

**APPLICATION OF GIS TECHNIQUES IN FLOOD EXTENT
MAPPING AND MANAGEMENT ON MATEBELE FLOOD
PLAIN IN SHANGOMBO DISTRICT, ZAMBIA**

By

Morris Kambeu Manyika

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DECLARATION

In accordance with the regulations and guidance provided in writing and submission of a dissertation for the partial fulfillment of a Master of Science Degree in the School of Natural Sciences, I hereby declare that this dissertation is my own work. No part of this work or this material has been submitted in any other University for the same or related purpose. All published works in this work have been clearly acknowledged and strictly referenced. In this regard, I hereby submit this dissertation for examination for the Master of Science in Geo Information Science and Earth Observations.

Signature:.....

Date:.....

APPROVAL

This dissertation for Morris Kambeu Manyika has been approved as fulfilling the requirements for the award of Master of Science in Geo Information Science and Earth Observations by the University of Zambia.

Internal Examiner

Name:

Signature:

Date:

Internal Examiner

Name:

Signature:

Date:

Internal Examiner

Name:

Signature:

Date:

Chairperson Board of Examiners

Name:

Signature:

Date:

Supervisor

Name:

Signature:

Date:

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LIST OF ACRONYMS

GIS – Geographic Information System

MFIS- Matebele Flood Information System

SNAP- Sentinel Application Platform

SAR- Synthetic Aperture Radar

DMMU- Disaster Management and Mitigation Unit

RS- Remote Sensing

EMS- Electromagnetic Spectrum

RGB- Red, Green, Blue

EFWS- Early Flood Warning System

GPS- Geographical Positioning System

DEM- Digital Elevation Model

KMZ- Keyhole Markup Language

DN – Digital Number

HCM - Hydrological Current meter

ADCP- Acoustic Doppler Current Profiler

ABSTRACT

Floods are among the world's most devastating hazards, and their effects negatively affect ecological and socioeconomic systems. Ecologically, they affect the distribution of provisional and regulatory services. Socio-economically, loss of lives, property, and financial costs. Application of GIS and Remote Sensing techniques in flood mapping is increasingly becoming significant to establish extents and effects of floods. This study focused on establishing the spatial extents and trends in the flooding events on Matebele Plain in Shangombo District of Zambia from 2008 to 2018 using GIS techniques. Using stratified and simple random sampling, a descriptive research design was adopted to collect data through interviews with 173 respondents. Primary data was sourced using questionnaire on 160 respondents and interview guides on 13 key informants. Sentinel 1A provided Synthetic Aperture Radar (SAR) images in the C-band or C-SAR. Interview data were analysed thematically with simple statistics, while Satellite images were processed and analysed using ArcGIS 10.3 software and Sentinel Application Platform (SNAP). Results indicated that the maximum aerial coverage of floods was recorded in 2018, covering an area of 16,441 km², representing 78% of the total area. A hypothetical analysis of the trends in time series using the Regression statistical analysis gave ($p < 0.001$), with r^2 of 70% indicating significant geospatial variations in the aerial coverage of floods from 2008 to 2018. A thematic analysis of the responses on the effects of floods on various land use activities gave a positive response rate of 97%. The general conclusion was that Matabele Plain experiences flooding with geospatial variations in extents. Further research to consider the impacts of floods on specific land uses is highly recommended.

Key words: GIS, Remote Sensing, flood extent mapping, Synthetic Aperture Radar

CHAPTER ONE: INTRODUCTION

1.0 Background to the Study

Floods are among the World's most alarming natural disasters. They are the most recurring, widespread, disastrous, and frequent natural hazards worldwide (DMSG, 2001). With climate change, floods are affecting many communities, leaving them vulnerable and causing them to have reduced adaptive capacity. A *flood* is a high flow of water that overtops a stream's natural and artificial banks. When riverbanks overflow, water spreads over flood plain and generally causes problems for inhabitants, crops, and vegetation (Wang et al., 2002). To achieve effective flood management and risk control during extreme flood events, determining the extent of flooding events is incredibly significant (Wang et al., 2002). Updated details of floodplain inundation extents serve as a rich source and the most valuable tool for mitigating, managing, and avoiding severe social and economic losses from floods. Accurately updated floodplain inundation and extent information also improve public safety, aid flood disasters, and mitigate institutions in planning and management. Scientific identification and assessment of flood-prone properties during emergencies allow public safety organizations to prioritize warning and evacuation. Armed with definitive information, government agencies can initiate corrective and remedial efforts before disaster strikes (Chapman and Canaan, 2001).

For a long time, flood extents from flood inundation models were validated using ground-based surveys, which could have consumed more time to provide results. The models have enabled developing, demonstrating, and validating information systems significant for flood forecasting, planning, and management (Fournier, 2007). The main aim of flood hazard assessment is to identify and delineate the areas within a flood-prone area at risk of flooding and resulting in disasters. Adaptation and

mitigation measures can then be developed to avoid or reduce the expected risks. In the era of scientific studies such as Geographic Information Science and Remote Sensing, flood hazard maps can be developed through assessments and delineation of flooded areas. This is an effective way to provide early warning to vulnerable communities and guide them in effective development planning. In addition, it makes the resource allocation process simple, resulting in smooth and effective implementation of the adopted flood management strategy. A small-scale flood analysis identifies the higher hazard zone, upon which a large-scale and detailed mapping eventually identifies the high-hazard areas (Sanyal and Lu, 2005).

Wetlands are well known to be areas of attraction to both human activities and biodiversity all over the World. This is because, among others, they provide food and shelter for most living things and are a major source of livelihood for many people, especially in developing countries (Costanza, 2014). This has resulted in settlements being established on floodplains to ease the accessibility of resources for many people. Activities commonly found on plains include crop farming, construction of settlements, social structures such as markets, grazing grounds for livestock, and access routes to production centers and water points.

The increase in settlements, livestock, changes in land uses, and climate variations on the Matebele Flood Plain have, over the years, been correlating with the changes in the inundation of the plains (Zambia Vulnerability Assessment Report on Shangombo District; 2009). According to the Rapid Flood Impact Assessment Report of March 2007, floods posed a substantial risk of water contamination. They flooded shallow wells for communities living around Matebele plain of Shangombo District. In 2009, four pupils from two schools, namely Mambolomoka and Lisisi

Primary Schools, were swept away and died due to the floods in the area (Lusaka Times, 2009). Additionally, flooding the plain submerged many roads and Shangombo District was reported to be the worst hit of the year. In the same year, reporting on the floods on the same plain and the whole district of Shangombo, the Disaster Management and Mitigation Units (DMMU) stated that infrastructure, such as roads and bridges, were damaged, submerged, and washed away. Mud houses had collapsed, resulting in 460 people (76 households) being displaced.

Furthermore, water points and toilets in the affected communities had been submerged, and some collapsed; three schools were closed due to submerged classrooms, teachers' houses, and toilets. Water points (boreholes with hand pumps), located at schools, were submerged by the floods, with a risk of contamination at some points. Furthermore, most crop fields and settlement areas were flooded (GRZ 2009b). Despite the increase in climatic impacts such as flooding in rural communities, very few studies have been conducted to establish the extent of the flooding in areas such as the Matebele Plain and how communities can adapt to other land uses during the flood periods.

Flood monitoring using satellite data proves to be an effective method to get a quick and precise overview of flooded areas, which are inaccessible especially during flood seasons, in addition to the vastness of wetlands. Flood extent is significant for calibrating and validating hydraulic models (Horritt, 2006). This enables the establishment of adequate and reliable information for planning and flood response. Earth-based observation (satellite) data from space can provide valuable and prompt information when spatial and temporal flood information is required. According to Shamsi (2002), Geographic Information Systems (GIS) plays a vital role in

floodplain management, such as base mapping, topographic mapping, and post-disaster verification of mapped floodplain extents and depths. Advancements in computer knowledge, modeling, Remote Sensing (RS), and Geographical Information Systems (GIS) have been handy in flood management. Through modeling coupled with RS and GIS use, floods can be predicted, and vulnerable areas can be mapped out. A Geographic Information System is a technology that is used to process data using programmed software to produce information that can be visualized through maps and other statistical information. The GIS, GPS, and remotely sensed data could be used to visualize, integrate, understand, and quantify research data that can solve environmental problems.

1.1 Statement of the Problem

The reliance on ground-based observation of floods, conventional flood mapping methods, and minimal wetland mapping studies conducted on Matebele Flood plain have resulted in time-consuming, inaccurate, and inadequate up-to-date information about its geospatial extents on the flooding events. The outcome has been flood-related disasters such as loss of human and livestock lives, infrastructure damage, food destruction and insecurity, hindrance in access to social services, and delayed progress on developmental projects. According to the Zambia Vulnerability Assessment Report of 2009, flooding events in Shangombo District resulted in submerging crop fields, grazing land, loss of lives, biodiversity, collapsing of houses, washing away crossing points, livestock deaths, diseases, loss of agricultural produce, social infrastructure, slowing infrastructural development, and reduction in socio-economic activities. Local Authorities and communities in the area have tried to mitigate the effects and understand the propagation of the flooding events. However, the results have been ineffective as complete mapping of the floods using

effective methods such as GIS and Remote Sensing have not been used. With detailed information about the extent and changes of flooding on the plain, communities living on the plain, government agencies, and other organizations will find it easier to plan and implement relevant programs in the area. Geoinformation technologies coupled with Remote Sensing have proven essential for capturing, analysing, and producing adequate information about flooding events, especially in large areas such as wetlands. Therefore, this scientific study's mandate is to apply modern scientific techniques through satellite-based information and participatory ground-based data collection and analysis to map the extent of the flooding events on Matebele Plain and manage the events.

1.2 Aim

To establish the spatial extents of the flooding events on Matebele Flood Plain in Shangombo District of Zambia from 2008 to 2018 using GIS techniques.

1.3 Specific Objectives

1. To establish the maximum aerial extent of the floods on the Matebele plain from 2008 to 2018 using Synthetic Aperture Radar satellite data.
2. To determine the geospatial trends in the flooding extents on the plain from 2008 to 2018.
3. To identify the effects of the flooding events on land use/land cover activities in the study period.
4. To develop an effective flood information system about the floods on the Matebele flood plain.

1.4 Research Questions

1. What was the maximum aerial coverage of flooding on Matebele plain from 2008 to 2018?

2. How were the geospatial variations of flooding extents on plain in the study period?
3. What land uses/land cover types were affected by the flooding of the plain in each flood cycle from 2008 to 2018?
4. What effective flood information system can be developed about the flooding events on Matebele Flood Plain?

1.5 Hypotheses

H₀: There were no significant geospatial variations in Matebele Flood Plain's flooding events from 2008 to 2018.

H₁: There were significant geospatial variations in Matebele Flood Plain's flooding events from 2008 to 2018.

1.6 Significance of the Study

The core aim of this study was to apply Geoinformation techniques on SAR satellite images to delineate flooding extents on the Matebele flood plain to develop flood management strategies and information provision to relevant stakeholders. Flood extent mapping is relevant in damage assessment and risk assessment by rescuers during flooding (Corbley, 1999). The results of this study will provide adequate information on the flooding events of Matebele Flood Plain, which forms part of the Zambezi Basin (Figure 1). Providing information about the flooding events on this plain contributes to understanding the hydrological regimes in the broader Zambezi Basin. The basin is significant for providing ecosystem services and supporting food security through the availability of water and an internationally recognized wetland. This, in turn, is significant for sustainable wetland management and preservation of ecosystem functions from the wetland. During floods, governments and Disaster Management Agencies require timely and detailed flood reports to locate the affected areas and implement the corresponding damage mitigation (Jeyaseelan, 2004). This

information on flood-prone areas will aid in developing responses and early warnings for communities on the plain. Zambia has, over the years, developed policies on disaster response (National Disaster Management Policy, 2011). According to the Zambia National Policy on Climate Change (2016), responding to climate change impacts through the development of effective strategies requires that information about climate-related disasters is made available both to the affected groups and the responsible authorities. The results will also aid in evaluating how effective National Disaster Management Policies have supported awareness and response to flooding events in Zambia. Further, the results will contribute to the body of knowledge about the extent and trends in inundation on the plain, as there is still a gap in the Zambian Hydrological studies. Overall, the study's findings are significant in flood hazard assessment, damage estimation, and land use planning on the Matebele floodplain.



Figure 1: Location of Matebele flood plain on Zambezi Basin

CHAPTER TWO: LITERATURE REVIEW

2.0 Introduction

The chapter gives a detailed analysis of publications of information that the researcher reviewed to establish the weaknesses, strengths, and supporting tools needed to undertake this study. As a guiding tool in shaping the research direction and deepening the researcher's understanding of the field of study, this chapter assesses different studies done and relevant in developing the methodology and suitable methods for this research.

2.1 Floods

All around the World, floods are usually associated with causal factors, including land use changes, deforestation that results in increased runoff, and often a decrease in channel capacity due to increased sedimentation. Although these have been linked to the causes, climatic factors have significantly impacted increasing flood events around the World (Nott, 2006). The increase in floods has resulted in about 50,000 deaths and adversely affects some seventy-five million people worldwide yearly. According to Scheuren et al. (2008), the World has continued recording high numbers of natural disasters, such as floods, affecting lives and increasing economic expenditures. These natural disasters require scientific data and information to respond to their impacts.

According to Smith (1992), a *flood* is defined as a high flow of water that overtops a river's natural or artificial banks. The primary flooding sequence begins with surface runoff from precipitation, which runs down the slope and enters the stream channels. Kron (2002) defines *flooding* as a temporary covering of land by water due to surface waters escaping from their normal confines or heavy precipitation. The river levels rise to carry the surface runoff from the land or direct rainfall. The stage at which a

river begins to discharge surplus water to surrounding areas is what is referred to as flooding, and flooded areas are plains commonly known as floodplains, marshes, fens, polders, or flats.

Flood management and control are necessary because floods impose a curse on society. However, the optimal exploitation of the land and proper management and control of water resources are vital for bringing prosperity to the communities living on flood plains. The regulation of flood hazard areas coupled with enactment and enforcement of flood hazard zoning could prevent damage to life and property from flooding in the short and long term.

2.2 Climate Change and Floods

Literature has revealed that the changing extents, impacts, and increase in floods worldwide are linked to Climate change (Tabari, 2020). The increased precipitation causing these floods is linked to climate change. With increasing amounts of carbon dioxide and other greenhouse gases in the atmosphere, climate science predicts an increase in the frequency and intensity of unusual weather events, including floods and droughts. Studies have shown a steady direct correlation between increased precipitation due to climate change and floods (Tabari,2020). To determine and qualify these conclusions, temporal changes in flood extents of water bodies are being examined through different scientific studies, including the application of GIS and Remote Sensing. Other studies linked the flooding problems with climate change variability and increased the number of other natural environmental disasters. (IPCC, 2001).

