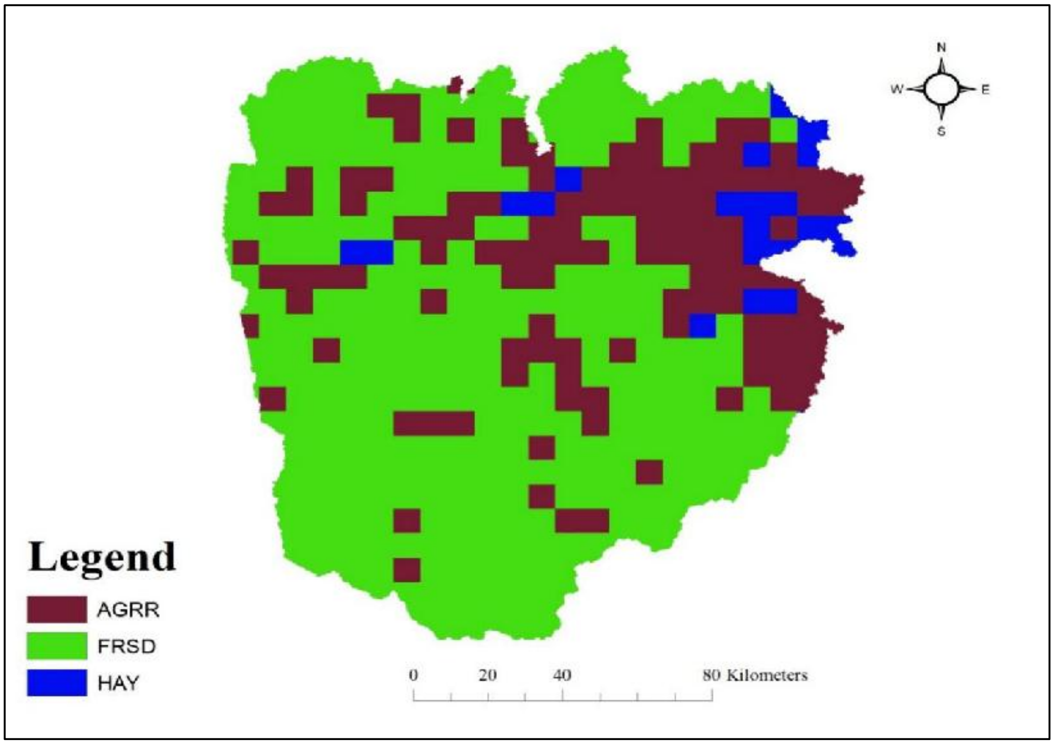


Figure 5.1: The Study area Catchment SWAT Land use Classes

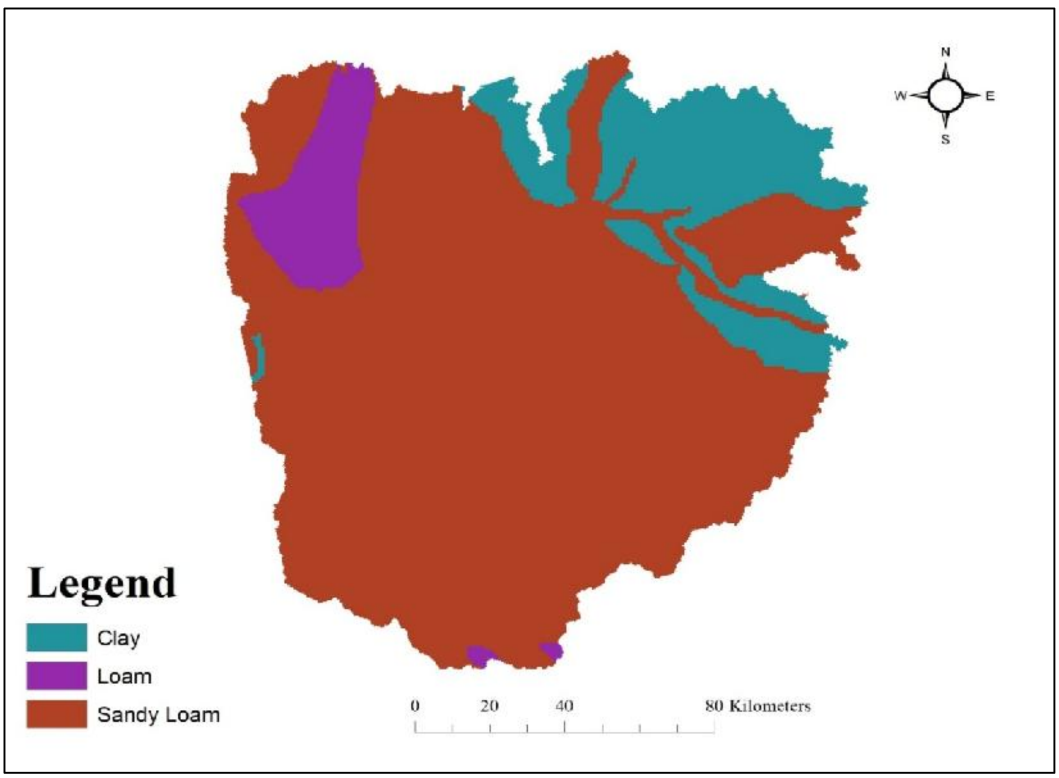


Figure 5.2: The Study area Catchment SWAT Soil Classification

As shown in Table 5.3, 87.78% of the area had a slope less than 10% while 12.22 % of the area are between 10-20%. The value of the soil presented in the Table 5.2 was after the definition of HRU and the figure 5.2 is the soil output after the definition.

From table 5.1 and figures 5.1 and table 5.2 and figure 5.2 perspectives, most of the land cover and land use in the study area was found to be Deciduous forest therefore making it possible to intercept the rainfall and that sandy loam soils have relatively high infiltration rates with relative less runoff potential tended to dominate the surface of the study area (79.64%), whereas most of the study area are settling within the low lands which are characterized by high water table and flooding in the rainy season from May to November, thus indicating susceptibility to flooding. This finding was reinforced by the fact that the HRU were mostly on flat surfaces table 5.3 (Slope<10%, 87.78%) making it relatively slow in releasing the surface water from the area therefore increasing the chance of surface inundation. The surface characteristics of the study area therefore could be said to play important role in flooding of Northern Bar El Ghazal.

5.2.2 SWAT Model Rainfall Output Analysis: Since Northern Bar El Ghazal was found to be poor in Rainfall and River Gauge stations network, the study relied on proxy data from satellite measurements (Global weather data) to approximate rainfall distributions and river flows. The proxy data needed to be gauged for true representation of the conditions in the study area. The first step was to ascertain the statistically distribution of the proxy rainfall data through normally test using the Kolmogorov-Smirnov test statistics. The results as indicated in figure 5.3 showed a close approximation of normality and therefore good representation.
The distribution of the event is normally distributed.

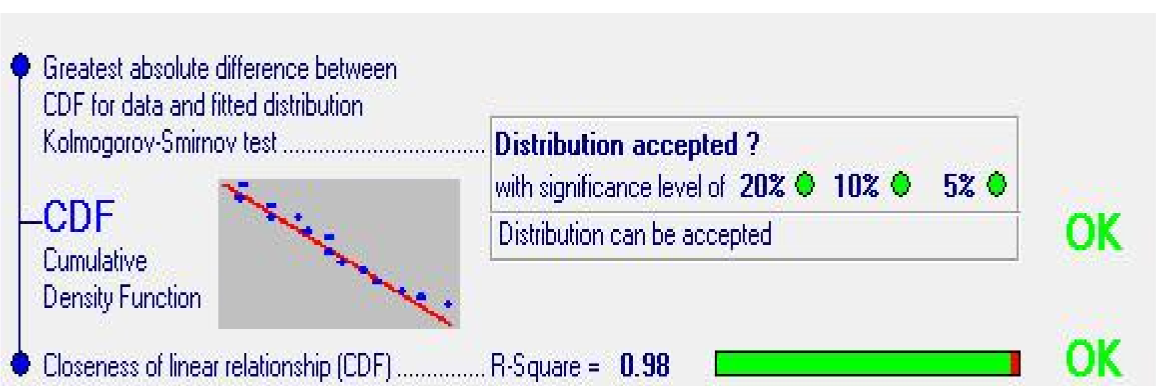


Figure 5.3: Simulated Rainfall Distribution

The results of Kolmogorov-Smirnov test were further validated by the use of double mass Analysis to check the consistency based on five available rainfall gauging stations in South Sudan. The double mass curve analyzing, therefore, was used based on the assumption that recorded data of the population is consistent. As a result, if the simulated data of SWAT model is consistent with the another existing observation stations, the study assumed that the simulated rainfall data of the SWAT model was consistent and could be used as substitute data to analyze the flood events in the study area or it could be used to represent rainfall data in the study area based on the principle that when the observed data are from the same population they must be consistent. The double mass analysis results (figures 5.4, 5.5 and 5.6) for the rainfall output data ranging from 1983-2013) were consistent with actual rainfall situations in Southern Sudan and therefore could be used in estimating flood situation in Northern Bar El Ghazal. The double mass curve uniquely identified the periods 1987-1999 and 2000-2013 as periods of contrasting conditions where the first period showed relatively low rainfall conditions while the second period showed relatively high rainfall conditions respectively. This unique finding was consistent with the findings of other study outcomes that (GHACOF, 2012)indicated increasing rainfall trends from 2000 in Eastern Africa and South Sudan in particular.