Berz *et al.* (2001) report that flood changes are expected to increase due to climate variability and change; therefore, the need to provide fast and accurate flood

information is/was critical to minimize flood-associated damages. Studies have indicated that climate change will increase floods in some places and a reduction in others (Tabari, 2020).

2.3 Recent Status of Floods in Zambia

According to the Vulnerability Assessment and Analysis Survey for Zambia conducted in 2007, the country has recorded decades of heavy floods with disastrous impacts. Annual heavy rains experienced in recent years have resulted in flash floods and waterlogging in valleys and flood plains, causing varying impacts on several sectors: infrastructure, agriculture, education, health, water and sanitation, and habitation (Zambia Risk Profile; 2011).

2.4 Flood Mapping Using Satellite Data

Satellite data has become an essential source of pertinent information for mapping flooded areas. In recent years, the availability of free satellite data has increased the frequency and ability to provide adequate information on flooding events (Berger et al., 2012). Earth-based observation has the potential to provide near-real-time data about the changes on the surface of the Earth in the mapping of geomorphological changes, observation of sequential inundation, depth of inundation, and direction of currents covering larger areas and aiding in the prediction of natural disasters (Western, 2002). Studies by Long et al. (2014) on the Chobe River in Namibia have proven that flood extent mapping using satellite data is critical in providing reliable information for disaster planning and management. Their study pointed out that flood extent mapping using sources of information that can provide quick data is relevant for relief agencies.

The Sentinel satellite constellation of the Copernicus program under the European Union (EU) provides Synthetic Aperture Radar data, which has proven suitable and

reliable for flood mapping (Berger 2012). The information can easily be analysed using software and respond to surface changes. The availability of satellite earth observation is enhancing the monitoring of wetland flooding. This is because, among other reasons, the inability to reach inaccessible areas affected by floods easily. It further enables the determination of historical events on wetlands and changes that have occurred over a long period to predict future events. Advancements in this technology are enabling the acquisition of near-real-time data about the changes in various areas around the World. In addition to the Sentinel, other satellite data sources that have proven significant include the Landsat and MODIS, among others (Justice, 1998).

Imaging radar has advantages over optical sensors that broadly capture data in the visible range of the electromagnetic spectrum when monitoring forested areas. This is because using microwave energy enables the detection of flooded areas in forest areas and detects moist soils and other hydrological features below deciduous forest canopies, seen as wet areas in images. Imaging radar also collects data independently of cloud cover and solar illumination, which is a challenge for passive sensors (Smith, 1997).

2.5 Application of Geographic Information Science in Flood Mapping

Sam U. Shamsi (2002; 7), in the report GIS Applications in Floodplain Management, has indicated that GIS is ideally suited for various floodplain management activities such as base mapping, topographic mapping, and post-disaster verification of mapped floodplain extents and depths. For example, GIS was used to develop a River Management Plan for the Santa Clara River in Southern California. A GIS overlay process was used to plan efforts further and identify conflicting uses along the river and areas to enhance stakeholder objectives. The lessons learned from this

mapping project indicate that GIS is useful in capturing and communicating vast information about the study area and the river. While the use of GIS and gathering and recording data were acceptable, the overall value of GIS outweighed those challenges (Sheydayi, 1999). Based on this analysis, GIS is ideally suited for geospatial analysis of environmental changes and natural disasters, including flood monitoring.

According to Evans (2008; 38), flood mapping in GIS requires storing and managing hydrological data to generate flood inundation and hazard maps to assist flood risk management. The frequent application of GIS in flood mapping has resulted in understanding, knowledge, and experience in developing flood maps for management and planning purposes. GIS has been central in integrating, organizing, processing, and visualizing spatial data from multiple sources.

In their study, Dams et al. (2009) demonstrated the potential of GIS-derived impervious surface cover maps to improve hydrological model parameterization in urban catchments. GIS tools, on the other hand, provide storage, analytical, and data presentation capabilities. Townsend and Walsh (1998) are examples of many studies using RS and GIS to predict floods. This study aimed to compare the flood detection abilities of RS data and GIS-based models. For RS data, Synthetic Aperture Radar (SAR) images were derived from SAR sensors and then analyzed using the Normalized Difference Vegetation Index (NVDI) to derive flood inundation. On the other hand, DEMs were used to generate GIS models representing potential wetness and flood inundations. Their findings indicated that both SAR images and GIS models obtained comparable results of flood inundation.

In their study of watershed modeling and flood prediction, Konadu and Fosu (2009) used a vector-based GIS and DEM to delineate watershed boundaries and predict areas of inundation during a flood event in Accra. In this study, digital contours obtained from the topographic map of the study area were utilized for DEM generation. The DEM generated provided the terrain representation and information regarding the direction of water in an area. Using GIS, raster analyses were performed to generate data on flow direction, flow accumulation, stream definition, stream segmentation, and watershed delineation. These data were valuable for developing a vector representation of catchments and drainage lines. Flood extent was then simulated based on the derived drainage lines, depth, and capacity to hold rainfall run-off. The flood level contours derived for the selected flood water levels of 0.5, 1, 1.5, or 2 meters were used to indicate areas that could face inundation in the event of any flood. The general idea is that RS and GIS provide spatial and temporal data input required by the distributed hydrological models to simulate run-offs and, thus, floods.

Gan et al. (2012) stated that Synthetic Aperture Radar (SAR) provides an all-weather, all-day tool for real-time imaging of flood events. SAR sensors can detect flooding because flat surfaces reflect a signal away from the sensor, decreasing the amount of returned radiation. SAR can also detect flooding in vegetated areas due to the brightening effects caused by the signal's double bounce off objects. In this regard, the researcher used this data source for this study.

Martins et al. (2009) pointed out that most SAR-based flood detection techniques have been developed to monitor and assess the changes in significant river flooding in temperate northern latitudes. However, only some studies have focused on

monitoring flooding using this technique in small areas like the Matebele floodplain, where seasonal flooding is expected. This study intends to verify this ability using these techniques through SAR-based techniques.

2.6 Wetland Management amidst Climate Change

Climate change is affecting all parts of the World today, resulting in many effects on many communities. In the ecosystem, wetlands play a significant role in moderating the climate. Wetlands also play a critical role by supporting ecosystem-based adaptation approaches among vulnerable communities affected by climate change. To support the sustainability and benefits that ecosystems provide to the environment, the changes in the inundation of wetlands must be mapped and communicated to beneficiaries. Through such studies, trade-offs can be established between land use activities on wetlands and the changes in the inundation extents. Effective management of wetlands can be established when the effects of land use activities are determined through remote sensing and analysis of the changes in the geographical features of wetlands.

2.7 Literature Gap on Flood Mapping in Zambia

Several studies on floods, hydrological modeling, flood monitoring, the adaptation of communities living in flood areas, monitoring inundation extents on flood plains, impacts of floods on livelihoods, and the use of different methods for early warning during flood disasters have been done in Zambia. For instance, in his study, Tiger (2008) used Satellite data to monitor the relationship between flooding and vegetation changes in the Kafue flats, using Landsat satellite images. The results indicated a modeled output of the flooding events on the Kafue plain. Aduah et al. (2012) applied remote sensing to map wetland floods in the Kafue Flats of Zambia. Meire (2012) also conducted hydrological and floodplain modeling on the Kafue River flats. Using satellite observations, Cai et al. (2015) surveyed people to

understand their perceptions of floods. More recently, Zimba (2017) assessed the trends in the extent of inundation in the Barotse Floodplain.

On the Matebele plain, the existing studies were those done by the Zambia Vulnerability Assessment Committee that assessed the impacts of floods on the communities during the 2008/2009 flood season. No scientific studies have focused on the spatial variations, trends, and extent of flooding on Matebele Flood Plain. Aerial mapping of the extent and spatial variations in the flooding of the plain and statistical analysis of the changes in the inundation still exist as a gap that requires further research. Additionally, very few studies have been conducted to determine the impacts of land cover/ land uses on flooding regimes of wetlands in Zambia (Kampata, 2013). A gap in the study area still exists on how changes in the inundation of Matebele Plain have impacted human activities and biodiversity in the area.

Most of the above studies in the public domain have used optically remote-sensed satellite images such as Landsat and MODIS satellite images to conduct their inundation monitoring. Studies have indicated that atmospheric conditions such as cloud cover usually affect the use of optical satellite images from passive sensors (Brivio et al., 2002). Flood seasons are usually accompanied by rainfall, cloud cover, and increased vegetation growth, especially on flood plains. Detecting floods in vegetation-covered areas during rainy seasons has proven challenging on images from passive sensors. This means most of the studies done so far in Zambia that applied satellite images from passive sensors have proven a gap in the use of satellite data from active sensors (Zimba, 2018; Aduha, 2013; Meier, 2010; Long, 2014).

It is significant to conclude that studies on applying GIS techniques using satellite data from active remote sensors, such as Sentinel, have not yet been widely done in Zambia. This calls for undertaking such studies to make the possible mapping of wetlands in Zambia available to use these data sources. Flood mapping must consider integrating the trades between flood events and human activities, especially on wetlands—these aid in developing effective response strategies for communities affected by these natural disasters.

This chapter focused on giving a general overview of floods, flood mapping, techniques used to conduct flood mapping, the application of Geospatial technologies in flood mapping, and determining the trade-off between climate change and the occurrence of floods as one of the impacts. The main aim of this chapter was to review several studies that have been conducted on flood mapping for the establishment of gaps and the identification of new techniques.

CHAPTER THREE: STUDY AREA

3.0 Introduction

This chapter discusses the location, description, the geographical and physical characteristics, and the general anthropogenic activities in the study area.

3.1 Location

The Matebele flood plain is an extension of the Barotse Flood Plain located in the Southwestern part and subject to seasonal flooding by flash floods from Kwando River in Angola. The Matebele Flood Plain is geographically located between 16-17° South and 22-23° East of Western Zambia mainly in Shangombo District (Figure 2). It covers an area of about 21,078 km². It is in the Southwest of the Zambezi floodplain and extends marginally into Angola. The plain covers the following areas: Mambolomoka, Beshe, Mulonga, Kaunga Mashi, and Mbunda wards of Shangombo District and Nalwashi and Kalongola wards in the Northern part of Sioma District.

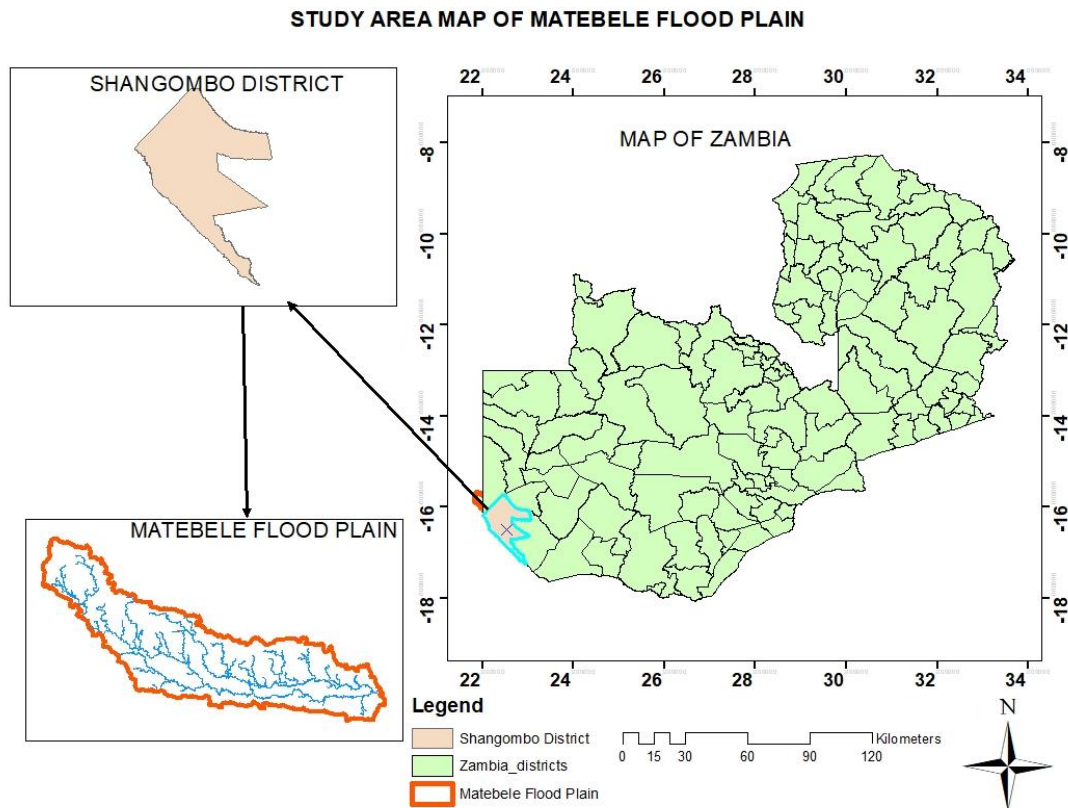


Figure 2: Location of Matebele flood plain in Zambia.

3.2 Description of the Study Area

The Matebele floodplain stretches from the Kwando River in Angola to the Zambezi River in Zambia. These rise from the Kwando River in Angola and bring water into the plain. When the Kwando River in Angola overflows, the water flashes into the Matebele plain as flash floods or pluvial floods. Statistics have shown that over 20,994 people are living on this plain, according to the Census of Population and Housing report for 2010 (CSO, 2012). The population is distributed as follows: Mambolomoka Ward 4,921, Mulangu 3,914, Mulonga 5,233 and, Namono 2,681, and Keyana 4,245.

3.3 Soil Characteristics of the Study Area

Kalahari sands stretching from the Namib Desert in Namibia, located in the southern part of Shangombo District, cover the plain. The soil characteristics of the area can be described as comprising sandy soils, in the forest areas, and clay and loam soils, on flood mounds. The compacted and mixed clay and loam soils covering the grass plains increase the extent of inundation, as well as the rate of flow of the flash floods downstream to the Zambezi River (Gils et al., 1988).

3.4 Human activities in the area

A significant part of human activities on the plain is characterized by subsistence farming on floodplain mounds distributed over the plain. The mounds also serve as settlement areas, especially during floods and the cultivation of sorghum and millet. The main activities are crop farming, cattle rearing, and other socio-economic activities such as local business centers and public services. The flood mounds are characterized by clay and loamy soil, which have supported agriculture in the area. They occupy about 20% of the plain (Gils et al., 1988). The flood plain is pasture with sparsely distributed crop farming near swamps and wetlands.

3.5 Vegetation of the Study Area

The area is characterized by thorn woodland and savannah. The forest cover is of thorny narrow-leaved trees and shrubs: *Acacia erioloba*, *Acacia Sieberana* (Mutubatuba), *Acacia fleckii* (Mukoka), *Acacia ataxacanta* (Munyantatau), *Peltophorum africanum* (Munyele) and *Dichrostachys cinema* (Musulesele). *Terminalia sericea* (Muhonono) and *Combretum* (several species) are characteristic broad-leaf trees of the Munga woodland. This vegetation type occurs parallel to the Kwando River and its tributaries, the southern fringes of the Matebele plain, and the Zambezi downstream of Sesheke (Gils et al., 1988). Flooding influences the distribution of vegetation on the plain. Flooding in areas covered by forest vegetation has necessitated the selection of the source of satellite images. The grassplain land cover comprises natural landforms and land uses found within the floodplain. These include porches of natural forests, agricultural fields, fallow land, and infrastructure that fall under land use.

3.6 Water Resources

The area is usually inundated by flash floods from the Kwando River in Angola and Lueti River in Zambia, located in the northwest and Northern parts of the plain, respectively. The plain annually experiences two types of floods: flash floods and river floods. Flash floods result from excess rain falling on upstream watersheds and moving downstream, spreading across the grass plain. Such floods take a considerable toll, and the damage becomes significantly pronounced and devastating when they pass across or along human settlements and infrastructure concentration areas like schools, clinics, and roads. Much of the significant floods experienced on the plain are attributed to the overflows of the Kwando River from Angola and Lueti rivers that overflow or burst their banks and inundate the plain.

3.7 Flood Plain Management

Flood plains have, all over the world, attracted human settlements and several other socio-economic activities. This is because they provide provisional and regulatory services to people and livestock. Provisionally, the plain supports the availability of grazing land for livestock, fish, water, building materials such as fiber, rids, and wild fruits, and cultural services such as tourism and heritage activities (Mitchell et. al. 2012). At the same time, regulatory services such as hydrological flows, erosion regulation, environmental cooling effects, and acting as a carbon sink are also included. They play a pivotal role in the ecosystem. Matebele floodplain is clustered with human settlements, various activities, and land uses. They included cattle rearing, crop farming, fishing, and economic and social activities such as community gatherings, religious activities, educational and health activities. Despite these settlements and socio-economic activities, management strategies need to be established to address the flood impacts experienced by the inhabitants. The local people usually depend on coping strategies such as using dug canoes to move and transport their goods. School-going children usually walk in the water to sustain themselves during floods.

This chapter gave a geographical description of the Matebele floodplain, outlining the location, vegetation characteristics, water, land use, land cover activities, socio-economic activities, and existing flood management strategies.

CHAPTER FOUR: RESEARCH METHODOLOGY

4.0 Introduction

All research is based on some philosophical assumptions that guide the validity of the research and the research methods suitable for conducting that research and achieving the required results for knowledge development. This chapter outlines the philosophical assumptions on which this research was based and the research design underpinning this research study. It describes the design as the framework and guides the research process. The chapter also discusses the research methodologies, data collection, analysis, and presentation procedures.

The philosophical positioning of every research paradigm consists of essential components such as ontology, epistemology, and methods. Ontological considerations concern a person's view of the world and how reality can be created or determined. Crotty (1998) defines Ontology as the study of being. Ontological assumptions are concerned with what constitutes reality. Epistemology is concerned with nature and forms of knowledge. It concerns how knowledge can be created, acquired, and communicated (Cohen, 2007).

Research paradigms have different ontological and epistemological assumptions about reality and knowledge, reflected in the adopted research methodologies and methods. This research's Ontological and Epistemological positions are realism and positivism or objectivism. The ontological and epistemological positions of the study required the use of positivist methods of observation through participatory GIS to assess flooding area areas and identification of natural vegetation cover that is associated with floods.

4.1 Research Design

The aim of the study, with its specific objectives, required that data from various sources of different natures be collected to arrive at a satisfactory conclusion. The research required integrating data from satellite images and hydrological and climatic data such as rainfall and temperature, collecting and analysing field-collected data from respondents, and consolidating field surveyed data. To achieve this, the descriptive survey research design was adopted.

4.2 Data Collection

Significant procedures were employed to collect all the necessary data for this study. Primary data, which included SAR satellite data, field observations, Meteorological data, and data from interviews, was collected using suitable techniques. The tools used for data collection included online search engines and the Geographical Position System (GPS), and the methods were interviews with inhabitants sampled from the study area. This aided in acquiring both qualitative and quantitative data. Outlined below are the diverse ways through which the data was collected.

4.2.1 Collection of Field Survey Data

Field surveys were undertaken to gather primary data. This included collecting location points of areas that are annually flooded based on the available literature, information from key informants, and field observations to validate the boundaries in the satellite images. Field surveys also supported the collection of qualitative data through participatory GIS (where the communities living on the plain were engaged during ground truthing of the floods flood plain). Suitable and relevant field sites, such as marshlands, swamps, and areas generally known to have floods by the local people, were sampled and visited to collect ground data such as GPS points, line transects around crop fields, villages, animal kraals, schools, health centers, and path routes to identify land use activities within flood zones, and participation and

verifications from the local people who have experienced the flooding of the areas for years. These were sampled using snowball sampling from amongst the respondents. The field data collection verified the images' observed tone, texture, association, size, shape, pattern, and aspect.

4.2.2 Field Observations and Participatory GIS

Field observations played a critical role in the collection of both qualitative and quantitative data in this research. Marshall (1989) defines observations as the systematic description of the events, behaviors, and art facts of a social setting. Field observation was done through participant and direct observations of the areas that were flooded and land use activities that were affected. The method enabled the researcher to observe the shifts in land use activities due to the changing flooding events in the plain.

Participatory GIS was used to collect points where floods are commonly observed by local communities through observation methods with the selected participants. The ten participants, two from each ward supported this process by using large topographic maps to identify areas of interest and later validating them on the ground through transect walks. The process supported the collection of GPS points used as inputs in transecting the area of interest and validating the observations in satellite imagery. Participatory observation with key informants provided additional data and a detailed explanation of visible surface activities that the researcher needed to identify quickly. It also assisted in determining the extent of flooding in their local areas during ground truthing and collection of ground-based information such as locational points. The researcher also observed other necessary changes in the distribution of biodiversity, forest cover, and vegetation changes to validate the extent of floods.

4.2.3 Interviews

Interviews are critical in obtaining pertinent information from the local people and other key informants to the research. The researcher used purposive and stratified sampling techniques to sample respondents for the research. Semi-structured interviews were adopted for their flexibility during data collection and enabled the researcher to introduce additional questions to collect detailed information from the participants (Adams, 2015). This method of data collection enabled the researcher to find out more about the areas on the plain that are regularly flooded, the land use activities that are affected, and the relationship between the changing flood regimes and the land use activities in the area. Data collected using this method (interviews) supported the analysis of information on flood-prone areas on the plain to assist in delineation and validation with satellite images.

Sampling is described as the process of selecting a sample from a population to collect data, and it represents the population (Bhardwaj, 2019). This study applied purposive, stratified, and simple random sampling. A purposive method was employed to sample the key informants. The total number of critical respondents was thirteen, comprising of teachers from schools on the plain, agriculture extension officers, and health officers. Qualitative data was also collected, especially on the impacts of the flood on human activities and biodiversity. A stratified sample was used to sample the larger sample, representing most interviews. The area has a population of 20,994 people. Stratified sampling was applied by dividing the Wards in the area into strata. In each stratum, simple random sampling was applied using the formula.

Ward sample size = total sample required x (total number of people in the ward/ total number of people in all wards). Population = 20994, Required sample size = 160.

(a) Mambolomoka Ward = $160 \times (4967 / 20,994) = 38$

(b) Mulonga Ward = $160 \times (5233 / 20,994) = 40$

(c) Mulangu Ward = $160 \times (3914 / 20,994) = 30$

(d) Namono Ward = $160 \times (2681 / 20,994) = 20$

(e) Keyana Ward = $160 \times (4199 / 20,994) = 32$

Population Size: $4967 + 5233 + 3914 + 2681 + 4199 = \mathbf{20994}$

Sample size: $38 + 40 + 30 + 20 + 32 = \mathbf{160}$

4.2.4 Hydro-Meteorological Data

Climatic data based on rainfall as this study's significant parameter, was collected online at the site <https://power.larc.nasa.gov/data-access-viewer/> POWER | Data Access Viewer (nasa.gov) platform, which provided accurate information from 2008 to 2018. The web platform provides climate information according to humidity, temperature, wind, and other weather parameters. Local data sources could not provide the requested data despite repeated efforts.

4.2.5 Satellite Imagery Acquisition

Synthetic Aperture Radar (SAR) is a remote sensing system that is not entirely dependent on the sun's electromagnetic energy or the thermal properties of the earth. SAR satellite data is preferred for flood mapping because it can capture images day and night (Martinis et al., 2015). SAR measurements are independent of daytime and weather conditions, providing valuable information for monitoring flood events.

The Synthetic Aperture Radar data sets used in this study are dual polarization. Polarization is the direction in which the signal is transmitted or received. Dual

polarization refers to two different signal directions: vertical and horizontal. The dual polarization (HH, VV, VH, HV) Advanced Sar (ASAR) sensor aboard the Environmental Satellite (Envisat) allows for the provision of SAR data in the L-band and C-band. The L and C bands are well suited for capturing data under forest canopy due to the low attenuation (Townsend, 1998). Sentinel 1 SAR datasets were acquired from Alaska, a National Space Agency (NASA) online platform, which provided false colour composite images that were processed to determine flooding extents. Satellite images were acquired and processed using ArcGIS and Sentinel Application Platform Software to determine the extent of the flood.

Additionally, SAR images can penetrate through clouds and hazy atmospheric conditions. In this regard, the study used time series RADARSAT SAR images in flood water detection, monitoring the spatial extent and propagation of the inundation. The area under study is usually flooded by flash floods from the Kwando River in Angola. The flow occurs day and night; therefore, this data source provided the changes that occurred even at night.

Additionally, SAR images were selected as they are not affected by the weather, such as cloud cover, and reduce the errors in correcting the images from atmospheric effects. SAR images have been selected to be suitable for the study as the area is primarily covered by vegetation (forests and grass), which may affect data analysis and interpretation of other images. The SAR images, as the preferred source of data for the study for the reasons shown above, are from 2008 to 2018 and were acquired from NASA at the website.

<https://asf.alaska.edu/data-sets/sar-data-sets/sentinel-1/>.

The image acquisition algorithm, through the Alaska geoportal as shown in Figure 3 and 4, was followed. The images were sampled and downloaded according to the periods and seasons in which the area is known to be flooded.

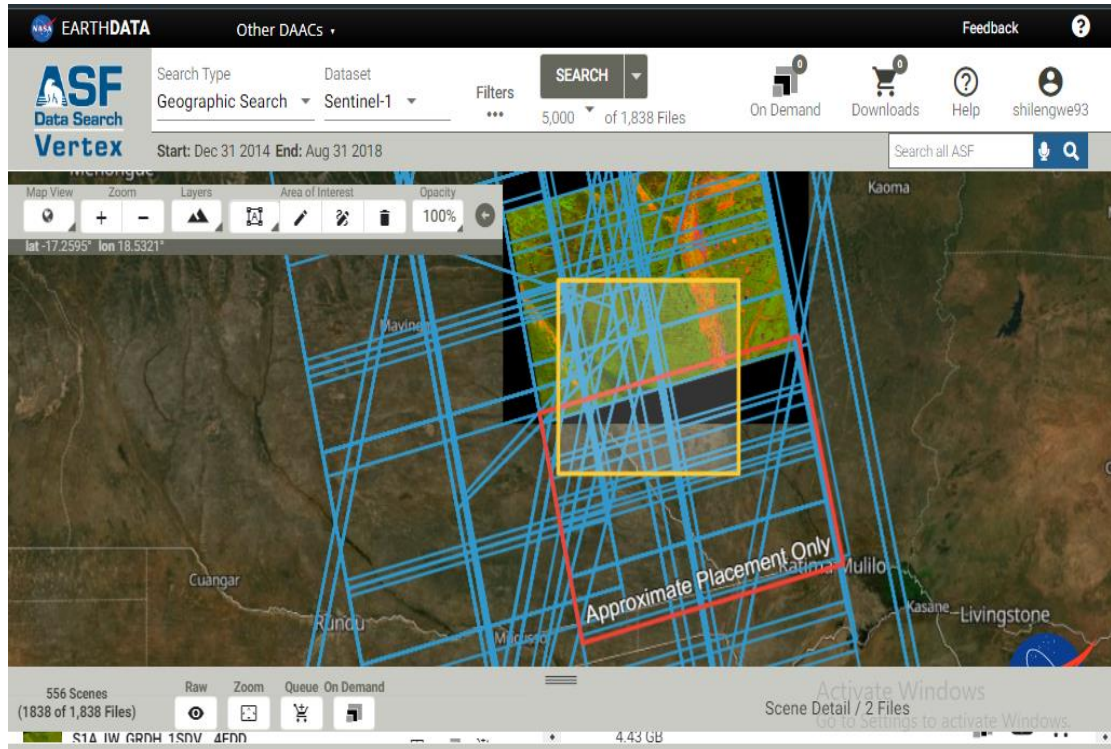


Figure 3: Extent of the tiles for SAR Data used for the study.

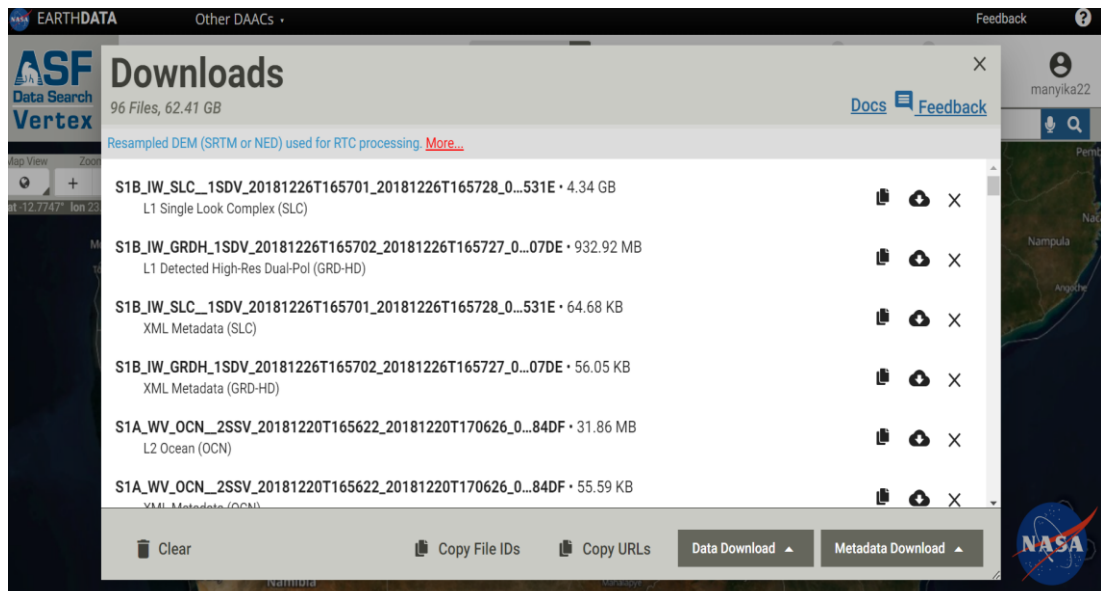


Figure 4: Image Acquisition process from Sentinel Data Hub

Figure 5 and 6 shows the algorithm followed to select and download the SAR images. Vital information such as the date of acquisition, angle of acquisition and the location of the image tile in relation to the study area, must be taken care of.