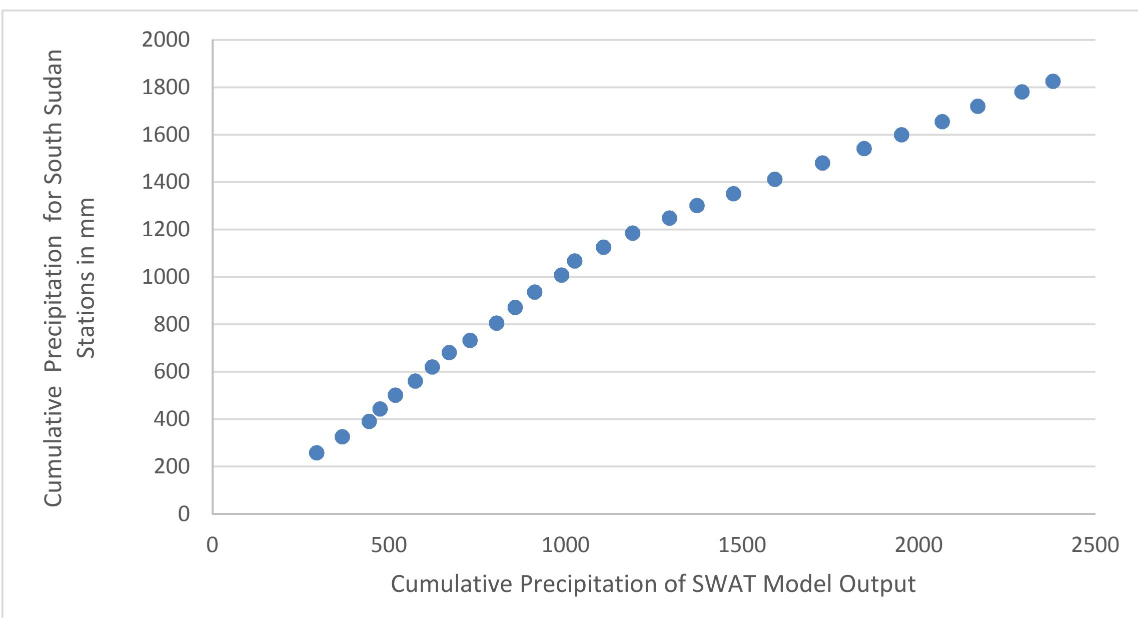


Figure 5.4: Double mass curve for the period 1983-2013

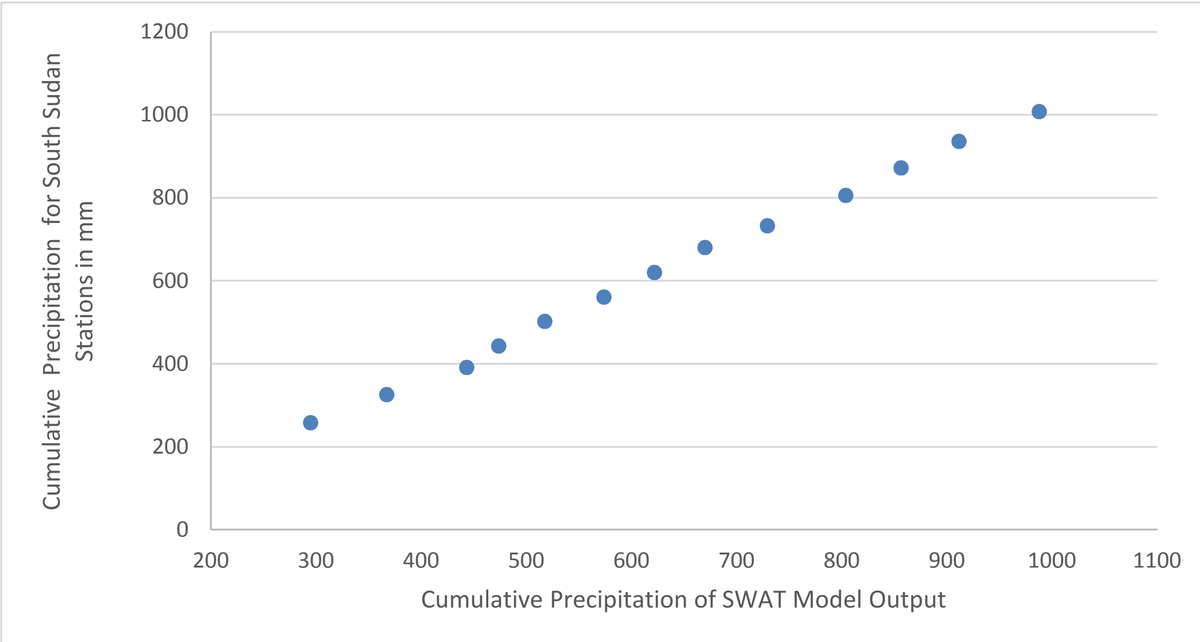


Figure 5.5: Double mass curve for the period 1987-1999

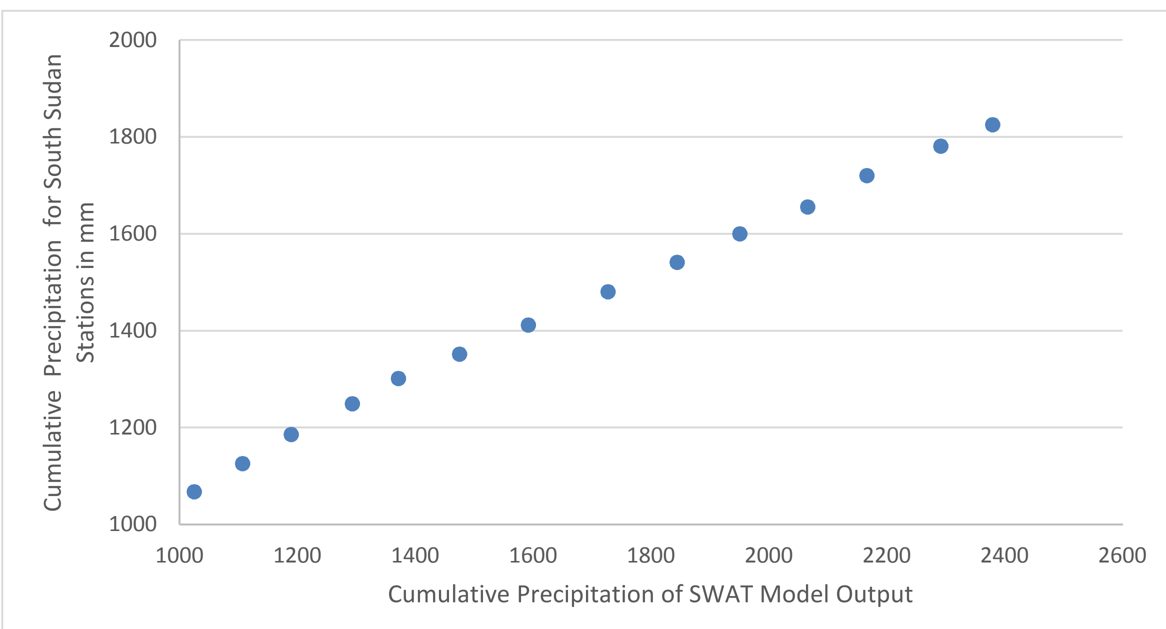


Figure 5.6: Double mass curve for the period 2000-2013

5.2.3 Detecting Shift on the Total Annual Rainfall: After establishing the consistency of the simulated rainfall, the study then attempted to measure the shift if any in the simulated rainfall as an indication of trend. The tool that was used was the Weibull distribution test (RAINBOW software) which measures the cumulative deviations from the mean to detect time series homogeneity. Where the time series homogeneity was detected, it meant that there was no trend in the series while detection of heterogeneity indicated trend in the series. The results showed (figure 5.7, table 5.4) that the simulated data homogeneity could be rejected at 90%, 95% as well as 99%. This might have been due to the maximum cumulative deviations cross the 90%, 95% and 99% thus indicating shift in the total annual rainfall as marked by the year 2000.

The deviation could have been due to instrumental installation errors, equipment position alteration or Climatic shift but these were not possible for the data was simulated therefore deviation largely a shift in the total annual rainfall.

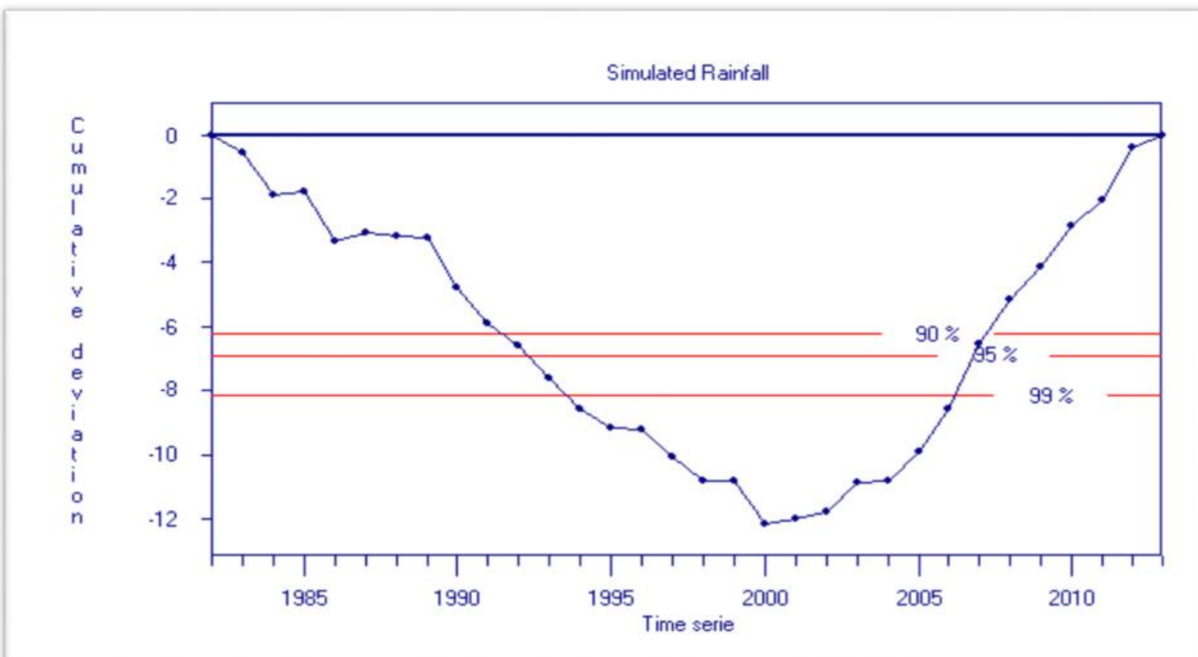


Figure 5.7: Rescaled cumulative deviation of annual rainfall of the simulated data

The shift in annual rainfall totals could also be seen in the SPI analysis figure 4.8 and the study therefore noted that the frequent flood events in the years from 2000 to 2013 were largely due to shift in the total annual rainfall.

Table 5.4: Probability of rejecting homogeneity of simulated annual rainfall

	Rejected?		
Statistics	90%	95%	99%
Range of Cumulative deviation	Yes	Yes	Yes
Maximum of Cumulative Deviation	Yes	Yes	Yes

Linear relationship (CDF) closeness R^2 =0.98

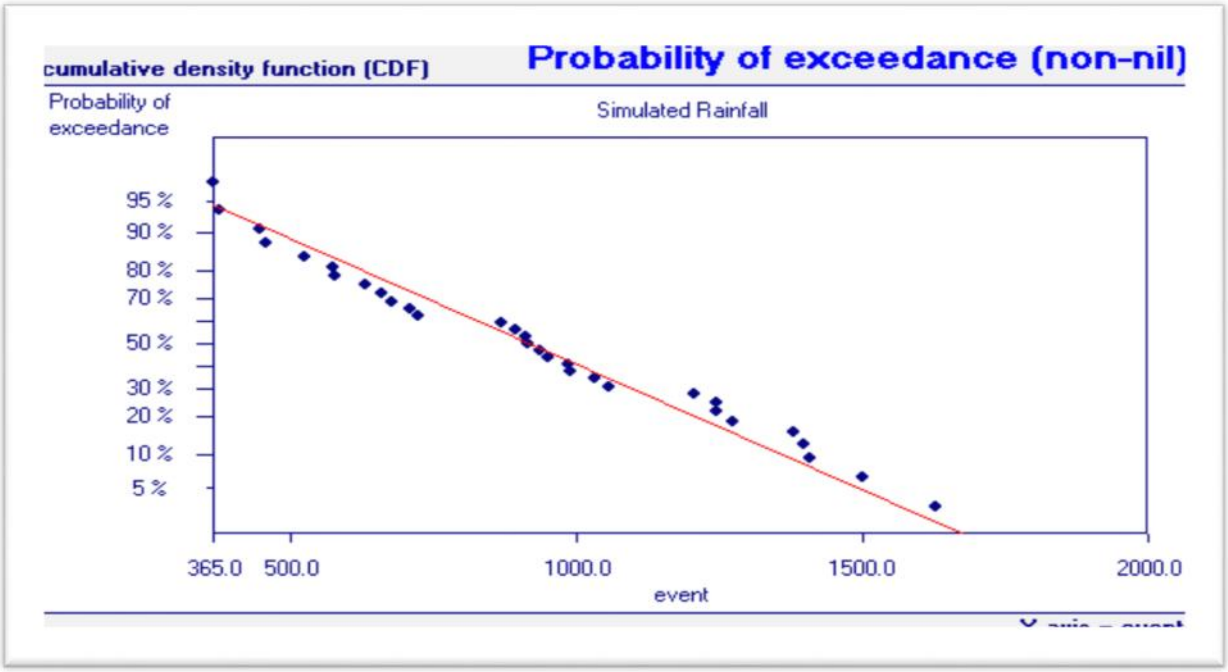


Figure 5.8: Probability plot of the annual rainfall of SWAT model Output

The least square fit R^2 is 0.98 to characterize the flood characters in Northern Bahr El Ghazal State. The SWAT output for rainfall was used to investigate the degree of flood severity in the study area and for more clarification for the climatic shift from the year 2000. This study based on floods occurring in Northern Bahr El Ghazal State of South Sudan during the last two decades, spotlighting particularly on the 2007 up to 2013 floods. By the applications of GIS and SWAT tools and their analysis potential to anticipate high flood situations as well as the use of the SPI as an index to determine flood frequency and magnitude.