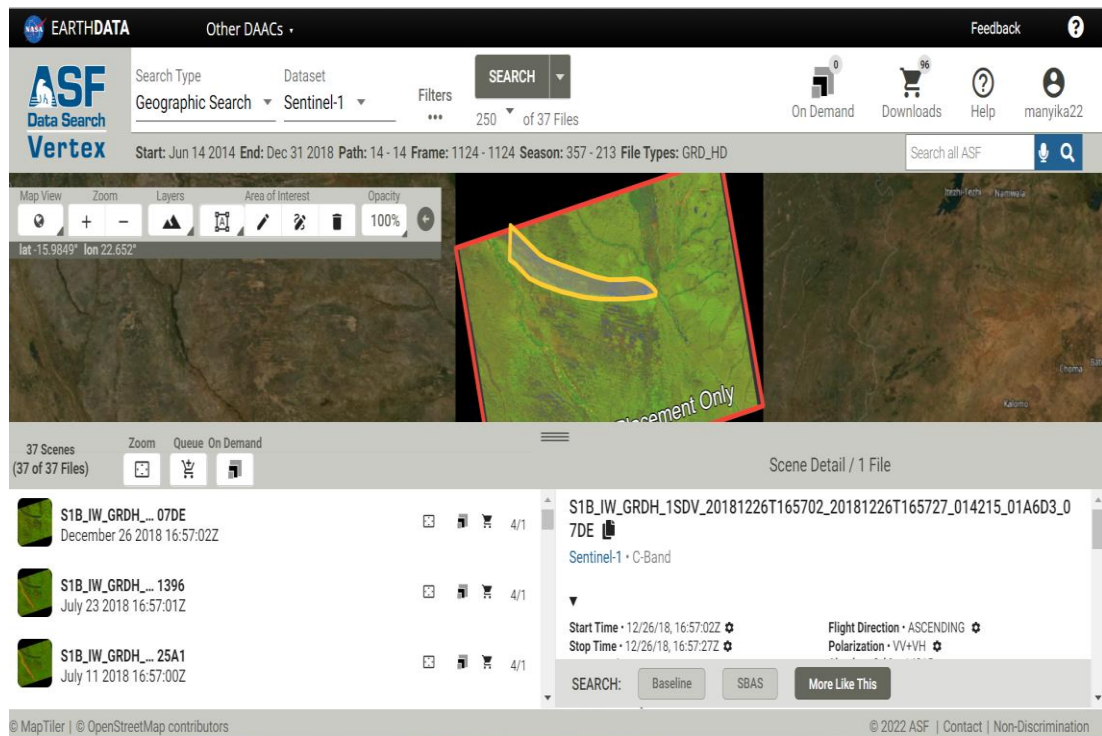


Figure 5: SAR Image acquisition process.

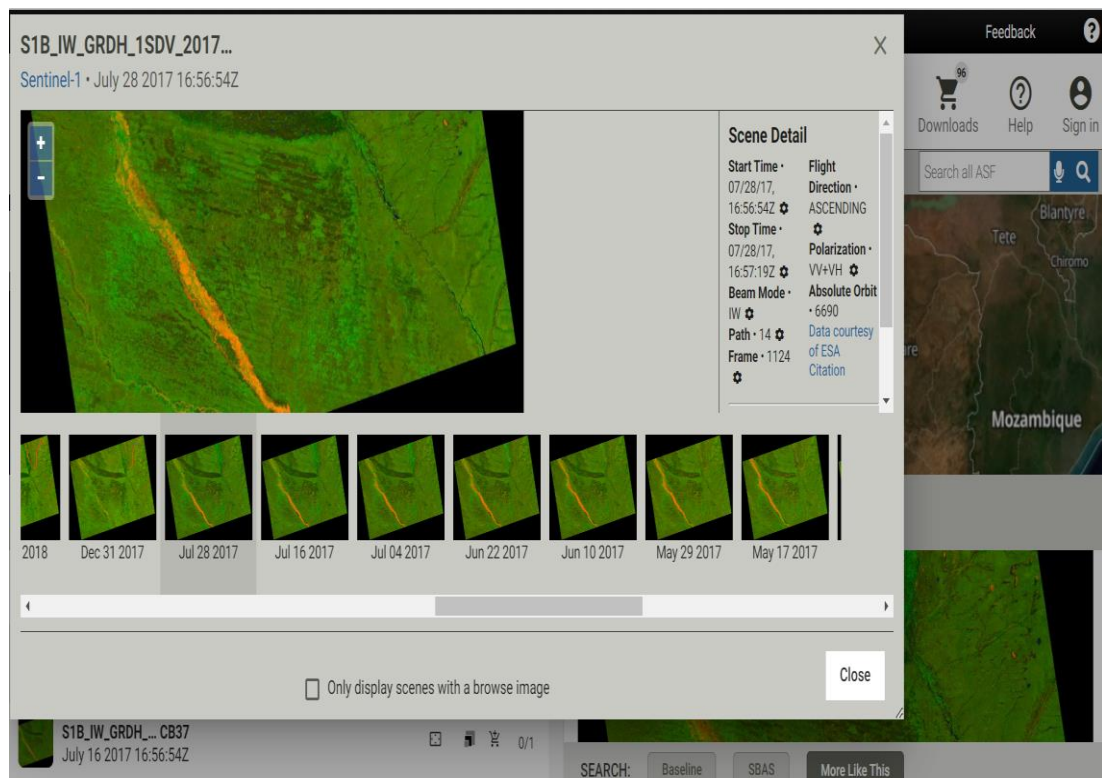


Figure 6: Downloading of all images covering the study period (2008-2018)

The following images (Table 1) were downloaded and processed to give findings in the results section of the report. The selection was purposively sampling two images in each year of the study using historical seasonal flooding and precipitation records.

Table 1: SAR Data Sets sampled for the Study and their Characteristics.

S/N	Acquisition Date	Images Details	Acquisition Model
01	01/09/2008	R1_63585_ST2_F858-L0_F858	VH + HH-Pol
02	02/02/2008	R1_63928_ST2_F858-_L0_F858	VH + HH-Pol
03	18/06/2009	LC08_L2SP_17507_202009-02_	Dual Pol
04	23/05/2010	ALPSRP227966850-H2.2_	VH + HH
06	11/08/2011	S1B_IW_GRDH_1SDV_20110814T165703_2011121	VH + HH
07	16/04/2015	S1A_IW_GRDH_1SDV	VH + HH - Pol
08	19/09/2012	S1A_IW_GRDH_1SDV	VH + HH - Pol
09	24/12/2016	S1B_IW_GRDH_1SDV	High-Res Dual-Pol (GRD-HD)
10	17/01/2017	S1B_IW_GRDH_1SDV	High-Res Dual-Pol (GRD-HD)

4.2.6 Topographic Maps

Topographic maps provide data on the area's main geographic features and land uses. Acquired from the Ministry of Lands, Survey Department, the maps of the study area were cardinal in guiding some land features in the area. The map guided the sampled respondents to show flood-prone areas for easy integration with observations from satellite data. These also provided data on administrative boundaries, land cover types and uses, vegetation areas, wetlands, and commonly accessible routes to productive centres.

4.2.7 Software

The study actively made use of three software namely, ArcGIS 10.1 for the delineation of the watershed using the Arc Hydro tool and other analysis tools, Sentinel Application Platform (SNAP) was used for processing of the SAR satellite images. Microsoft excel was used analyse thematic data and presented through visual charts.

4.3 Data Processing and Analysis

All collected data was analysed both qualitatively and quantitatively and using selected software and image and data analysis techniques. The following components (Figure 7) describe the procedures of analysing each set of data that was collected.

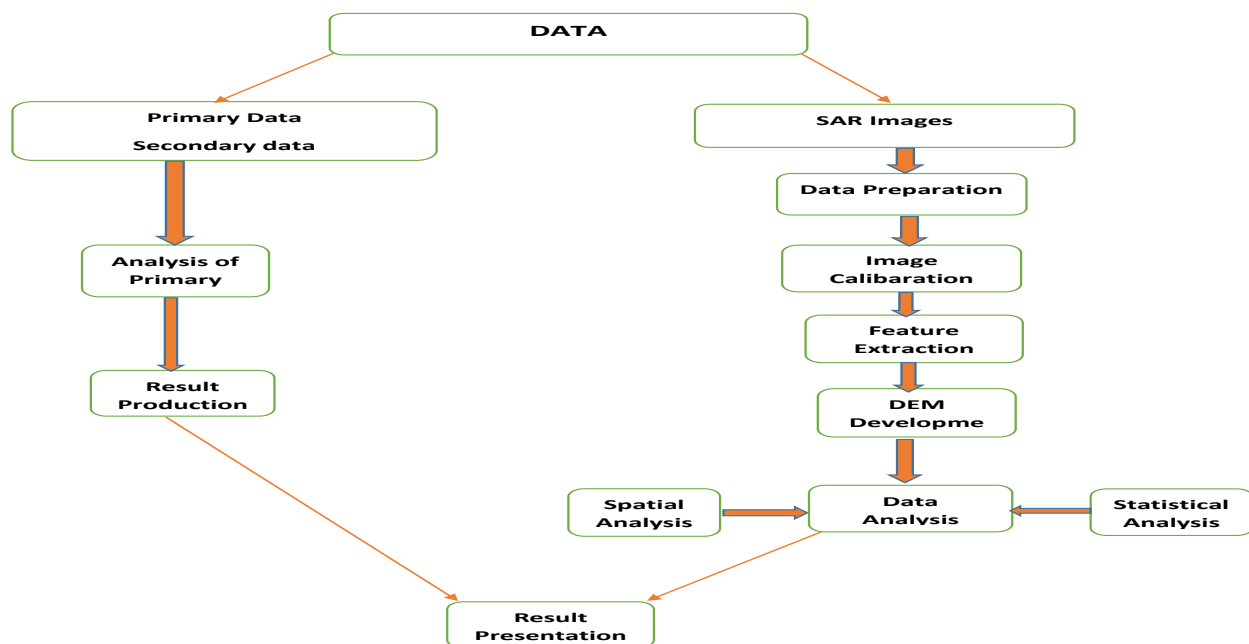


Figure 7: Analytical Framework

4.3.1 Qualitative and Quantitative Data Analysis

Qualitative data analysis was done using qualitative content analysis, which focuses on analysing the content as it is collected from the field before in-depth analysis. Coding and interpretation techniques of the transcribed data from interviews and field notes were to be the initial step in analysing this type of data. Merriam (1998)

states that this process aids in describing and interpreting the data. Detailed interpretations and conclusions were drawn from the observations and responses.

Quantitative data analysis was done using the statistical image analysis techniques in the ArcGIS software that was used to process the SAR images. Quantitative statistics on flood extents and geospatial variations were calculated through segmentation, thresholding, and area calculation. Using Sentinel 1 VV and VH, which are Ground Ranged Detected, enhanced the process of radiometric and geometric corrections. Quantitative Precipitation data was analysed using the Mann-Kendall statistical test, while the variation of the flooding events was analysed using Analysis of Variance (ANOVA).

4.3.2 Analysis of Satellite data and Imagery

Geographic information systems (GIS) are computer-based systems that provide capabilities for input, data management (data storage and retrieval), manipulation and analysis, and output to handle georeferenced data (Aronoff; 1995). GIS provides a broad range of tools for determining areas affected by floods and forecasting areas likely to be flooded due to high water levels in a river. According to Wang (2002), flood mapping requires, among other data, two sets of remotely sensed data or high-resolution images whose analysis was based on one set of images acquired before the flood event and the other acquired during the flood occurrence.

Processing of the SAR images collected before, during, and after the flood in each flood season began with calibration, geometrically corrected, and filtered. A threshold method was applied to extract inundated areas from the images. As the study proposes to estimate land uses affected by the flood, density slicing was applied in the threshold method to separate the water areas from the non-water (land)

areas in the images. Superimposing and analysing the flood maps for each flood cycle will then be done to determine the spatial variations in the flooding extent of the plain. On the other hand, DEMs were used to generate GIS models representing potential wetness and flood inundations. The results were presented through maps delineating the boundaries and extent of flooding in the study area and establishing possible management measures. The images were used to classify inundated areas using the visible red and IR channels. The SAR images were georeferenced, and suitable image enhancements were done to facilitate the delineation of flood areas and interpret the various thematic information. Visual and digital interpretation methods were used to derive information from the satellite images and topographic maps to enhance interpretation. ArcGIS 10.1 software was used to process and analyse the images for easy availability and familiarity.

The critical procedure to determine the aerial extent included the determination of the climate, mainly the precipitation received in the area for the period under study. Then, the Digital Elevation Model of the area is used to determine the average direction of the flows. The research acquired the study area's images, which were later processed and analysed to determine the extent of the inundation in the study area. Historical SAR images about the inundation of the plain were extracted from RADARSAT SAR images in the C-band frequency with HH polarization, and the terrain characteristics of the plain were extracted from DEM. Determination of the aerial extent of the flooding events on the Matebele Flood Plain was done by acquiring satellite images of the area during the peak of the floods. This was mainly done by comparing three images: one was of the floodplain before the floods, the second was during, and the third was after the flood. The geospatial imagery was displayed in GIS as layers after being georeferenced for detailed analysis. The

extents of the floods were then delineated in each image, and other variables, such as land use activities, could be modelled in the images to enhance analysis of the impact of the floods on land use activities. Landsat images were also incorporated to identify the land use activities in the study area for further analysis (Figure 8).

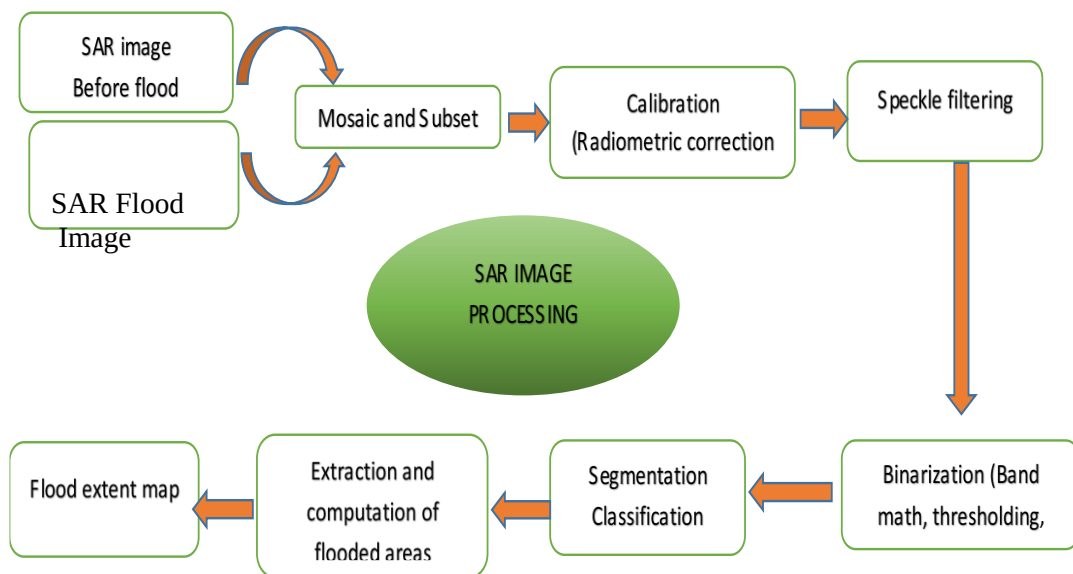


Figure 8: Image Analysis Procedure

4.3.3 Image acquisition and analysis Procedure

In this study, satellite remote sensed images from Sentinel-1 in the C- band were acquired through asf.alaska.edu using Earth data login. The images were from Sentinel-1 and Sentinel-2, acquired in dual polarization, to enhance the analysis of the results. As earlier indicated, Synthetic Aperture Radar (SAR) images are acquired using radar remote sensing, which operates in the microwave region of the Electromagnetic spectrum. The images are not affected by the absence of illumination from the Sun, and they can be acquired even during nighttime. This enhances the ability to read and analyze the changes occurring during nighttime.

This study opted for SAR images to map the flooding extent on the Matebele plain because they are not affected by clouds and can acquire images day and night.

Synthetic Aperture Radar (SAR) is a radar imaging system that operates in the microwave region of the Electromagnetic spectrum to produce high-resolution remotely sensed images. The imaging system is sensitive to minor changes in reflectivity. It does not depend on solar illumination, giving it the advantage of collecting data about geospatial area interest at any time. (Schumann, 2007). The variations in radar backscattering from different targets on the ground give the ability to determine the extent of water from the other land surface features. Images were collected at different intervals, through sampling, to monitor the progression and recession of flood inundation within a brief period. In each image, the extent of flooding was determined by delineating the inundated area.

Flood extent mapping procedures from SAR imagery follow three analytical steps; firstly, reconstruction and acquisition of the satellite images, which are raw data taking into account all calibration and radiometric corrections and development of digital elevation models (DEM); secondly, image analysis procedures such as the development of composite bands for images in greyscale, image classification and segmentation and thirdly flood extent analysis through calculation of the areas covered by flood in the sampled images. To accomplish this, various GIS-based image analysis methods such as geo-processing, digitizing, creating of shape files, spatial analysis, area calculation, and overlay were used to determine the extent of floods in flood extent mapping. This study, therefore, established the use of the multi-temporal image flood mapping technique. This technique is based on a scientific analysis of images that were taken at various times of the year in the same study area. Features in the images taken during the flooding period are identified and delineated. A comparison of the two images is done to distinguish the various

features. In this case, the study distinguished water-covered areas from non-water-covered areas.

Following the acquisition of one image in each year from 2008 to 2018, the analysis process began with image geo-referencing, calibration, segmentation, and classification processes. Each image was analyzed separately to determine the aerial coverage of the flood in that particular year. As seen in the example of the image for March 2018, all images were processed in the same way. ArcGIS was used to support the above processes of the images. Matebele Flood Plain mainly has a history of being flooded from March to July every year. Therefore, the research acquired images before and during this period. The images below show the first image taken before the perceived flooding period. The satellite images were acquired through links such as [EarthExplorer \(usgs.gov\)](https://earthexplorer.usgs.gov), <https://search.asf.alaska.edu/>, and usgs.gov. Satellite images were acquired on a seasonal basis when Matebele floodplain experiences flooding, from February to July every year. The images were then imported into the ArcGIS software and processed using image analysis tools.

In principle, to conduct a flood extent analysis or flood risk analysis, the following key techniques should be performed:

1. Development of a Digital elevation model (DEM) of the study area
2. Assessment of the slope in the area to identify flood-prone areas.
3. Assess the land use/land activities in the study to establish the impacts of the flooding events.
4. Analysis of the precipitation received in the study area.
5. Analysis of images for flood water coverage

Pre-processing of satellite images (Figure 9) acquired in different portions of the Electromagnetic spectrum provides a unique way to enhance image classification and segmentation.

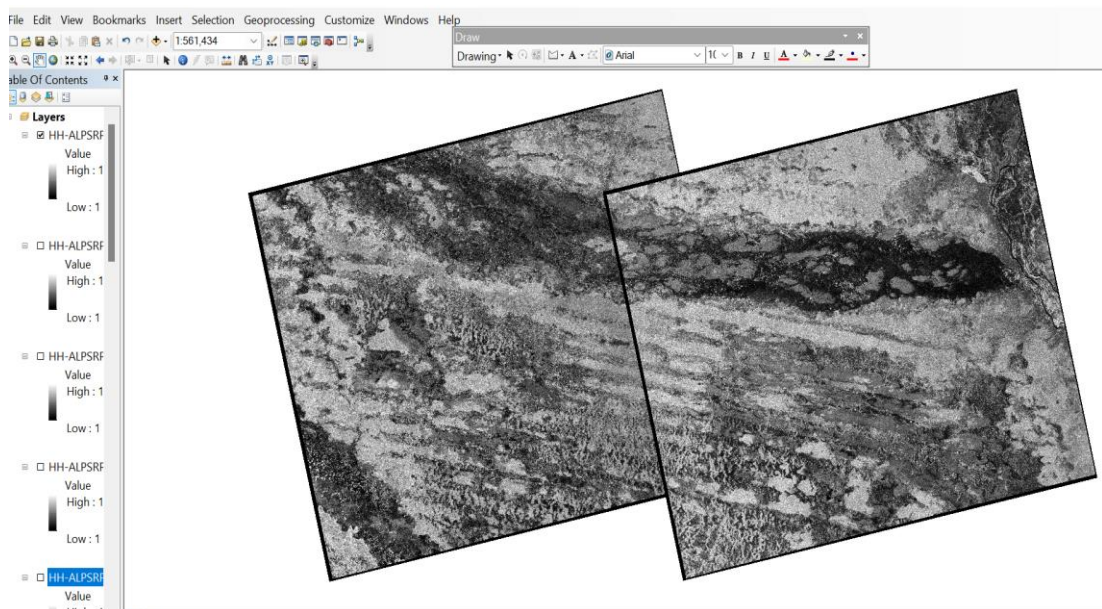


Figure 9: Processing of 2009 samples images.

Following the classification of different features, an extract from the area of interest (Figure 10) shows the distribution of blue pixels over the areas indicating the areas covered by water. As observed in the resulting image analysis, it can be concluded that the Matebele flood plain experiences high inundation during mid-year.

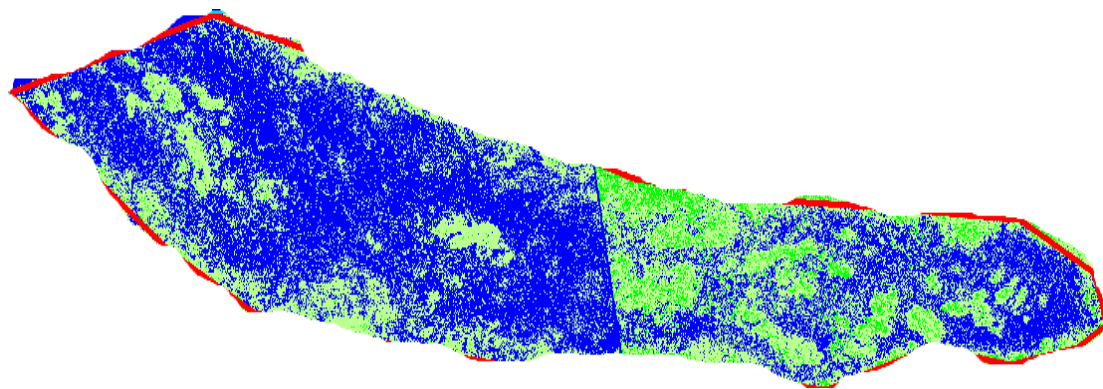


Figure 10: Results from the processed image of July 2009

Image processing to determine the extent of flooding events in each respective year required different images are processed to determine inundation extents. Figure 11 and 12 shows the algorithm followed.

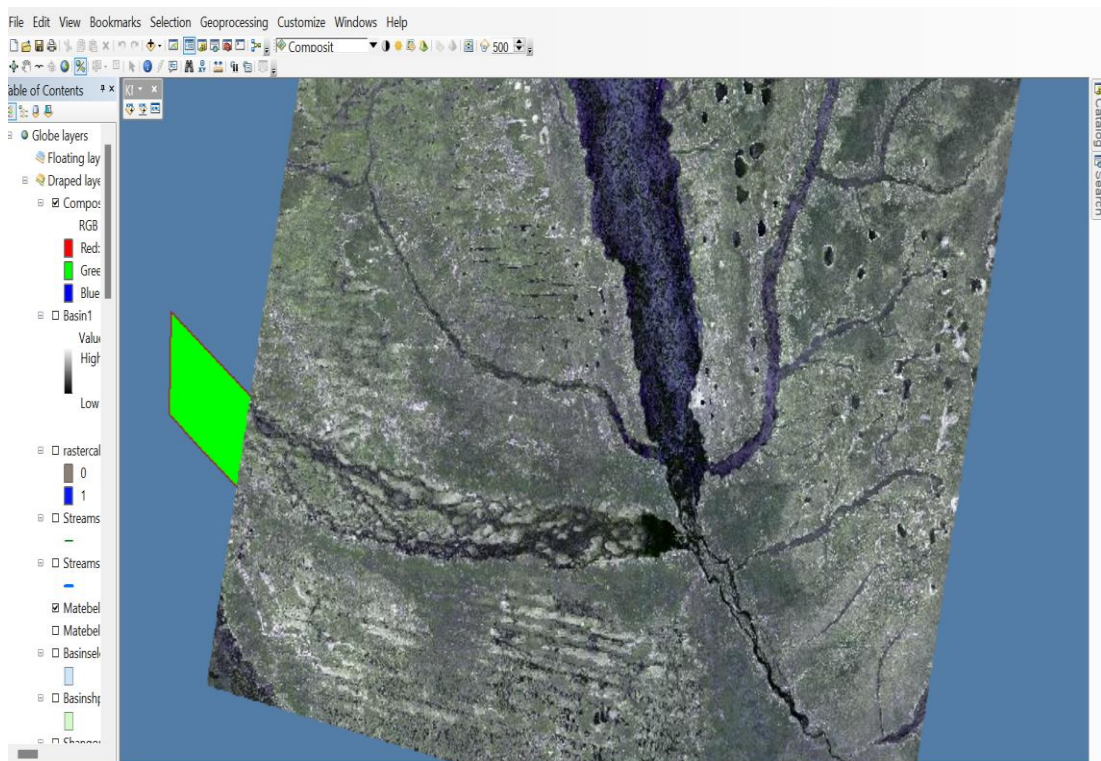


Figure 11: Analysis of flood image for May 2011

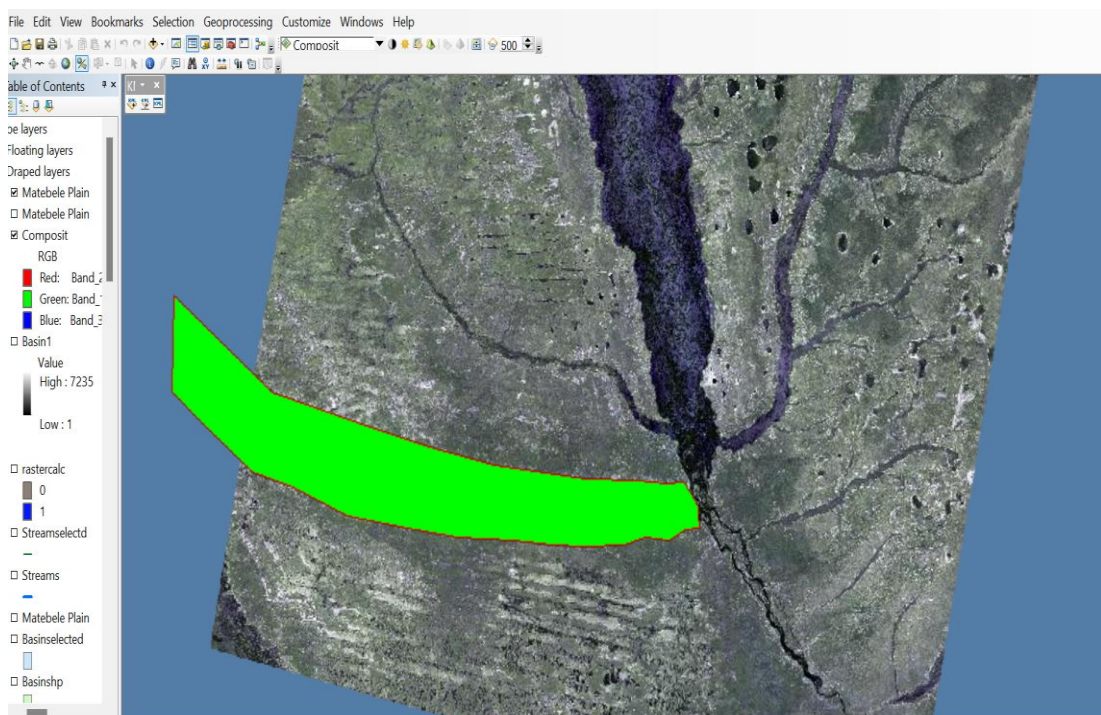


Figure 12: An overlay of the study area for analysis of May 2011 image.