The SPI at 12 and 24 timescales reflects long-term precipitation patterns. The 12 and 24 month SPI is a comparison of the precipitation for 12 or/ 24 consecutive months with that recorded in the same 12 or/24 consecutive months in all previous years of available data. Because these timescales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend to gravitate toward zero unless a distinctive wet or dry trend is taking place.

By using the 24 months (SPI_{24}), well defined seven wet cycles were identified in Northern Bahr El Ghazal State (NBGS) from the analyzed series there are major floods related with four of the cycles Figure 5.9 – 5.11 the same wet cycles were clearly observed.

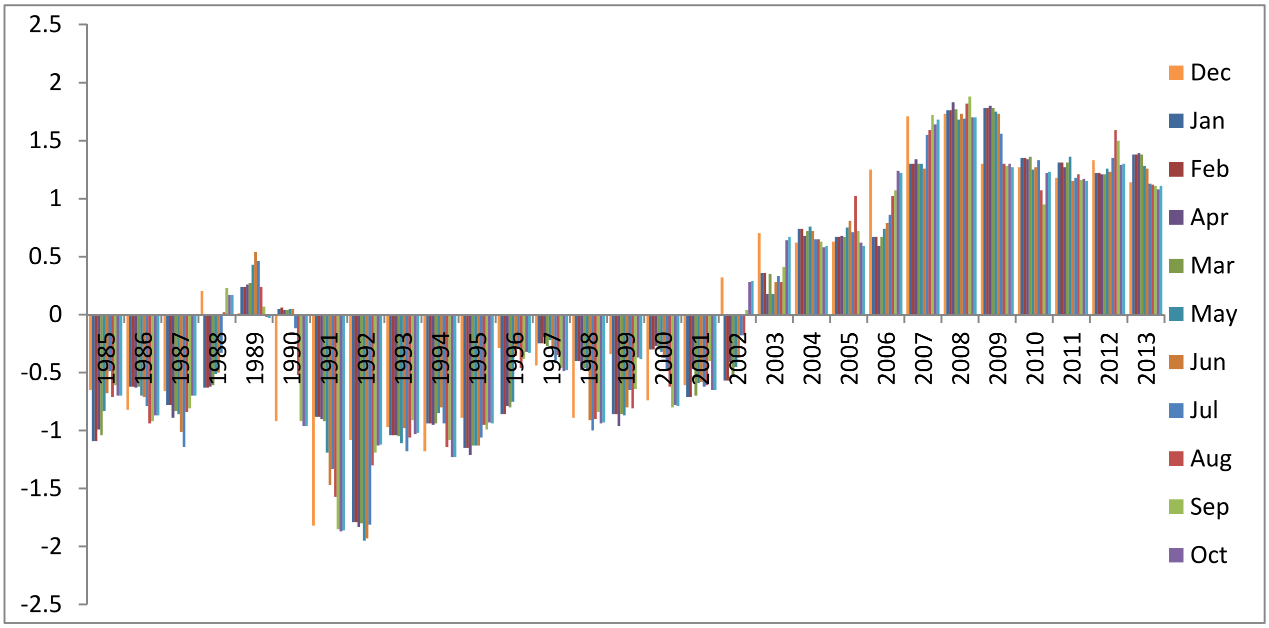


Figure 5.9: SPI values for Northern Bahr El Ghazal State calculated from the 1984-2013 months (SPI_{24}) series for periods of 24 months well-defined wet cycles

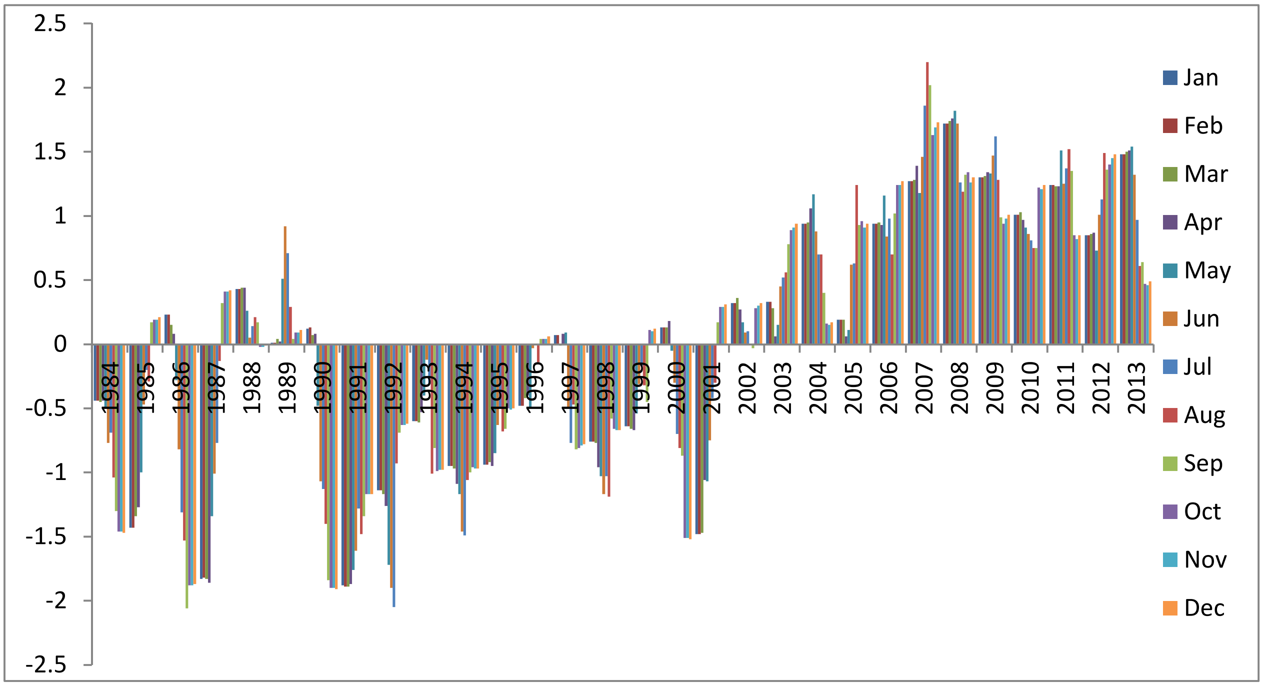


Figure 5.10: SPI values for Northern Bahr El Ghazal State calculated from the 1984-2013 series for periods of 12 months (SPI_{12}) well-defined wet cycles

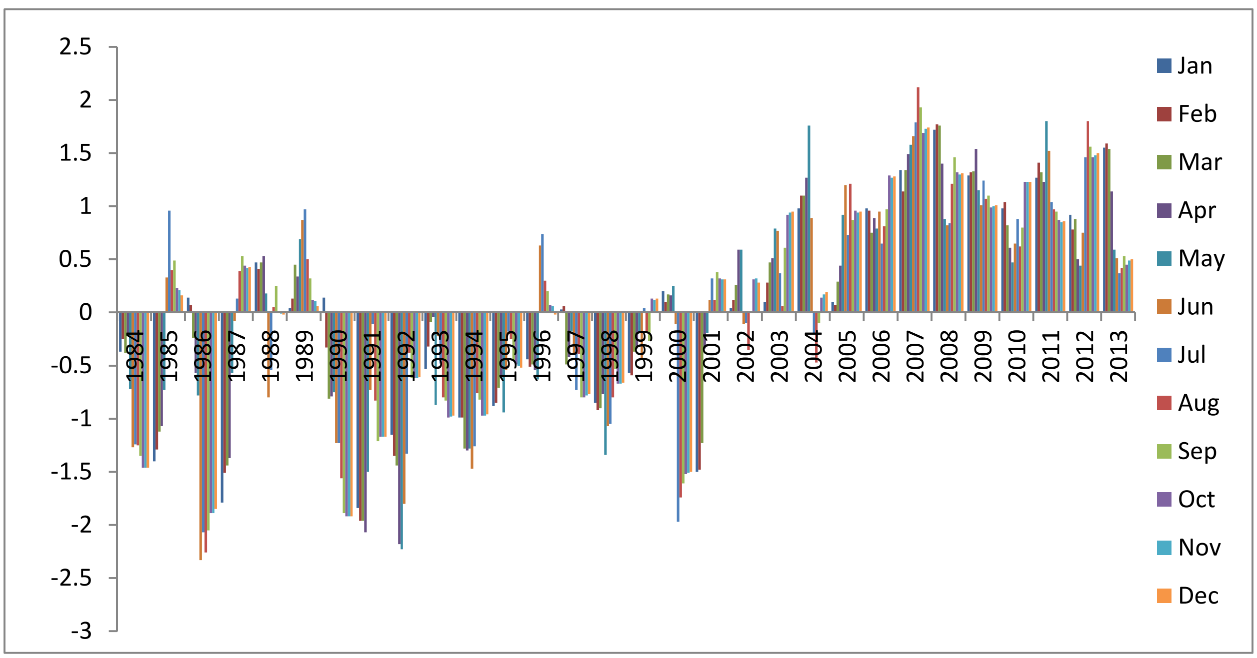


Figure 5.11: SPI values for Northern Bahr El Ghazal State calculated from the 1984-2013 series for periods of 9 months (SPI_9), well-defined wet cycles.

For the 3 month periods (SPI_3), and 6 month period (SPI_6) the SPI values for Northern Bahr El Ghazal State frequently fluctuated between very wet (1.5 to 1.99) and moderately wet (1 to 1.5) (Figure 5.12 and Figure 5.13). even though Northern Bahr El Ghazal State results from 1984 to 2000 show relatively longer period where the SPI values were near normal (-.99 to .99) to moderately dry (-1.49 to -1.99) (Figure 4.5). The longer timescales (12 and 24 months) have shown high SPI values from the 2000 to 2013 (Figure 5.9 to Figure 5.11) Imply abundance of water resources over the region, which can be related to trends of increased rainfall events and this also in line with what has been shown in figure 4.6, that there is a trend in the increase in rainfall events in the area and the year of change is 2000.

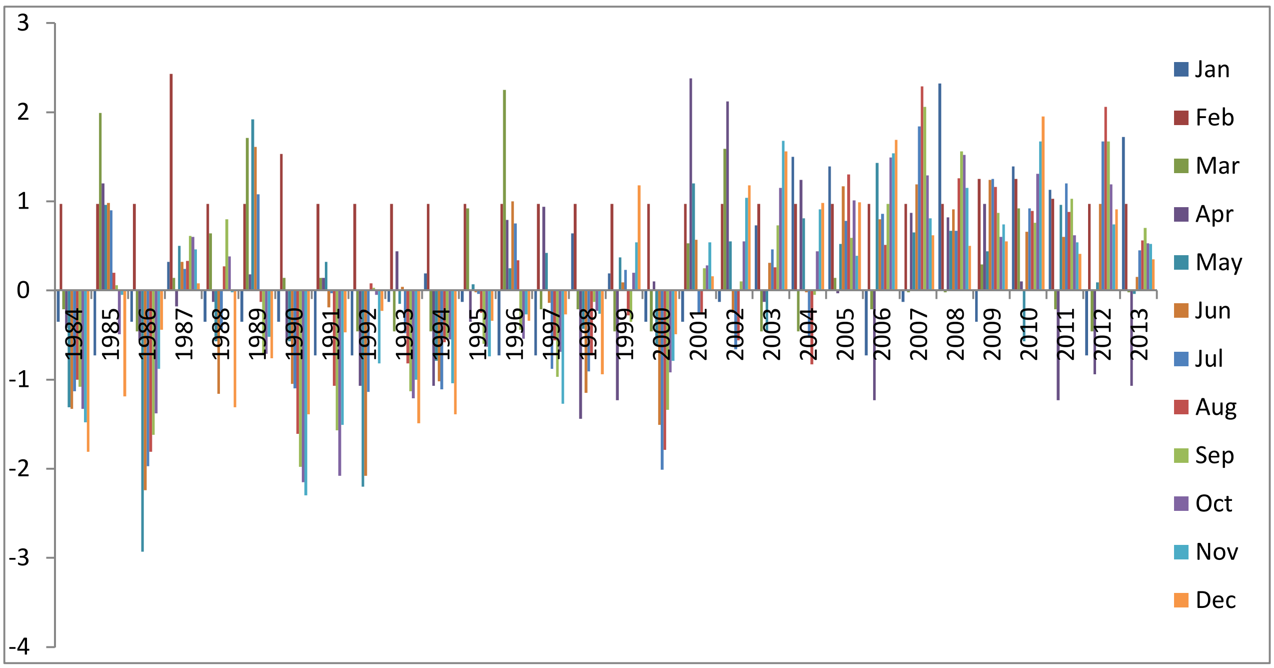


Figure 5.12: SPI values for Northern Bahr El Ghazal State calculated from the 1984-2013 series for periods of 3 months (SPI_3), SPI values frequently fluctuated between very wet (1.5 to 1.99) and moderately wet (1 to 1.5).