The drainage pattern of any landscape helps to determine the expected flow of water and the areas expected to have high intensities of flooding. To determine and understand the drainage pattern of the study area, Figures 13, 14, 15, 16 and 17 provided the steps and results.

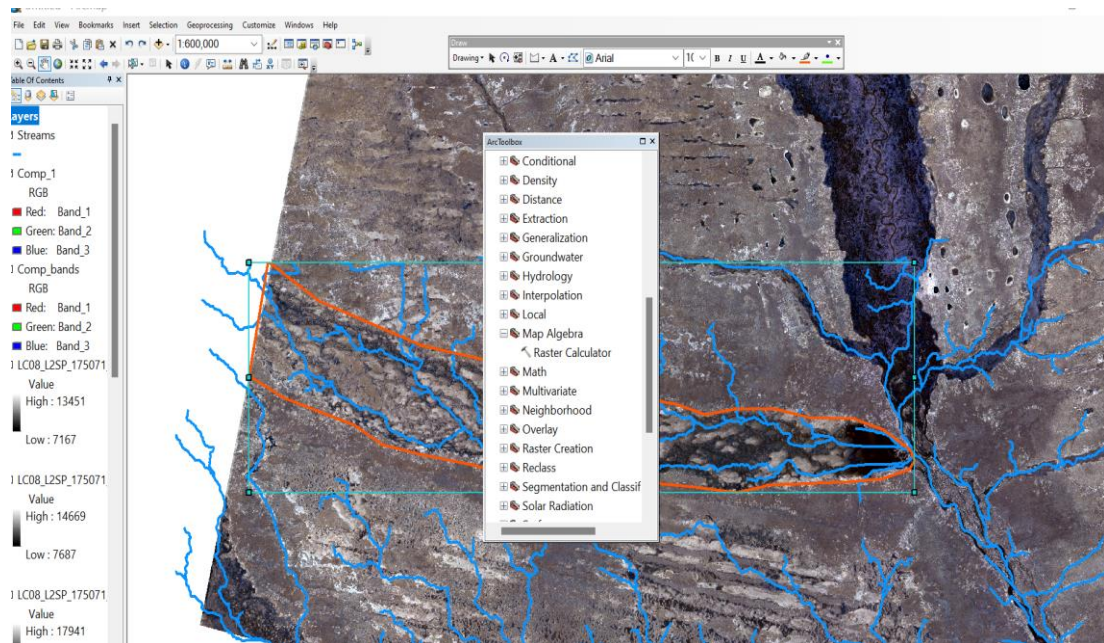


Figure 13: An overlay of stream flows on Matebele plain and surrounding watersheds.

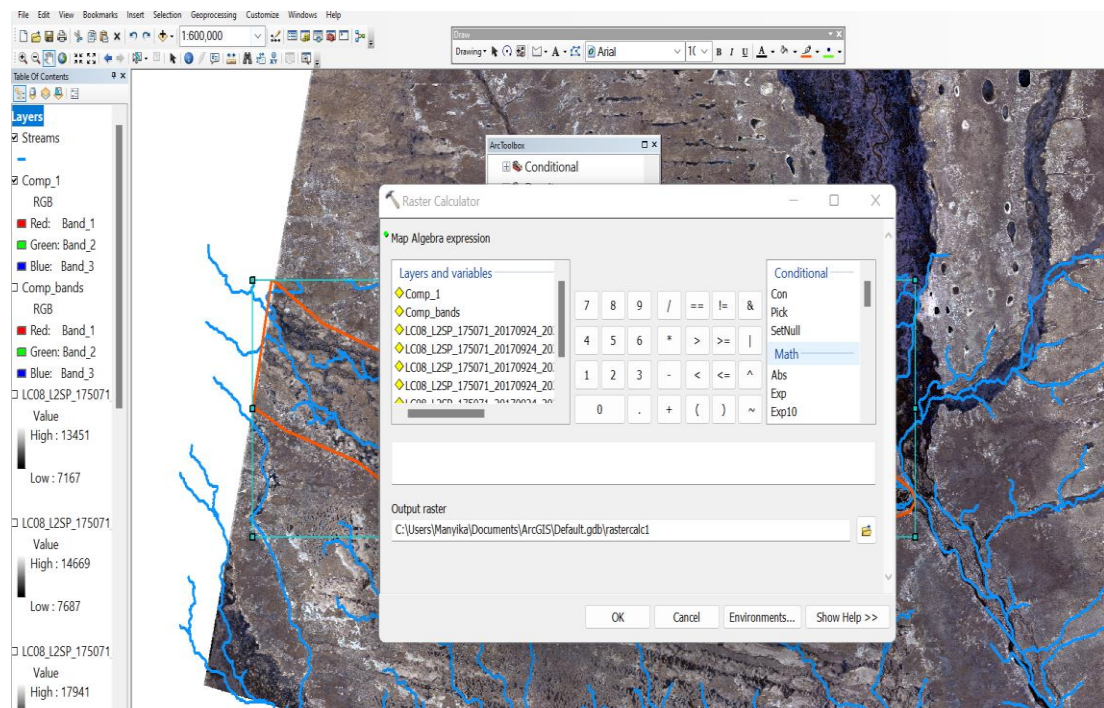


Figure 14: Quantification of pixels representing water in image (blue pixels > 800)

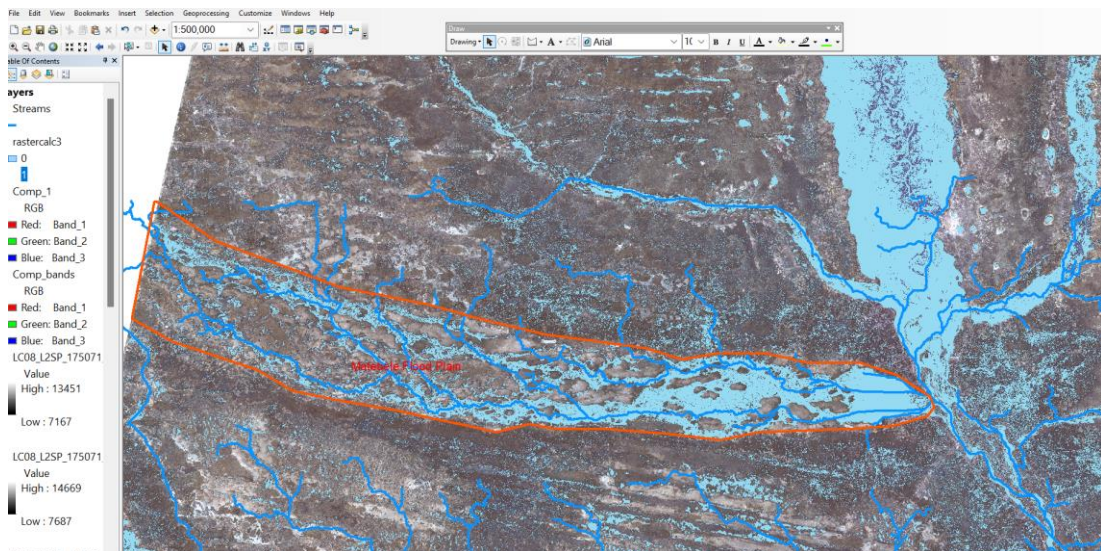


Figure 15: Results Water Coverage represented by the Blue Pixels- 2011 image.

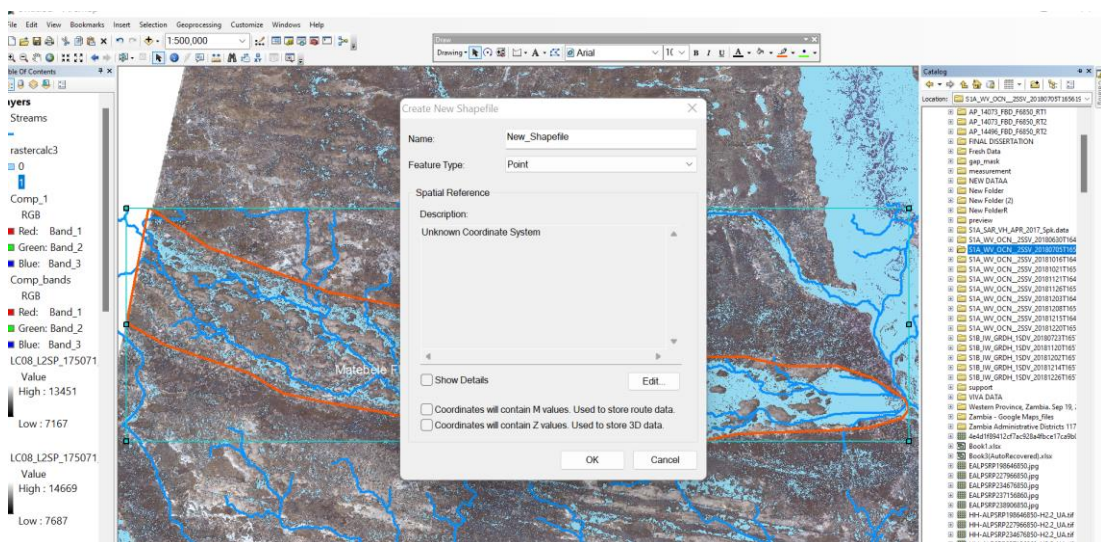


Figure 16: Creation of new shapefile for Matebele flood plain.



Figure 17: Image showing the distribution of blue pixels on Matebele flood plain.

The satellite image of 2011 was then processed to determine the number of pixels falling in the classes of red, blue and green as shown in Figures 18 and 19.

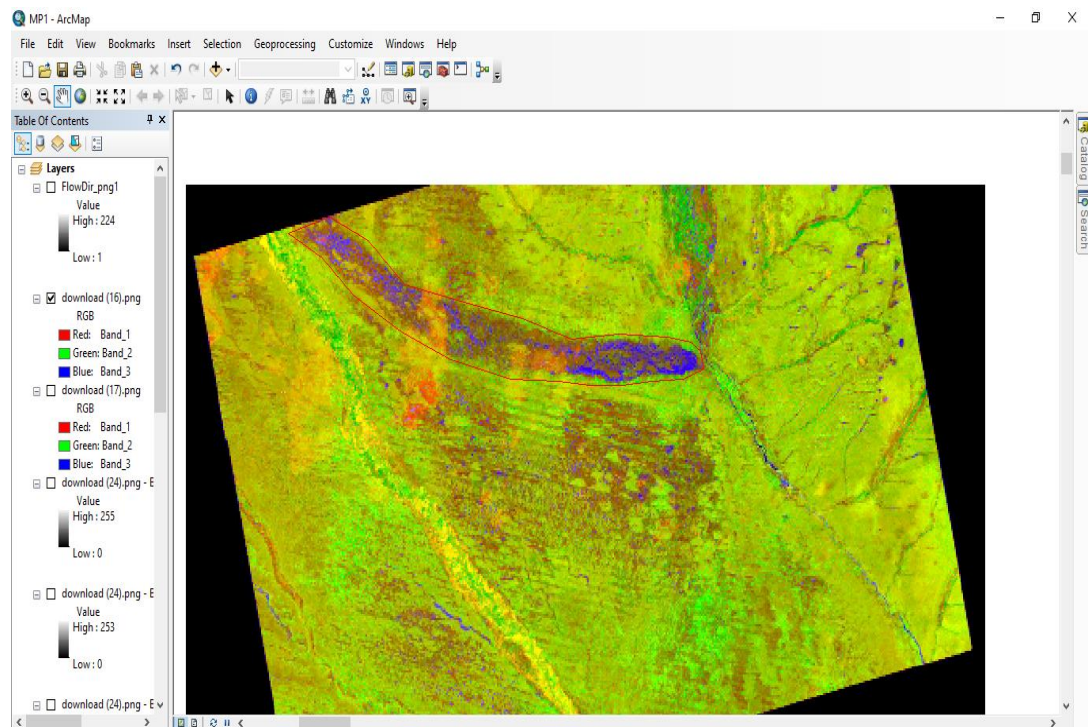


Figure 18: Image Processing in ArcMap

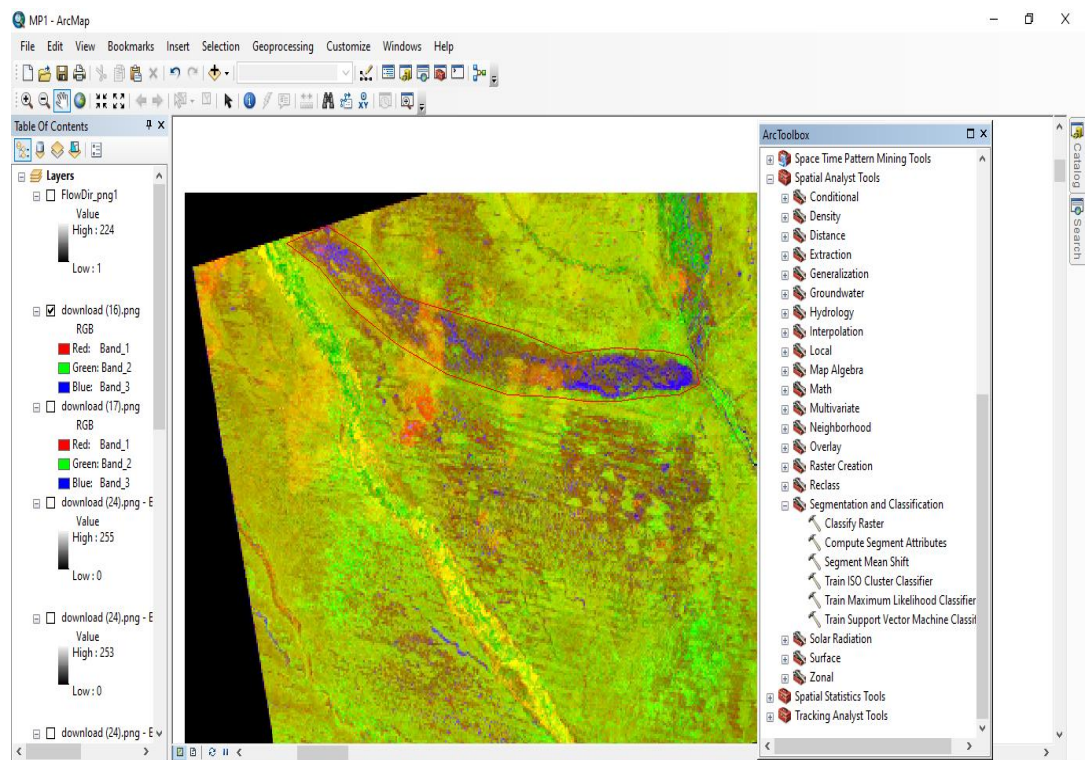


Figure 19: Image Processing for 2014 sampled image.