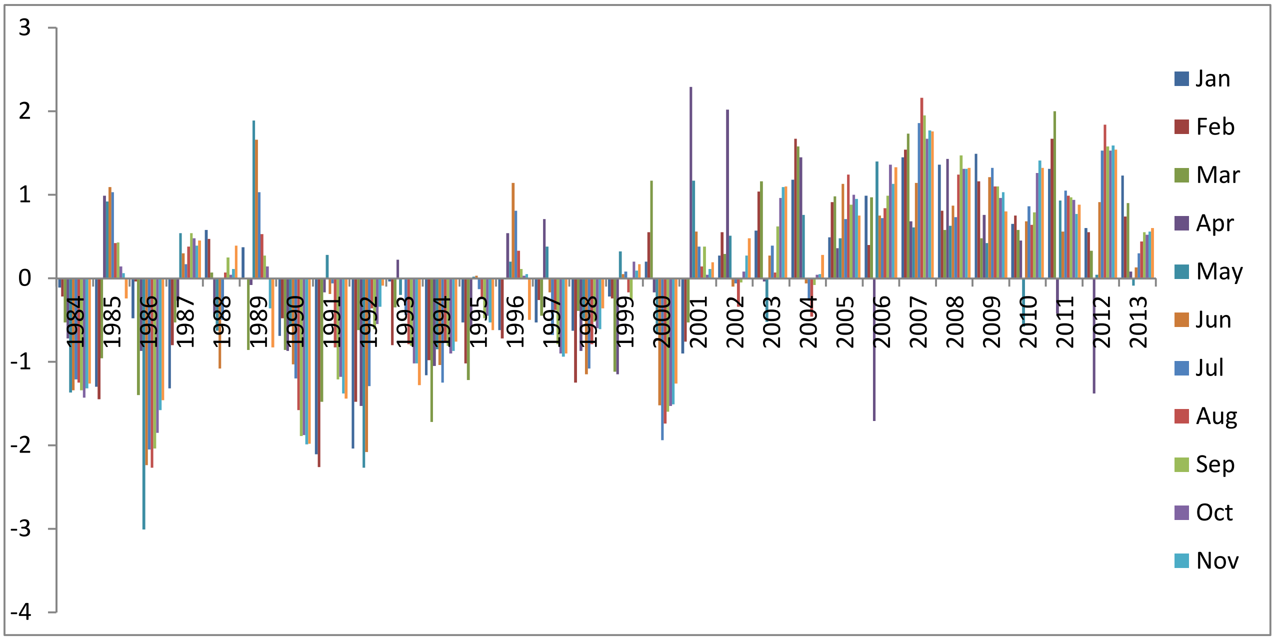


Figure 5.13: SPI values for Northern Bahr El Ghazal State calculated from the 1984-2013 series for period of 6 months (SPI_6), long period SPI values were near normal (-.99 to .99) to moderately dry (-1.49 to -1.99) from 1984 to 2013.

Northern Bahr El Ghazal State (NBGS) analysis of the SPI result for the period of record demonstrated that the longer time scales SPI_{24} and SPI_{12}, showed excessively humid cycles that were observed for NBGS from (Figure 5.9 to Figure 5.11 respectively). The wet cycle recognized were seven, with 2002 there was an observable increase of the SPI values were largely positive and at least four flooding event took place in 2007, 2008, 2010 and 2012 respectively and this is in line with the community response to the field work that has been curried in the study area figure (Figure 5.10 The most sever flood), the community confirmed these years have all witnessed flood events but different in frequency and magnitude. In some cases of those floods the SPI values were ranging from moderately wet, but the communities have suffered from flood and this could basically be referred to the low elevations of those areas affected and the bad drainage characteristics of the flood plain as demonstrated by the terrain of Digital elevation Data (DEM) the used for delineating the study area by using SWAT Model. The longer time scales (SPI_{24} and SPI_{12}) have provided an overall good perspective of the great quantity of water resources through the entire region, providing insight about the possible cause of increased of rainfall, surface follow and/or the increase of the water yield during the major flood events in Northern Bahr El Ghazal State area in 2007, 2008, 2010 and 2012 (Table 5.5).

Table 5.5: Rainfall, Water yield and surface flow in four flood events in Northern Bahr El Ghazal State.

Year	Month	Monthly Precipitation mm/month	Annual Precipitation mm/year	Surface flow mm/month	Water Yield mm/month
2007	July	394.69	1626.02	41.61	165.60
	August	451.41	1626.02	63.01	256.58
2008	August	413.05	1409.60	51.12	178.49
	September	349.70	1409.60	53.02	171.47
2010	October	333.56	1381.70	40.48	198.50
2012	August	423.46	1501.42	57.68	244.73

Flood Frequency analysis and return period:

Rainfall

Table 5.6: Simulated Rainfall:

Year	SWAT Model Rainfall Output												
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1983	0	0	0	3	48	131	96	234	158	51	1	0	724
1984	0	0	1	10	38	55	121	152	73	7	0	0	456
1985	0	0	26	33	118	198	208	130	219	18	1	0	950
1986	0	0	0	9	4	42	89	93	87	45	0	5	374
1987	0	1	2	12	128	118	157	287	240	85	1	0	1032
1988	0	0	7	9	63	43	193	314	226	15	1	0	870
1989	0	0	21	2	244	206	111	155	139	34	0	0	912
1990	1	2	0	7	72	44	101	102	22	14	0	0	365
1991	0	0	3	19	108	73	178	67	30	48	0	0	527
1992	0	0	0	4	21	37	154	321	75	61	2	0	676
1993	0	0	0	30	71	124	98	132	108	8	4	0	574
1994	0	0	0	4	65	56	95	242	102	12	2	0	579
1995	0	0	10	2	102	114	141	195	91	56	0	0	711
1996	0	0	31	11	83	258	154	153	149	56	0	0	895
1997	0	0	1	47	89	69	84	243	36	52	8	0	630
1998	0	0	1	1	84	31	123	214	180	23	4	0	662
1999	0	0	0	3	130	98	172	173	128	212	1	0	915
2000	0	0	0	21	56	15	61	151	95	46	1	0	446
2001	0	0	6	125	67	98	159	192	248	91	2	0	988
2002	0	0	19	93	34	67	168	161	236	203	9	0	990
2003	0	0	0	16	68	173	200	174	339	255	20	0	1244
2004	0	0	0	61	104	53	130	170	234	166	18	0	936
2005	0	0	3	15	126	237	137	415	128	185	0	0	1247
2006	0	0	1	2	216	104	196	301	279	296	2	0	1397
2007	0	0	2	43	108	230	395	451	258	102	37	0	1626
2008	0	0	2	41	112	185	181	413	350	126	0	0	1410
2009	1	1	2	46	90	254	253	247	250	115	16	0	1274
2010	2	0	8	13	58	232	238	218	266	334	13	0	1382
2011	1	0	0	3	174	118	293	275	226	116	0	0	1207
2012	0	0	0	5	110	232	350	423	206	151	24	0	1501
2013	0	0	2	2	103	133	202	276	228	89	21	0	1056

Table 5.7: The probabilities of exceedance of the Model Rainfall Output (mm)

Probability of Exceedance (%)	Return period (Year)	Magnitude Event
1	**100.00**	**1725.4**
2	**50.00**	**1631.1**
3	**33.33**	**1571.3**
4	**25.00**	**1526.3**
5	**20.00**	**1489.7**
6	**16.67**	**1458.5**
7	**14.29**	**1431.2**
8	**12.50**	**1406.7**
9	**11.11**	**1384.4**
10	10.00	1363.9
11	9.09	1344.9
12	8.33	1327.1
13	7.69	1310.2
14	7.14	1294.3
15	6.67	1279.1
16	6.25	1264.6
17	5.88	1250.6
18	5.56	1237.2
19	5.26	1224.2
20	5.00	1211.6
21	4.76	1199.5
22	4.55	1187.6
23	4.35	1176.1
24	4.17	1164.8
25	4.00	1153.8
26	3.85	1143.0
27	3.70	1132.4

Water-yield:

The simulated water yield used in the flood analysis was simulated for the year 1983 to 2013 on monthly and annually time step. The result is shown in Table 5.7 and Table 5.8.

Table 5.8: Simulated monthly water yield (ha-m) at diversion point

Year	Simulated Water YIELD												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec	Total
1983	1.8	0.99	0.82	0.61	3.74	20.32	10.53	53.88	67.22	40.37	20.42	3.04	224
1984	0.71	0.5	0.4	0.59	2.04	4.21	12.08	24.29	13.71	3.32	0.94	0.22	63
1985	0.17	0.12	2.07	3.93	16.54	51.64	50	51.07	89.44	42.62	20.94	3.59	332
1986	0.89	0.61	0.5	0.81	0.31	3.09	8.33	9.19	9.02	5.79	0.27	0.09	39
1987	0.37	0.05	0.05	0.64	15.44	16.17	32.9	87.8	96.91	83.94	36.45	12.37	383
1988	1.47	0.89	1.02	0.85	5.05	2.96	28.24	94.38	109.18	54.26	29.49	5.27	333
1989	1.05	0.72	2.4	0.48	40.12	74.14	47.19	52.64	63.17	30.48	8.77	1.07	322
1990	0.69	0.56	0.39	0.44	8.27	3.35	10.47	12.98	1.12	0.65	0.1	0.06	39
1991	0.04	0.03	0.12	0.53	12.3	8.78	40.36	9.08	4.56	9.71	0.59	0.2	86
1992	0.15	0.1	0.08	0.13	0.88	2.04	17.75	87.65	31.34	19.41	7.93	1.22	169
1993	0.59	0.4	0.34	2.47	6	15.14	10.91	20.31	23.54	4.03	1.6	0.35	86
1994	0.27	0.18	0.15	0.17	5.31	5.71	9.56	41.25	42.89	13.45	7.15	0.55	127
1995	0.42	0.29	1.05	0.18	11.08	14.41	21.43	52.55	32.82	27.3	7.05	0.87	169
1996	0.48	0.34	3.19	0.45	7.19	70.54	42.66	55.3	68.1	38.51	13.21	1.52	301
1997	0.77	0.52	0.46	3.46	11.85	6.04	7.3	72.19	12.23	16.56	4.8	0.73	137
1998	0.3	0.21	0.18	0.12	10.12	1.85	13.08	44.25	49.79	24.29	14.64	2.09	161
1999	0.57	0.39	0.33	0.3	14.38	12.16	31.81	37.27	48.57	104.84	39.97	18.66	309
2000	1.94	0.79	0.64	1.78	5.61	0.69	5.47	23.39	12.54	10.53	0.42	0.2	64
2001	0.16	0.11	0.48	21.26	7.17	10.78	25.29	54.04	82.17	72.49	35.95	14.34	324
2002	1.19	0.77	2.08	14.64	4.56	6.92	33.65	42.26	91.03	78.22	59.25	21.77	356
2003	2.17	0.81	0.68	1.52	6.25	23.62	43.89	57.85	174.97	181.79	68.42	35.43	597
2004	5.66	1.34	1.08	7.01	15.77	6.52	15.5	40.07	80.29	99.05	36.81	14.04	323
2005	1.21	0.7	0.62	1.26	16.77	57.24	48.6	176.8	100.58	135.5	53.68	22.69	616
2006	2.43	1.22	1.04	0.76	39.62	20.55	52.53	127.8	150.82	192.95	82.47	48.84	721
2007	11.38	1.78	1.4	5.16	13.77	56.41	165.6	256.6	214.86	119.3	60.65	21.33	928
2008	2.62	1.6	1.34	3.46	20.13	42.31	47.07	171.5	234.25	144.43	69.27	30.93	769
2009	3.09	1.53	1.32	4.01	12.59	51.37	95.65	128.5	134.12	89.11	46.58	14.26	582
2010	1.94	1.08	1.13	1.14	4.12	41.65	71.65	84.62	148.31	198.5	85.7	49.98	690
2011	12.25	1.78	1.36	1.01	25.99	29.59	106	131.8	137.77	97.73	47.39	17.86	611
2012	2.01	1.2	0.96	0.84	14.59	51.18	116	244.7	167.64	133.05	62.24	28.94	823
2013	3.47	1.53	1.39	0.95	12.01	23.36	45.84	101.5	114.12	77.6	39.8	12.64	434

Table 5.9: The probabilities of exceedance of Water yield (ha-m)

Probability of Exceedance (%)	Return period (Year)	Magnitude Event
5	20.00	773.2
10	10.00	681.7
15	6.67	619.9
20	5.00	570.8
25	4.00	528.7
30	3.33	490.9
35	2.86	455.9
40	2.50	422.7
45	2.22	390.5
50	2.00	359.0
55	1.82	327.4
60	1.67	295.3
65	**1.54**	**262.1**
70	**1.43**	**227.0**
75	**1.33**	**189.2**
80	1.25	147.1
85	1.18	98.0
90	1.11	36.2
95	1.05	0.0

Flood frequency analysis is a technique used by hydrologists to predict flow values corresponding to specific return periods or probabilities along a river or rain storm. The application of statistical frequency curves to floods was first introduced by Gumbel. Using annual peak flow data that is available for a number of years, flood frequency analysis is used to calculate statistical information such as mean, standard deviation and skewness which is further used to create frequency distribution graphs.

There are many frequency distributions from the existing statistical distributions such as Gumbel, Normal, Log-normal, Exponential, Weibull, Pearson and Log-Pearson. In this study Weibull was selected for the probability distribution for the annual maxima rainfall data, flood frequency curves were plotted. These tables (5.7 and table 5.9) then can used to estimate the design flow values corresponding to specific return periods which can be used for flood planning purposes for this study. Flood frequency plays a vital role in providing estimates of recurrence of floods which is used in designing structures such as dams, bridges, culverts, levees, highways, sewage disposal plants, waterworks and industrial buildings . In order to evaluate the optimum design specification for hydraulic structures, and to prevent over-designing or under designing, the use of this vital statistical tool were applied to create flood frequency estimates. These estimates are useful in providing a measurement parameter to analyze the damage corresponding to specific flows during floods. Along with hydraulic design, flood frequency estimates are also useful in flood insurance and flood zoning activities. Accurate estimation of flood frequency not only helps engineers in designing safe structures but also in protection against economic losses due to maintenance of structures.

5.3 Flood Distribution in Northern Bahr El Ghazal State:

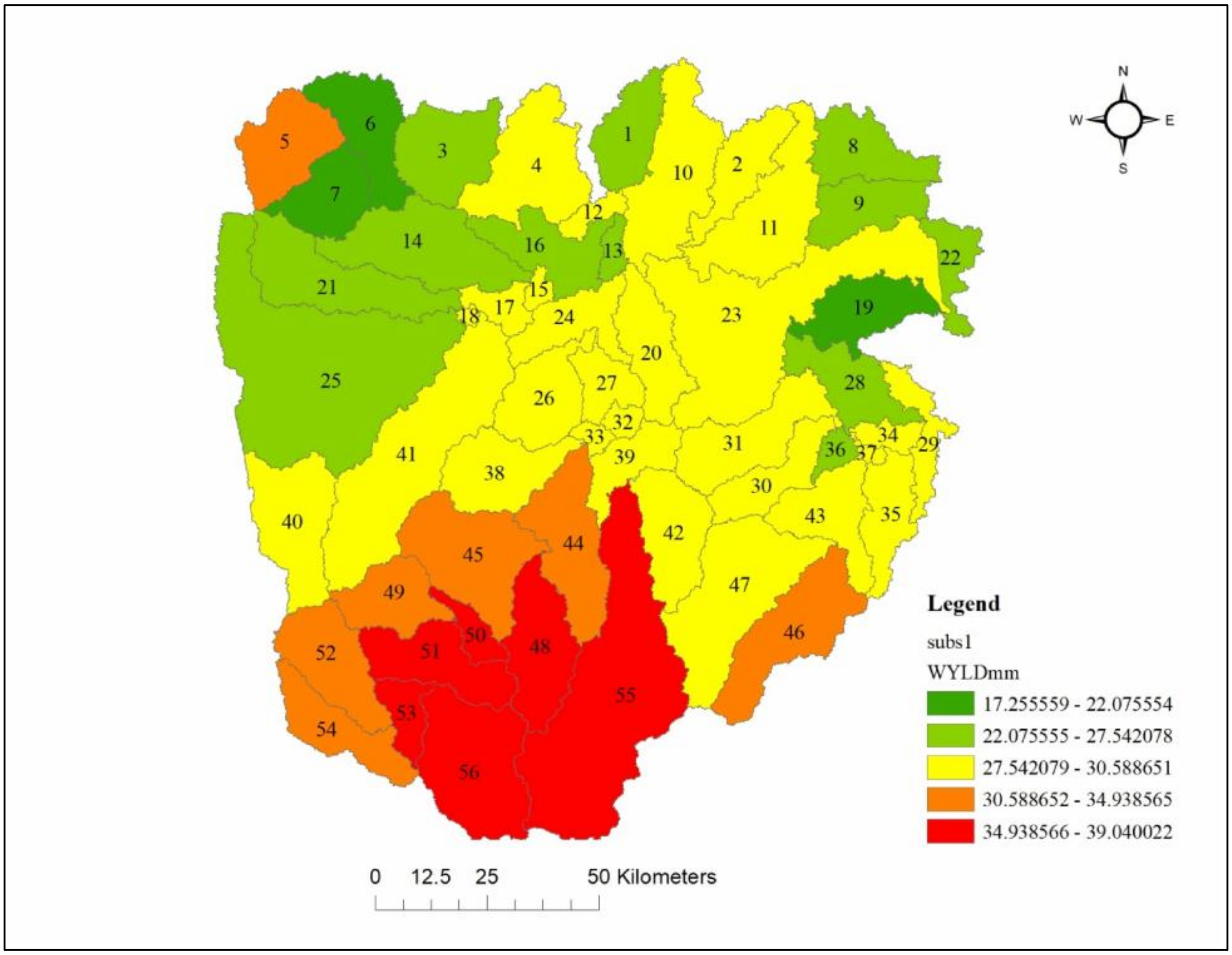


Figure 5.14: Water-yield distribution with respect to sub-basin

The water yield distribution analysis indicates that the larger flood can only be generated when the water yield in the whole parts of the basin is high. The above map illustrates the water-yield distribution according to the average amount of the water yield per basin and it show the southern part of the study area are of the highest in term of water yield or flood water. The study found that most of the study area is problematic to flood and in addition to the low slope of less than 10% add more susceptibility for flood to the local community. This can clearly explain the severe impact on the community due to the availability of water in most of the study area with large amount of water the inundated water were found to be the most factor that to contribute to flood impact such as spread of diseases like Malaria, Typhoid, Bilharzia because of the availability of the inundated water. Therefore, water-yield could be used as determining factor for the severity of a sub-basin in long term.

5.4. Flood Impact on Households

5.4.1 Characteristics of Households

Table: 5.10: Households levels of Education and Occupations

Characteristic	Category	Frequency	Percent
Gender	Male	83	79.8%
	Female	21	20.2%
Highest level of education	Primary	17	16.3%
	Secondary	46	44.2%
	Tertiary	17	16.3%
	No formal education	24	23.1%
Family size	1-3	7	6.7%
	4-6	32	30.8%
	7-9	28	26.9%
	10-12	14	13.5%
	12	23	22.1%
Years lived in the area	< 5 years	11	10.6%
	5-10 years	47	45.2%
	11-15 years	8	7.7%
	16-20 years	5	4.8%
	> 20 years	33	31.7%
Number of income generating activities	0	7	6.7%
	1	53	51.0%
	2	33	31.7%
	3	11	10.6%
Occupation	Salary work	63	64.9%
	Crop cultivation	54	55.7%
	Labor	11	11.3%
	Trading	10	10.3%
	Livestock raising	8	8.2%
	Running small businesses	4	4.1%
	Gifts and food aids	1	1.0%

Source: (Researcher 2015)

The study to determine flood frequency and flood impacts on Households in Northern Bahr El Ghazal State of South Sudan was conducted among 104 respondents. The sample mainly 83(79.8%) comprised of males and individuals who had secondary 46(44.2%) and tertiary education 17(16.3%). However, 24(23.1%) did not have formal education and 17(16.3%) only had primary education. Most households 60(57.7%) had 4-9 family members respectively. Most respondents had started living in the county more than 5 years ago and had more than one income generating activities. Greater proportion of the respondents relied on salary work 63(64.9%) and crop cultivation 54(55.7%) as sources of income for food. More information on demographic characteristics is as indicated in Table 5.10 above.

The sample mainly 79.8% comprised of males and individuals who had secondary education stands at 44.2% followed by tertiary education 16.3%. However, 23.1% did not have formal education and 16.3% only had primary education, the level of education can affect the sources of income. For instance those with formal education have higher chance to get formal employment and not necessarily depend on primary products which are likely affected by floods.

Education also has impacts on their coping mechanisms because those with formal employment as a result of education they do not need to sell or bid their properties to cope with flood impacts. They can depends on their employment salary to cater for their needs after floods induced losses and their children are likely have a better chance from dropping out of school. Unlike households with low level of education that entirely depend on agricultural products for their livelihoods and majority of them loss their income generation activity when it floods.

5.4.2 Flood frequency and inundation period

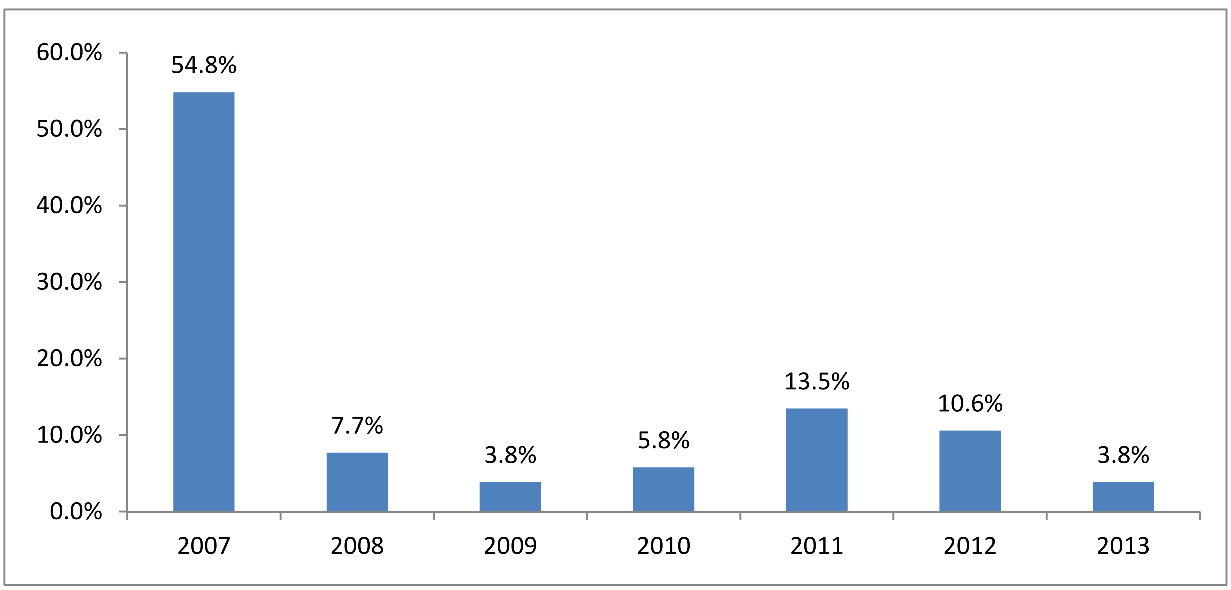
Flood events are common during the rainy season. The study found out that the flooding and the area under inundation are increasing in the study area in the last two decade. It is learnt that Effects incurred due to flood are relatively increasing every year. People reported that different secondary effects due to flood are in increasing trend in the study area. Flood frequency was reported to mainly 52.9% occur annually in the past 7 years. Duration of the flood water inundation was mostly 9 to 12 weeks 65.4%.