Figures 20, 21, 22, 23, 24 and 24 are showing the algorithm followed in using Sentinel Application Platform to establish the concentration of water pixels in the satellite image. A step-by-step process enables the provision of results which feed into establishing the water coverage and extent of the water pixels. As Wang (2002) indicates, two sets of images are required for flood mapping. These are images of the area before and during the highest peak of the flooding. The image before the flood period is used as the reference image, which will help analyse the changes in the flooding process.

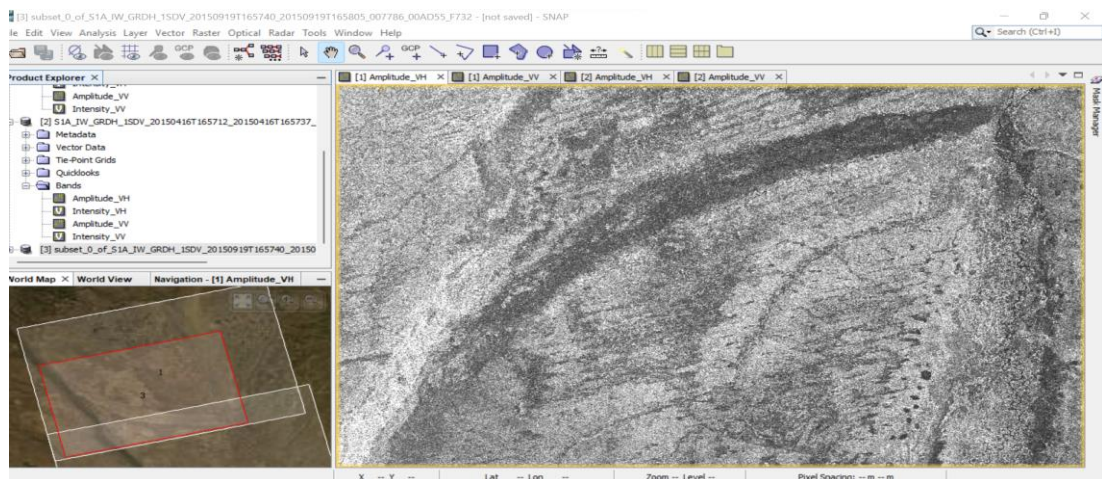


Figure 20: Flood Analysis for August 2015 Image in Sentinel Application Platform

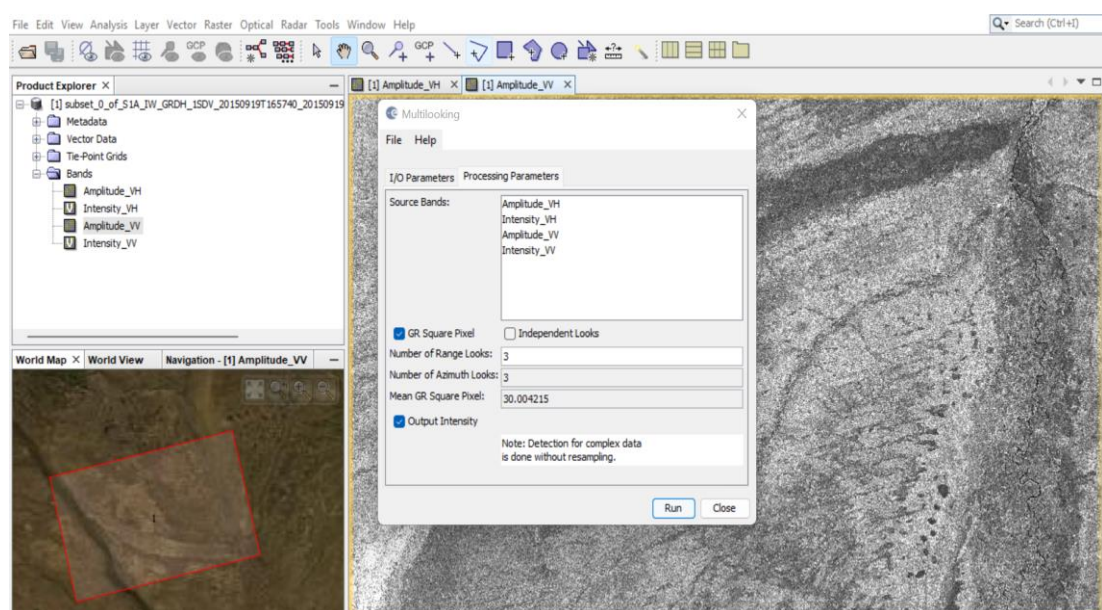


Figure 21: Image speckle removal.

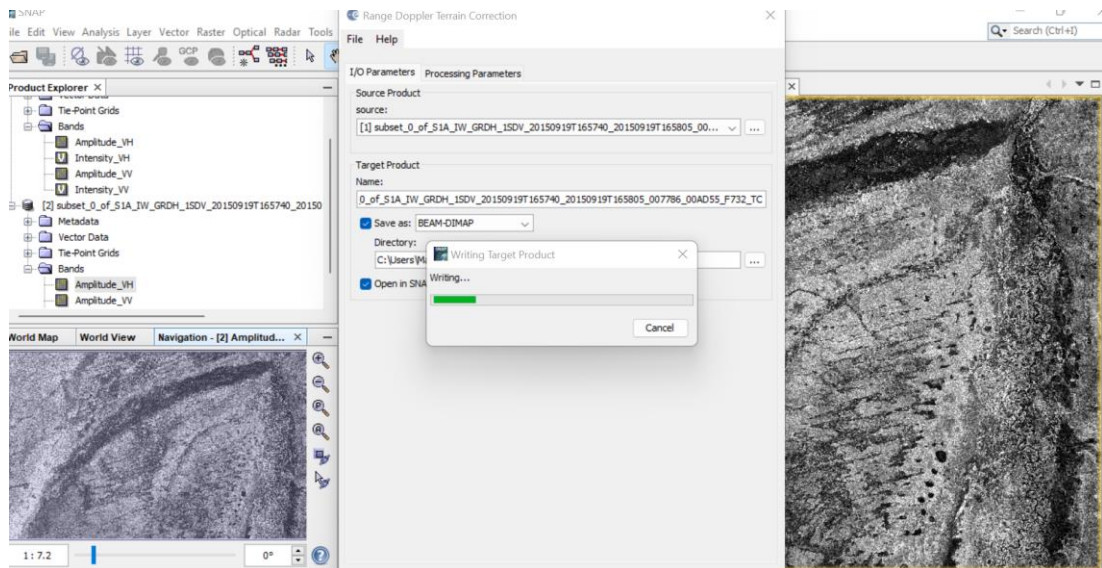


Figure 22: Geometric Correction of the image.

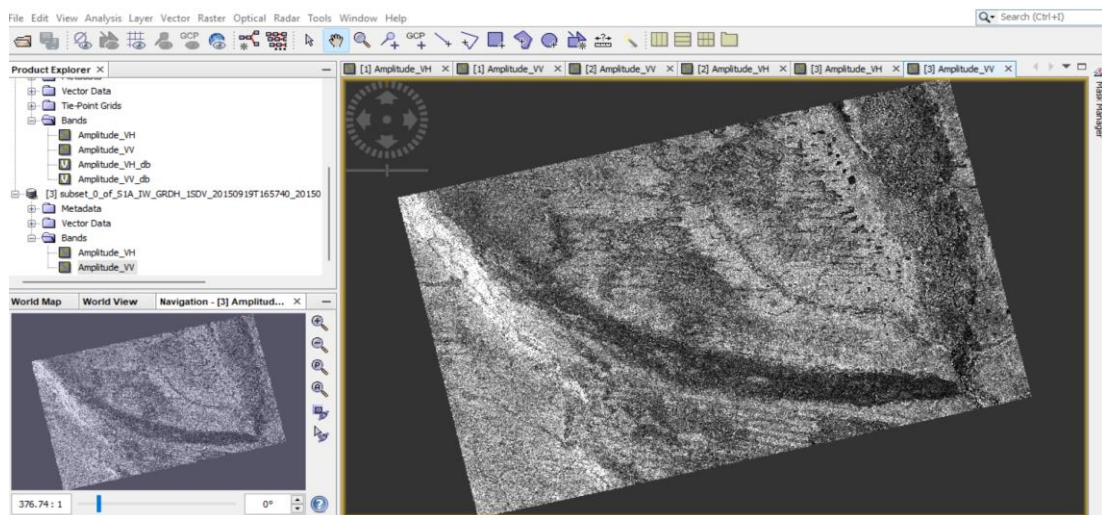


Figure 23: Terrain Correct image.

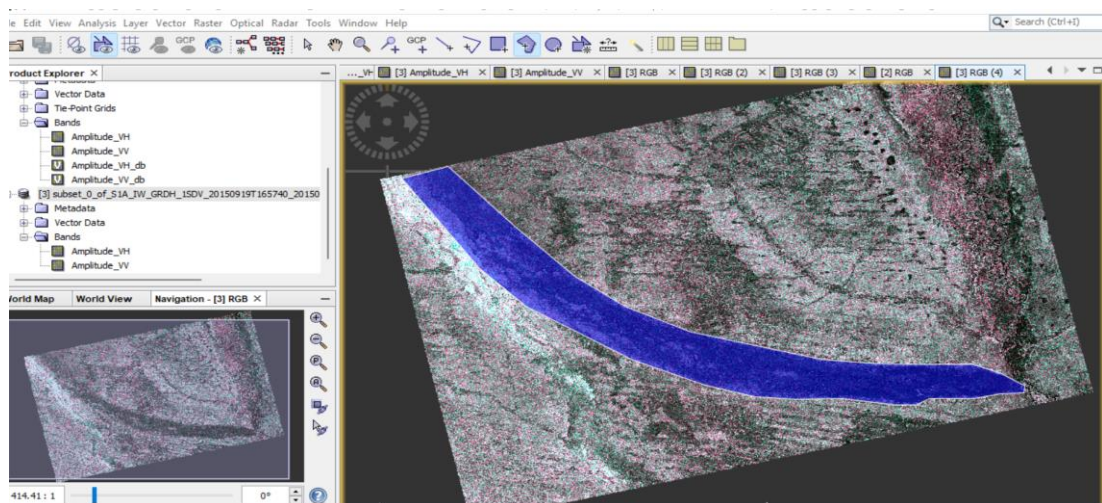


Figure 24: Study area flood analysis.

An analysis was done on the image taken in March 2018 as shown in Figures 25, 26 and 27. This was sampled based on multi-temporal flood mapping techniques, where images were analysed before and during the flood period to determine the extent of inundation. The results indicate that the area under study has the highest coverage of floods. This strengthens the conclusion that the extent of flooding on Matebele Plain covers almost 78% of the area. Water coverage in the area was analysed based on red, blue, and green bands of the Electromagnetic spectrum to detect water surfaces and other land uses. The results indicated that much of the study area was covered by blue pixels, concluding that water has the highest percentage during the flood season.

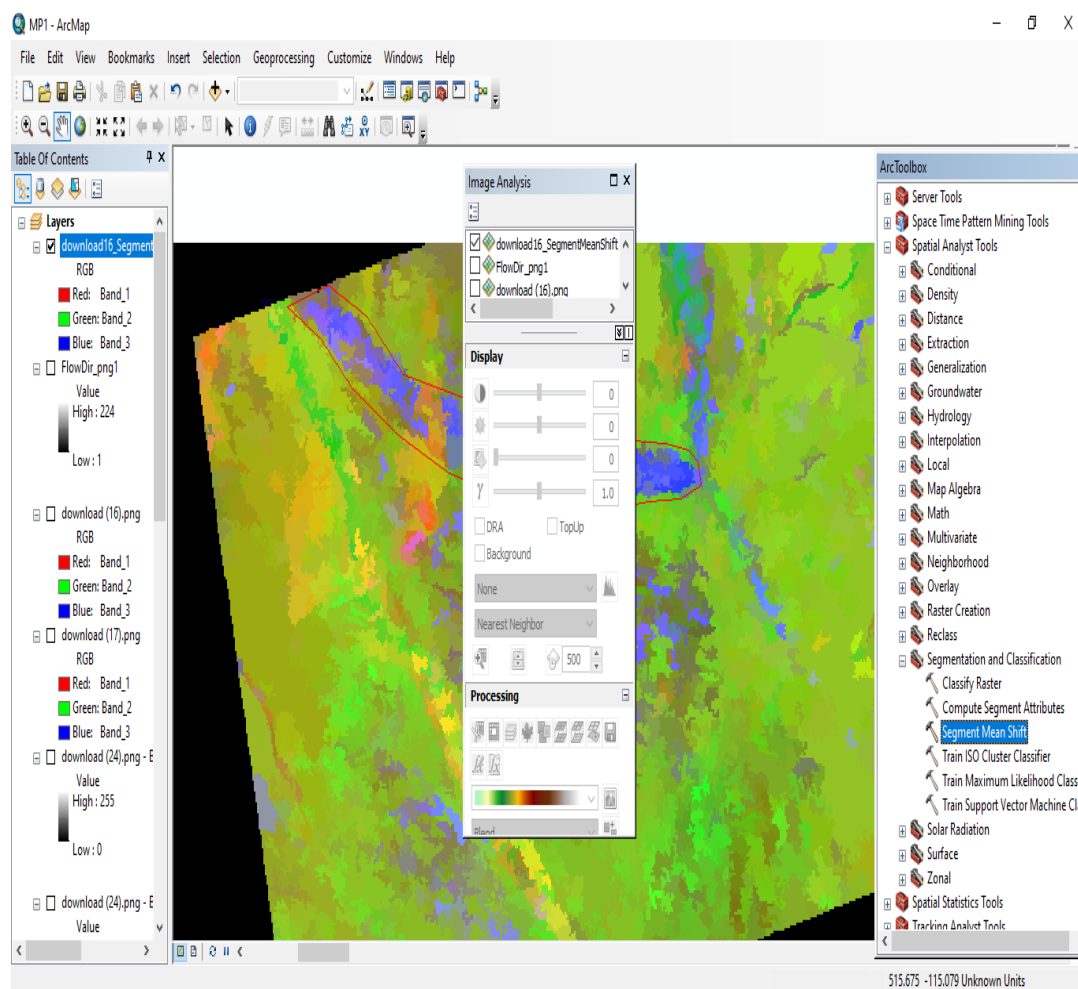


Figure 25: Image processing for 2018.