This long period of inundation might in the other hand lead to many other impact and spread of diseases such as Malaria, Typhoid and Diarrhea as secondary effects for flood. In the hypothesis (the flood frequency and flood inundation has no impact on households) it has been found that: there are no enough evidence for the hypothesis to be accepted. There was significant relationship between flood frequency and flood water inundation (p-value=0.025). Most annual flooding took longer durations for flood water inundation as shown in Table 5.11 below.

Table: 5.11: Flood duration and inundation period

Flood duration in weeks	Flood occurrences in a year									
	Three Times		Two Times		Once		Not Yearly		Total	
	F	%	F	%	F	%	F	%	F	%
9 - 12	16	15.4%	10	9.6%	37	35.6%	5	4.8%	68	65.4%
5 - 8	1	1.0%	2	1.9%	8	7.7%	3	2.9%	14	13.5%
3 - 4	1	1.0%	3	2.9%	9	8.7%	0	0.0%	13	12.5%
≤ 2	6	5.8%	1	1.0%	1	1.0%	1	1.0%	9	8.7%
Total	24	23.1%	16	15.4%	55	52.9%	9	8.7%	104	100.0%

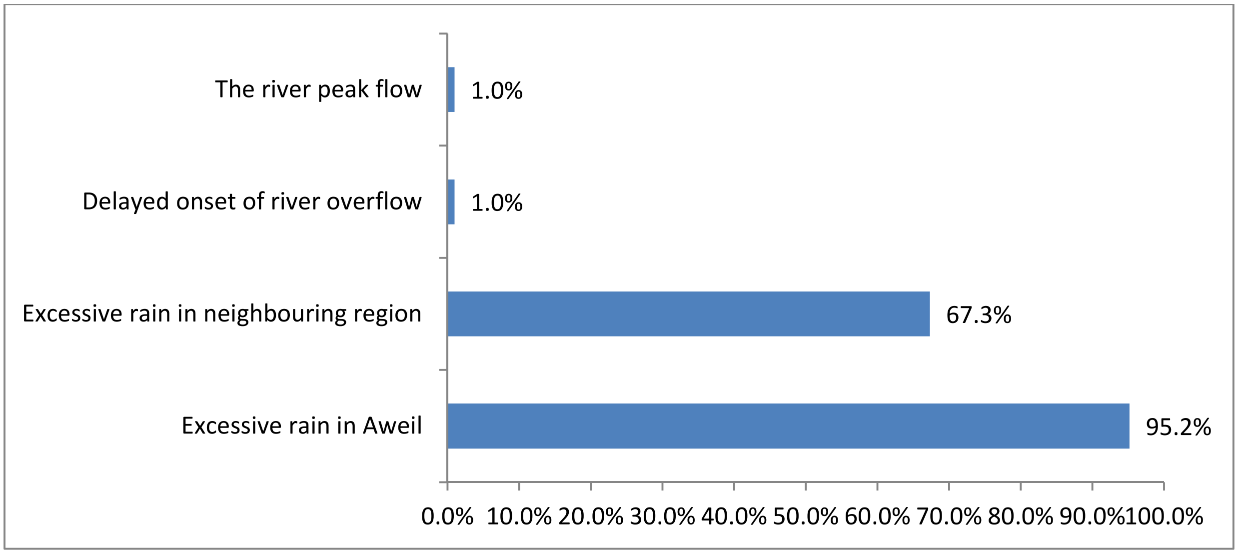
5.4.3 Flood Severity and Magnitude



Source (Researcher 2015)

Figure 5.15: The higher flood magnitude

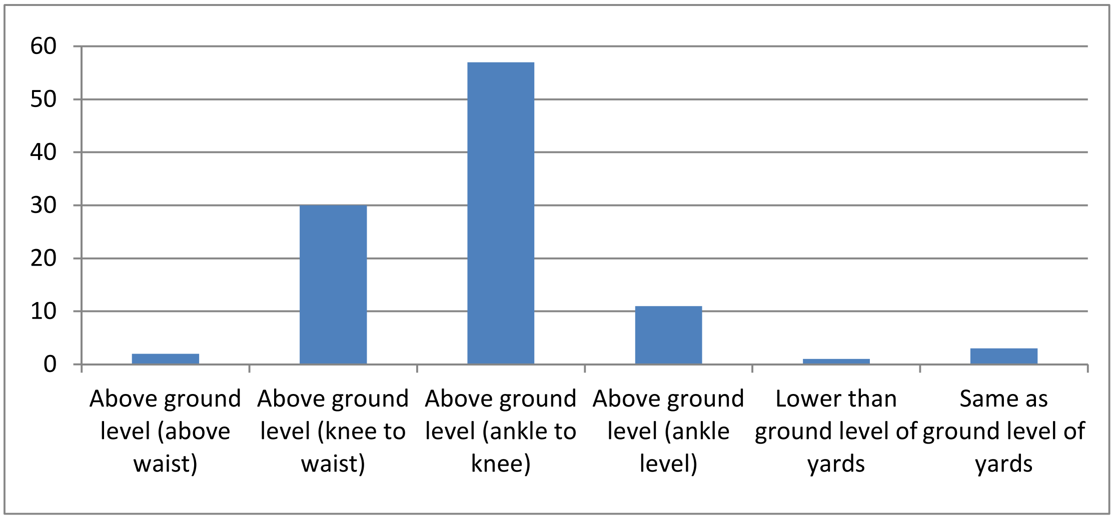
Figure 5.15 shows that the higher magnitude flood in Northern Bahr El Ghazal State from 2007 to 2013 was in 2007 as reported by 54.8% of the respondents as indicated in Figure 5.15. The analysis of the SWAT model data based on floods occurring in Northern Bahr El Ghazal State of South Sudan during the last two decades, the analysis of the rainfall in the area and the amount of water yield has also spotlighting particularly on the 2007 was the biggest flood peak in the last 7 years figure 5.9 to figure 5.11). And also they reported that there are trends in flood occurrence yearly especially 2008, 2009, 2010, 2011, 2012 and 2013 in the last 10 years. This can be referring to the increase in the amount of rainfall in the area.



Source: (Researcher 2015)

Figure 5.16: Source of Flood in the Study Area

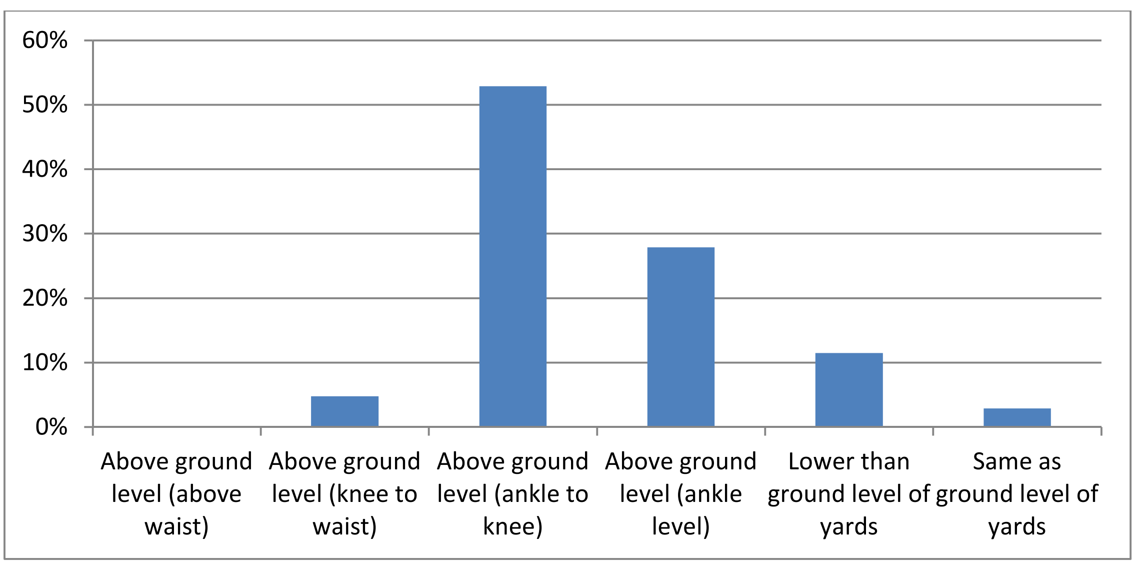
Excessive rain in Northern Bahr El Ghazal region and neighboring region were found to be the main contributors to the severity of flood in the study area as shown in figure 4.5 above it shows that 95% of the water as a result of excessive rain in Northern Bahr El Ghazal and 67% clam the flood water comes from the neighboring region mainly Central Africa and DR Congo and 1% reported it is from the river flow. The study are is a flat land from the west to the east toward the Sudd Wetland which has been classified by Ramsar as the biggest topical wetland in Africa in 2006 and Northern Bahr El Ghazal is a lowland and some studies has classified the study area as a part of the Sudd land in the past therefore it is a passage of the water flowing from Central Africa and DR Congo on it is way to the Sudd wetland.



Source: (Researcher 2015)

Figure: 5.17: The water heights just outside respondent' yard (compound)

The depth of water just outside respondent' yard (compound) was mainly above ground level (ankle to knee) as indicated in figure 4.16 this to a great level indicate the severity of flood in the study are which can affect movement, activities and also can led to the end of some generating activity for income such as daily marketing, firewood collection activities, brick making…etc leaving households vulnerable for poverty as well as a lot of disease prevalence.

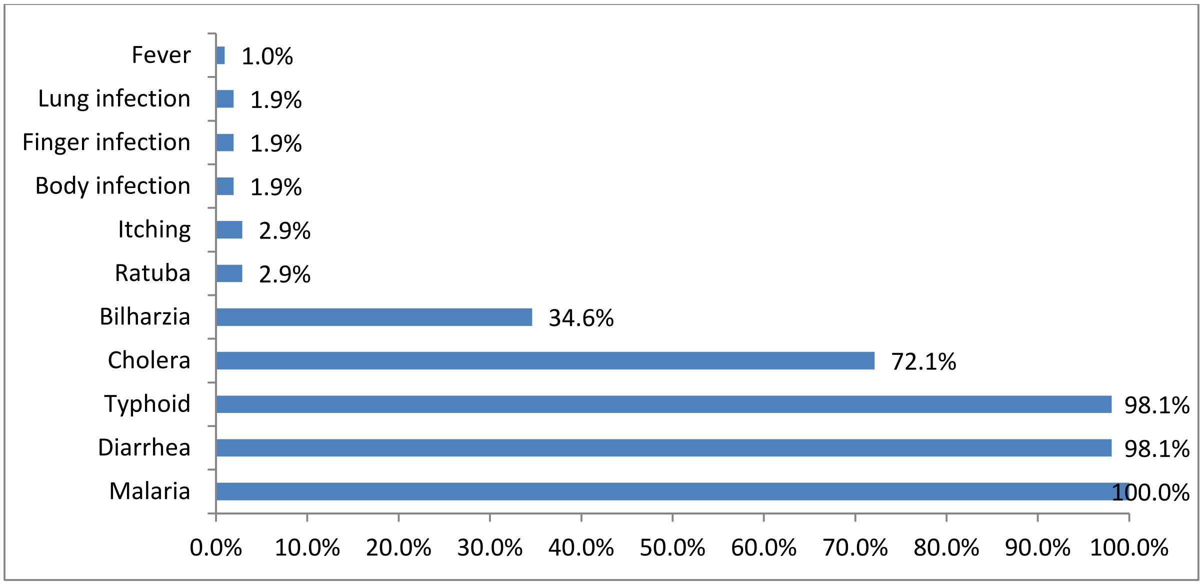


Source (Researcher 2015)

Figure: 5.18: The water heights inside respondent' house

The heights of water inside respondent' house was mainly above ground level (ankle to knee) as this also causes many effects on the households including damage of physical assets such as houses and pit latrines which can let to serious health hazards in the other hand it can also cause a lot of damages to the household's properties such as beds, tables and other valuable furniture. People in the study area shared that there is increasing trend of different secondary effects due to flood in the study area.

5.4.5 Flood related morbidity and mortality

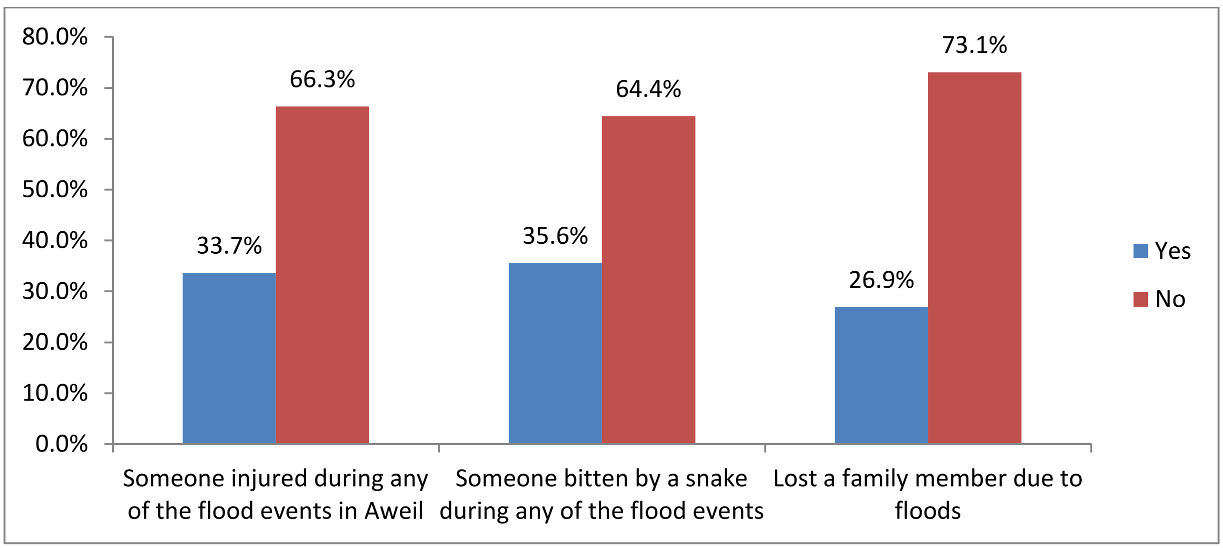


Source: (Researcher 2015)

Figure 5.19: Diseases most prevalent during flood periods

The research also revealed that out of the all the 104 sampled households directed having at all the members of their household getting sick one or more during the floods. Malaria was amongst the most significant diseases experienced an the sampled households have affected at least once of the respondents with a 100%, Typhoid 98%, diarrhea 98%, Cholera72%, Bilharzias 34%, Arthritis 2.9%, itching 2.9%, and body infection (skin diseases), finger infection and lung infection 1.9%. 65.4% of respondents of the study said that "the flood water was stagnant for 9-12 weeks and the road and transports were under water and consequently respondent's family members were unable to move on the flood water. For this reason they easily suffer from fever, Malaria as a result of mosquito breeding, Typhoid, diarrhea and snake bites. They have also reported that the economic cost was very high to treat themselves from such flood water borne diseases.

Never the less, other sampled households indicated that they experienced more disease post the flood period, for instance, outbreak such as itching, cough, scabies, sores and rash. Furthermore the survey recognized that the source of water for households was mainly ponds (big Artificial ponds for reserving drinking water), and that household members falling sick followed by a small group of households who indicated Hand-pumps water sources as their main source of drinking water. Therefore, households will continue to be vulnerable to disease outbreak as long as the boreholes (Ponds) continue to be their main source of their drinking water. This is as a result of increased contamination that occurs during flooding. Despite Hand-pumps being the safest water source for drinking, it has been reported by respondents that carrying of the water by households for a long distance from the source has led to increased abortion for pregnant women. As for that almost half of households their main source of drinking water from the river have underwent many water borne diseases such as itching, skin disease and cholera as well.



Source: (Researcher 2015)

Figure 5.20: Flood Injuries and Causalities

A proportion of 35(33.7%) respondents knew of a person who had been injured during the flood events mostly between 2012 and 2014. Moreover, there were a proportion of 37(35.6%) respondents a person who had been bitten by a snake during the flood events in NBGS mostly in 2014 flood due to water logging into snakes wholes, snakes as a result find it is ways to households compounds then bit them. In addition, a proportion of 28(26.9%) respondents had family members due to floods. Most 17(60.7%) deaths were caused by flood-related diseases while 11(39.3%) were caused by drowning from flood waters as indicated in Figure 5.20.

5.4.6 Flood effects on resident households& the environment

Among the major effects ever incurred due to floods in the last two decades, as reported by respondents included Housing Damage (91.3%); displacement (76%); Health problem (76%); Damage of crops (76%); and Loss of properties (74%). Others were as indicated in Table 5.12 below.

Table 5.12: Effects incurred due to floods

Effects incurred due to floods	Frequency	Percent
Housing damage	95	91.3%
Health problem	79	76.0%
Displacement	79	76.0%
Damage of crops	79	76.0%
Loss of properties	77	74.0%
Damage of infrastructure	68	65.4%
School dropout	66	63.5%
Damage of bridges and roads	61	58.7%
Loss of income generating activity	60	57.7%
Loss of livestock	33	31.7%
Loss of fowls	22	21.2%

The study area is one of the most susceptible areas of flooding in that South Sudan. Flood occurs every year with a very devastating flood impact especially on households. The majority of the people in Northern Bahr El Ghazal state depend on seasonal agricultural product in this area. However, there are a lot of flood induced effects to the agricultural sector annually. Most of the households (76%) of the study said that the damage of crops as well as house damage was the most affected during the flood.

5.4.6.1 Housing damage

From the field observation the researcher observed that the most of the house is made with either grass wall (47%) and the roofing is grass or the mud wall (26%) and the roofing is grass, roofing of most of the houses were made from grass (74%).

And very few respondents indicated that they used timber (6.7%), bamboo (6.7%) and stone only (2.9%) for the wall and (12%) indicated they used Iron sheets (Zink) roofing in addition to (13.5%) has used tents. Among the one hundred and four (104) sampled households, more than 91% respondents indicated that their houses collapsed due to excessive impacts of floods while the rest had their houses together. Furthermost, majority of the people whose houses damaged due to floods, reported that the flood water enter their houses every year due to excessive water inundation in the area and the low leveling of the house table 5.13 below show the typology of the house and the heights of the house as indicated by the respondents.

Table: 5.13: Typology of the house and the floor heights of the house

Typology of the house	Categories	Frequency	Percent
Type of housing walls	Grass	49	47.1%
	Mud	28	26.9%
	Bricks	10	9.6%
	Timber	7	6.7%
	Bamboo	7	6.7%
	Stone	3	2.9%
Type of house roofing	Grass	77	74.0%
	Tents	14	13.5%
	Iron sheet (zinki)	13	12.5%

Source: (Researcher 2015)

Source: (Researcher 2015)

Plate 5.1: Flood affected house

About (76%) of the respondents reported they have been displaced from their houses after severely they were impacted by floods. And there are no safe houses available. All respondents of the study said “the flood water enters in their house and the level of water rises day by day”. 76(73%) respondents reported “their houses are at the same level of the ground”, and 19(18%) above the ground level (ankle level) while 4(3.8%) above ground level (ankle to knee) Almost all the respondents of all said “a lots of money will be needed just after the flood to renovate or prepare house for living”. The respondents revealed that children of the displaced households were sent to stay with other relatives during flood. This has led to disrupt their social lives as well as children drop out of school as a result. As indicated in figure 5.17 and figure 5.18 above the increase of water level just outside the respondent’s house and the water level inside the respondent’s house most of the respondents have shifted to higher ground inside the house temporarily. It is important to mention that some households altogether have shifted to a new area such as (Mabeer). There was more observable and prominent houses damage.

The extent of damage to the houses was to a great extend depends on the roofing and wall structures. It was found that continuous rain can cause unlike roofs with CGI sheets, straw roofs exhibited water leakage. Further, it was reported that mud walls that soak water were collapsed easily. It was found that this mud-made houses were more sustainable and their protection capability is very low. Therefore, continuous rain during the monsoon period water makes the house wall becomes soft and loos. Houses with cemented pillar, brick wall and concrete houses are partially damaged from the flood while thatched houses are severely damaged after flooding whereas.

Table: 5.14: Floor heights of the Houses

	Characteristic		
Floor height of house	Same as ground level	76	73.1%
	Above ground level (ankle level)	19	18.3%
	Above ground level (ankle to knee)	4	3.8%
	Knee to waist	3	2.9%
	Lower than ground	2	1.9%

Source: (Researcher 2015)

Source: (Researcher 2015)
Plate 5.2: Floor height of a house

5.4.6.2 Loss of Livestock

Mostly all the population depends on their livestock as a source of food dowry and pride. Especially cows, sheep and goats are the types of livestock at the study area. Most of the respondents said that the livestock are normally migrate to a higher ground every year and the loss was on the few left for the immediate family needs but most of their livestock were kept away.

5.4.6.3 Damage of Crops

Most of the households in the study area indicated that crop fields were damaged fully by floods. It was also reported that most of the crops were damaged by floods; most of it was the main year production. The long term flood water inundation was the main problem, reported by the respondents. Most of the respondents complain that, the main crops were under the flood water during the flood time. Seventy nine respondents (76%) of households reported that flood water entre into the crop land and cause large damages of the crops. Most of the respondents said that the reason for famine in the area which has been declared was because of the loss of crops.

Majority of the respondents said that flash flood which happens suddenly could not allow them to collect crop in due time. Accordingly the total crop production goes to be damaged. During flood, Sometimes, most of the ponds are over flown by the flood water so that, people lost their income generating activities due to insufficient fish in the pond especially fisher men.

5.4.7 Knowledge of flood and flood awareness

Only 11(10.6%) reported existence of flood warning in the area including excessive and continuous rainfall, marking banks of sand and relatives in upper areas. Majority was aware (76.9%) and had someone who informed them (78.8%) of what to do before, during and after flood event had occurred. Only 8(7.7%) had a first-aid kit or improvised facility for the same at the household and only half of these households with a first-aid kit had a member trained in administering first-aid. It is learnt that flood awareness is very important tool to make people more aware of the flood to avoid as possible flood hazards and to embark early preparedness methods such as collection the crops before flood.

More-over, knowledge about flood will change attitudes and households behavior toward better flood preparedness. The simulation results in this study from tables 4.7 and table 4.9 then can used to estimate the design flow values corresponding to specific return periods which can be used for flood planning purposes for this study. Flood frequency plays a vital role in providing estimates of recurrence of floods which is used in designing structures such as dams, bridges, culverts, levees, highways, sewage disposal plants, waterworks and industrial buildings . In order to evaluate the optimum design specification for hydraulic structures, and to prevent over-designing or under designing

Table: 5.15: Knowledge of flood and Flood Awareness

	Yes		No	
	F	%	F	%
Presence of any flood warning in the area	11	10.6%	93	89.4%
Awareness of what to do before, during and after flood event	80	76.9%	24	23.1%
Anyone who informs on what to do before, during and after flood event	82	78.8%	22	21.2%
Presence of household first-aid kit or improvised facility for the same	8	7.7%	96	92.3%

Source: (Researcher 2015)

5.5 Flood preparedness techniques

Type of housing walls (47.1%) and roofing (74%) was mostly grass. Floor height of majority (73.1%) houses was same as ground level. Majority household used making the ground (37.5%); digging new ditches (29.8%) and leveling the houses (15.4%) as flood preparedness methods to prepare for the flood events and their impact. Only 48(46.2%) thought that the preparedness methods they had been using had helped to reduce effects of floods by slightly reduced water getting in house and drainage of water.

Table: 5.16: Flood Preparedness Methods

Method	Frequency	Percent
Increasing the level of the ground (Sand)	39	37.5%
Digging new ditches	31	29.8%
Leveling the houses	16	15.4%
Construct boundary wall around house	16	15.4%
Making sand banks	15	14.4%
None	11	10.6%
Migration	10	9.6%
Cleaning old ditch	9	8.7%
Housing repairing	5	4.8%
Dyke	2	1.9%
Making alwak (traditional type of house)	0	0.0%

Since flood risk have a tendency to rise in many areas, So as to improve flood preparedness, structural and non-structural flood preparedness methods has to be introduced such as dikes, dams and flood control reservoirs, diversions, etc. it worth mentioning that the study area has no any of these methods. In other hand improving water storage on the land surface and underground (water harvest) and also other non-structural measures includes flood forecasting–warning system; awareness raising as well as zoning; insurance. Structural methods, both dikes and dams of different sizes, have a very long tradition (thousands of years) they play a vital role in flood prevention.

Moreover, reservoirs serve multiple purposes: flood control, hydropower, irrigation, water supply, navigation, etc. Recent floods events have shown that that continuous maintenance as well as strengthening and heightening of the available dikes alone is not sufficient to prevent extreme disasters. For extremes flows, it is unlikely to avoid damage and one can only struggle towards reducing losses, instate. Most importantly is to build up a stronger system of flood forecasting–warning– response and to improve the operation of existing storage reservoirs. There are many advances have been recently reported in different aspects of flood forecasting (e.g. Paudyal, 2002; Maskey & Guinot, 2002; Campolo *et al*., 2003) and flow forecasting (e.g. Xia, 2002; Xiong & O’Connor, 2002; Chibanga *et al*., 2003; Cigizoglu, 2003).

5.5.1 Flood coping mechanisms and response

Households majorly used savings, shifted to higher grounds and repaired their damaged houses in their attempts to cope with flood events.

Table 5.17: Coping mechanisms used by households

Coping mechanisms used by households	Count	Percent
Using savings	23	25.3%
Shifting to a higher ground	23	25.3%
Housing repairing	21	23.1%
Borrowing money	19	20.9%
Selling properties to get income	17	18.7%
Using social connections	10	11.0%
New income generation activities	10	11.0%
Help from NGOs or charities	9	9.9%
Migrate to safer places	7	7.7%
Community group repairing houses	7	7.7%
Assistance from government	3	3.3%
Sharing resources in community	2	2.2%

Source: (Researcher 2015)

Only 44(42.3%) of respondents received support for flood impacts with nearly half of these receiving support from NGOs. Most of the support was inform of provision of shelter after flood events as indicated in Table 4.17 below.

Table 5.18: Sources and the types of household assistance to cope with impacts of flood

	Shelter	**Financial assistance**	**Borrow money**	**Food assistance**	**Material assistance**	**Medical assistance**	**Total**
Social network	2	0	3	0	0	0	6
Relatives	5	6	4	1	0	0	15
Neighbor	2	0	1	0	0	0	3
Friend	0	5	5	0	0	2	12
Government agency	1	1	0	0	2	1	3
NGO	10	1	0	12	13	3	21
Religious organization	0	0	0	1	1	1	1
Total	17	11	13	13	14	6	44

Source: (Researcher 2015)

36(34.6%) perceived that the coping mechanisms they had been using had helped to reduce effects of floods citing slight prevention of water from getting in house as some of the outcomes while those who perceived otherwise cited inadequacy and lack of sustainability. Only 11(11.5%) had fully recovered from effects of a flood before the next flood within an average period of 3 to 6 months mostly. To accelerate recovery from flood loses majority 82(78.8%) thought that Widening of water channels would work best.

Table 5.19: What needs to be done to accelerate recovery from flood loses

What needs to be done to accelerate recovery from flood loses	Count	Percent
Widening of water channels	82	78.8%
Construction of wider roads	37	35.6%
Creation of dams	10	9.6%
Financial and food aid	9	8.7%
Assessment and flood preparedness	8	7.7%
Provision of shelter	6	5.8%
Provision of medical services	6	5.8%
Provision of clean drinking water	5	4.8%
Creation of awareness on disease management	4	3.8%
Water and hand pumps	3	2.9%
Provision of mosquito nets	3	2.9%
Relocation	2	1.9%
Banking of sand	2	1.9%
Level houses by sand	1	1.0%

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

The study on flood impacts in Northern Bahr El Ghazal State of South Sudan using spatial analysis techniques made the following conclusions based on the results:

1. The SWAT model was a very useful in simulating flood occurrence on both monthly and yearly bases.
2. The Subbasins that are most problematic with respect to water-yield were found to be as follow: Highly flooded Subbasins (48, 50, 51, 53, 55 and 56), Moderately flooded Subbasins (5, 44, 45, 46, 49, 52 and 54). These Subbasins considered being problematic because the amount of water-yield in these basin is very high which leads to more flood water in these Subbasins.
3. Households health situation was the most affected by flood due to increase prevalence of waterborne diseases and poor food supply and damage social and physical infrastructures.
4. The individual household ability to cope with the impacts of floods did not depend on external support but on internal socio-economic and geographic characteristics such as borrowing money from relatives, communal support, ability to relocate to less vulnerable locations and the amount of savings and property.

6.2 Recommendations

Based on the above conclusions, the study made both policy recommendations and research recommendations on flood situations in Northern Bahr El Ghazal state of South Sudan.

6.2.1 Policy Recommendations

This study made the policy recommendations to assist authorities concerned in addressing the flood problem in South Sudan. The recommendations are grounded in scientific findings as follows:

1- Due to lock of good observations record on flood and associated meteorological conditions the national government and the local authorities should rely on suitable hydrological models such as SWAT in flood management.

2- Flood control measures need improvement in the most problematic subbasins through drainage channels widening and flood control dams.
3- There should be more government and the NGOs
4- There should be a government policy through ministerial establishment in support of flood coping activities in South Sudan.

6.2.2 Research Recommendation

The research recommendations in this study have been based on the limitations of the study and they are:

1- For the SWAT model to be used more effectively in South Sudan there is need for imperial studies on rainfall intensities and river flow regimes based on actual measurements for improved SWAT calibration and sensitivity tests. Further, the SWAT geodatabase does not take into account the tropical biodiversity and soil variation and the attempts should be made to make it global.
2- Sedimentation study should be carried out in the most flood prone are of South Sudan.
3- There is a need for a study of household vulnerability to flood in South Sudan and how to address the problem.
4- There is need for a comprehensive study on flood preparedness at the household level in the most flood prone areas of South Sudan.

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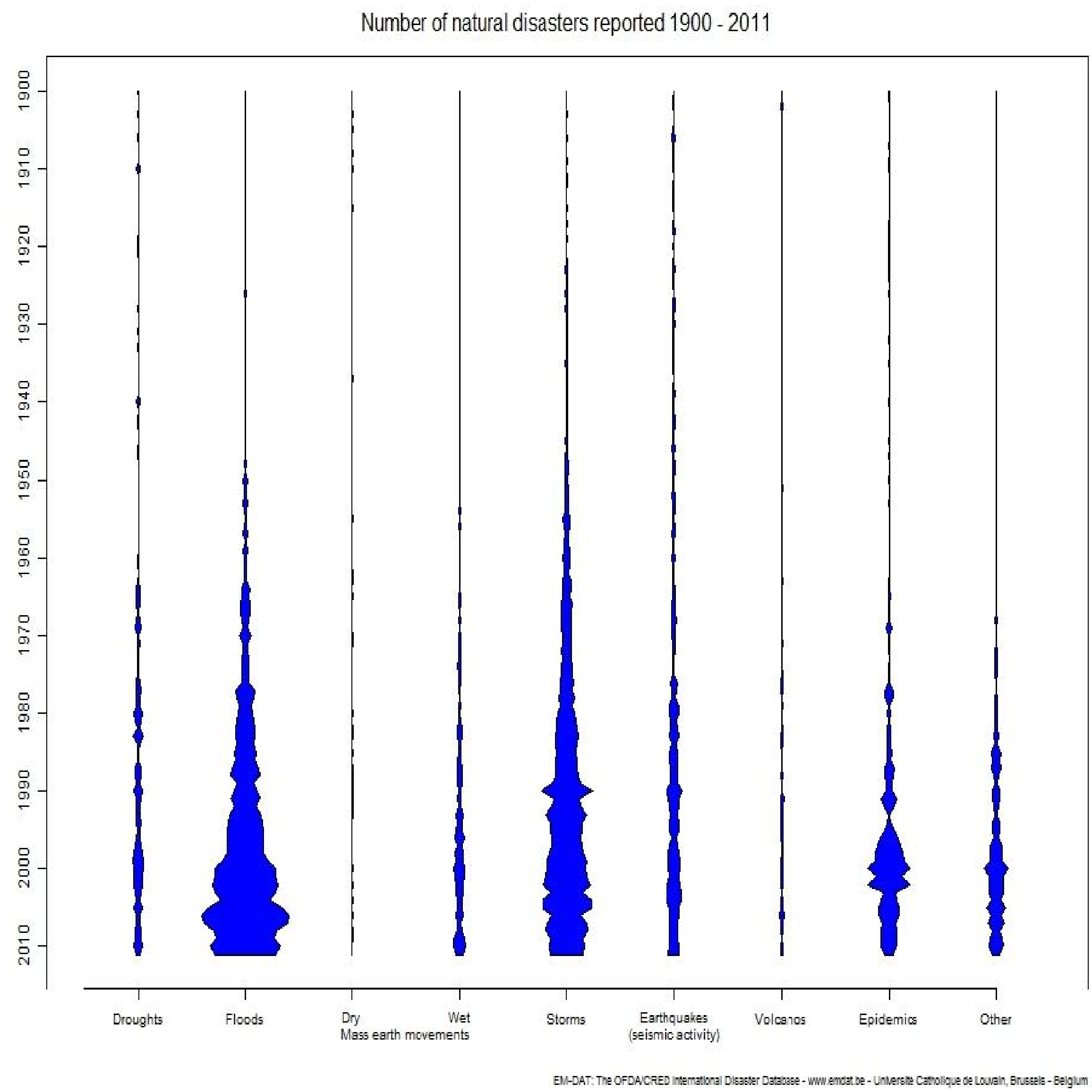
APPENDICES

APPENDIX I: THE RISE IN FLOOD AMONG OTHER NATURAL DISASTER



Number of the natural disaster reported 1900-2011(CRED 2013)

APPENDIX II: PROJECT BUDGET

Item description	Budget	
	Quantity/cost per item (Kshs))	Total Cost(Kshs)
Traveling from Nrbi/Juba	Two way plane ticket	45,000
Traveling from Juba to Aweil	Two way plane ticket	20,000
Enumerators	2Staff	36,000
Questionnaires	200 Questionnaires +50 Interviews	6,000
6. Field work 45 days	Phone calls, meals, etc	18,000
Stationery	2 rims of fullscaps @ 600 each	1,200
	1 biro pen packet	200
	2 notebooks @ 300 each	600
Proposal writing and research	Internet research	2,143
	Printing and binding	2,750
Project research	Data collection	15,000
Data analysis	Data coding, entry and computer software (SPSS)	10,000
5. Report writing	Printing and binding	4,000
6. Miscellaneous	Phone calls, meals, etc	1,500
Total		82,473

APPENDIX III: SCHEDULE PLAN