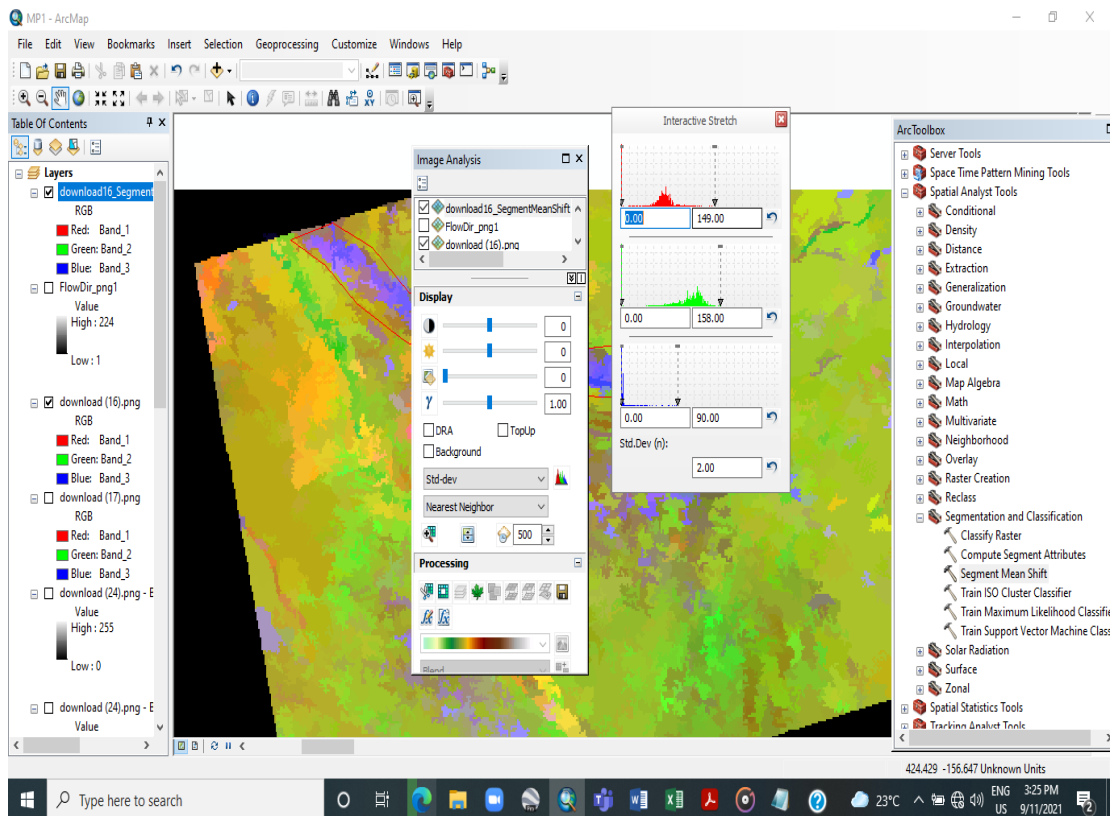


Figure 26: Segmentation and RGB extent analysis- 2018 image.

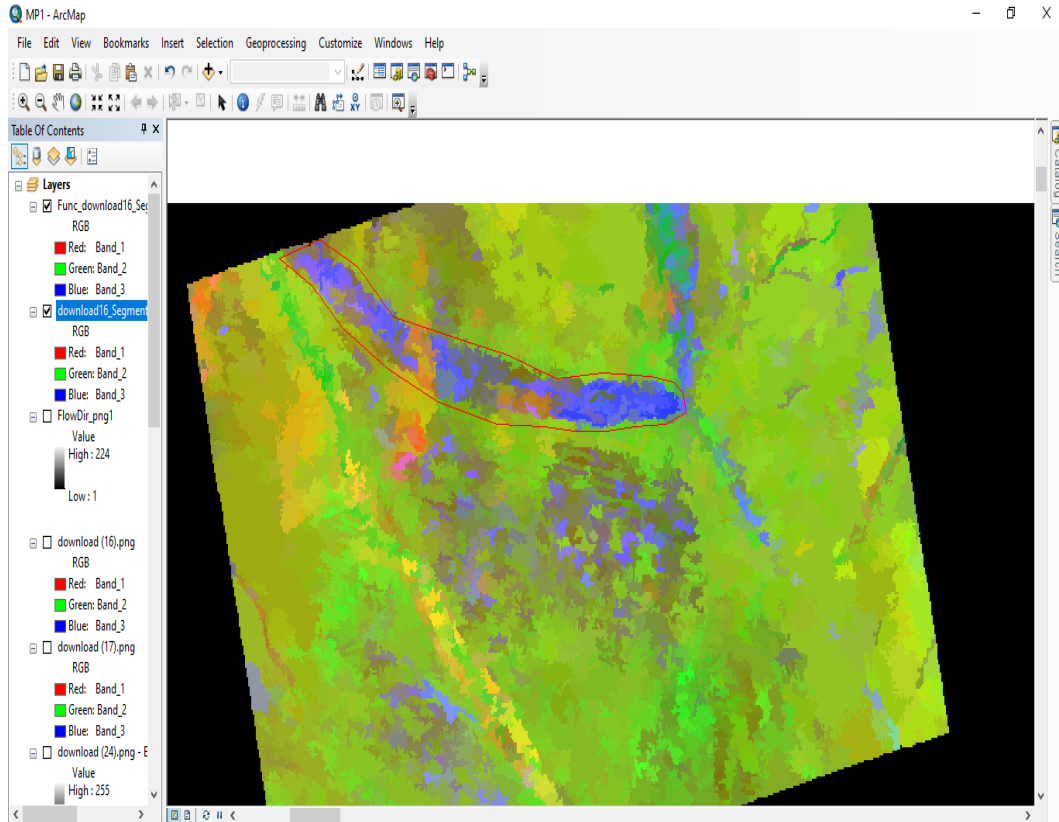


Figure 27: Results from image classification (March 2018 image)

4.4 Testing for Reliability and Validity

Reliability is the consistency of the results when tested several times. Validity is the accuracy of the results when the research is repeated. To achieve reliability of the collected data and the results, the study has adopted the administration of an interview schedule that was administered on all respondents. The sample from which data came from the same population meaning people that have experienced the floods on the plain. A reliability coefficient which is often a statistic of choice was determined to carry out the reliability test. Validity of the results was tested using two types of validity. Content validity and predictive validity. Content validity was based on the collected data from interview schedules, assessments using topographic maps, field observations and analysis of data from satellite images. A closer relationship in these validated the results Predictive validity was based on comparing the field data from the respondents and the data in the satellite images. The closer the correlation, the more valid was the results.

4.5 Ethical Considerations

Discussions, reports, assessments and activities on land matters in Western Province have been drawing attention from local authorities. Additionally, any research task requires that the respondents give consent to the information being sought. The researcher ensured that all local authorities inclusive of the area chief, the village headmen, custodians of protect areas such as Marshlands on Matebele plain were informed of the research to which they made consent through signing of a consent form attached to every interview schedule used. All participants and respondents were assured of confidentiality in all information gathered. Ethical clearance was obtained from the University of Zambia to undertake this study as attached in Appendix III.

CHAPTER FIVE: RESULTS

5.0 Introduction

This chapter presents the results and findings of the study to the following objectives: the maximum aerial extent of the area covered by floods in the period 2008 to 2018, spatial variations in the flooding events in each flood cycle, determination of the land uses affected by floods in each flood cycle on Matebele Flood Plain. Four main sections of this chapter are developed to achieve the objective requirements.

5.1 Aerial coverage of floods on Matebele Flood Plain

Extraction of flooded areas can be done using Synthetic Aperture Radar (SAR) images, which have been widely used to delineate flooded areas through various algorithms (Clement et al., 2017). The processing algorithms apply change detection techniques to several images to detect the backscattering of signals from geospatial surfaces, which are then acquired as flood images. This enables the sampling of suitable images to delineate flood extents and risk areas and arrive at the highest detected flood extents in an area of interest.

Table 2: Computed estimates of flood extents from 2008 to 2018 on Matebele Flood Plain based on sampled images with highest flood coverage.

Image Date	Pixels Count	Pixel Size	Area Coverage (Km ²)
16.07.2008	37724	0.25	9431
12.06.2009	59744	0.25	14936
07.07.2010	45280	0.25	11320
04.08.2011	26284	0.25	6571
29.07.2012	20376	0.25	5094
21.05.2013	24084	0.25	6021
18.07.2014	22932	0.25	5733
14.08.2015	30168	0.25	7542
22.06.2016	37700	0.25	9425
09.07.2017	50645	0.25	12645
14.04.2018	65764	0.25	16441

Following the visual checks, magnitude indexing ranging from 0-4, where 4 is denoted as the maximum coverage of the flood, classification, and segmentation processes in ArcGIS software, the results from the analysis of the ten sets of mosaicked images of this study based on Matebele Flood Plain, acquired from Copernicus Open Source for the period 2008 to 2018 and processed using the various techniques in ArcGIS, giving the results in Table 2, indicated that the maximum aerial extent of the flooding events were recorded in March 2018 with the highest aerial coverage of 16,441km². This represented 65764 pixels, which shows wetness in the image. This represented 78% of the total land area, which is 21078 km², spreading across the five wards of Matebele Plain.

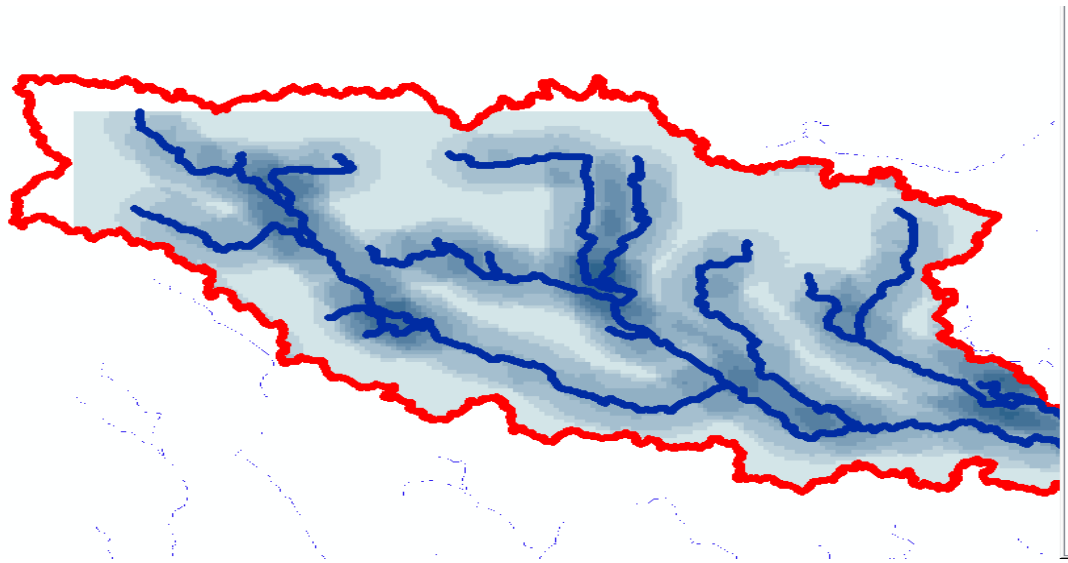


Figure 28: Maximum aerial coverage of floods on Matebele Flood Plain-2018

Overall, the highest pick of the floods (maximum flood extent) on the plain was recorded during the 2017/2018 flood season. Based on the radiometric threshold process applied to the sampled SAR flood image for March 2018, pixels in the blue band covered an area of 16,441 square kilometres with the highest threshold in the histogram analysis of the pixels (Figure 28). Compared to the lowest extent, which occurred in 2012, and the mean flood extent of 9559.9 km², the maximum flood

extent has a difference of 6881.1 km² over the lowest extent and 5094 km² above the normal, respectively. However, the results showed a slight difference in the aerial coverage in 2009 when the area experienced an aerial coverage close to the maximum in 2018.

5.1.1 Precipitation in relation to Flooding in Matebele Plain

The study area has no gauged rainfall stations that could support the availability of rainfall data daily. Additionally, the discharge point from Kwando River to the Matebele Plain has no Hydrological Current meters or Acoustic Doppler current profilers to measure the flows into the Matebele Plain. Therefore, the archival precipitation data received in the Matebele flood plain from 2008 to 2018 was downloaded from the site <https://power.larc.nasa.gov/data-access-viewer/> [POWER | Data Access Viewer \(nasa.gov\)](#) platform, which provided satellite precipitation data from 2008 to 2018. Figure 29 and 30 shows the site and process where climate data for the study area was downloaded from, putting in the parameters such as the year and the area of interest (AOI). Data was then presented in a table for easy analysis as shown in Table 3.

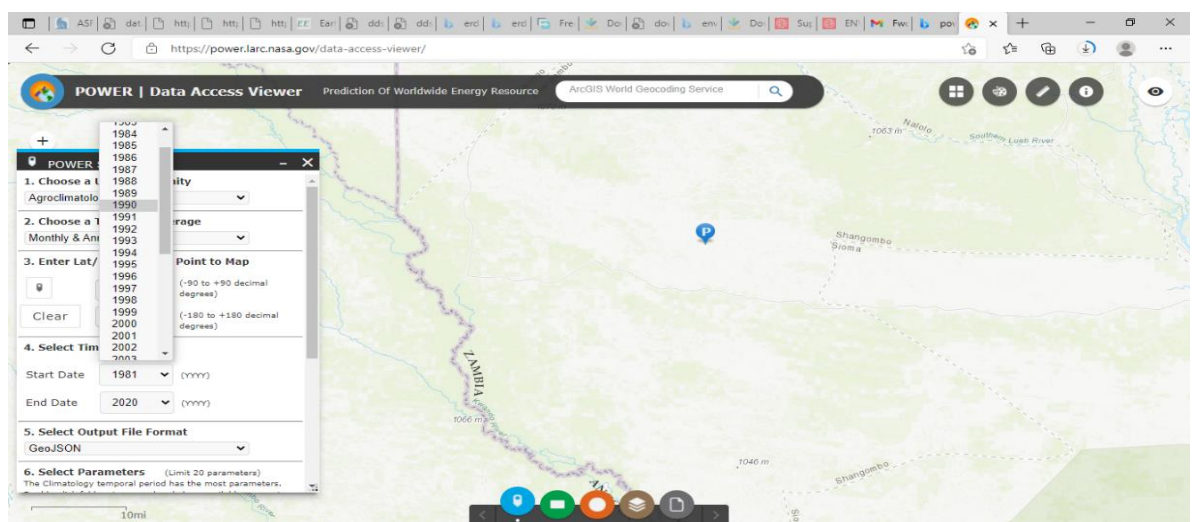


Figure 29: Acquisition of Climate Data

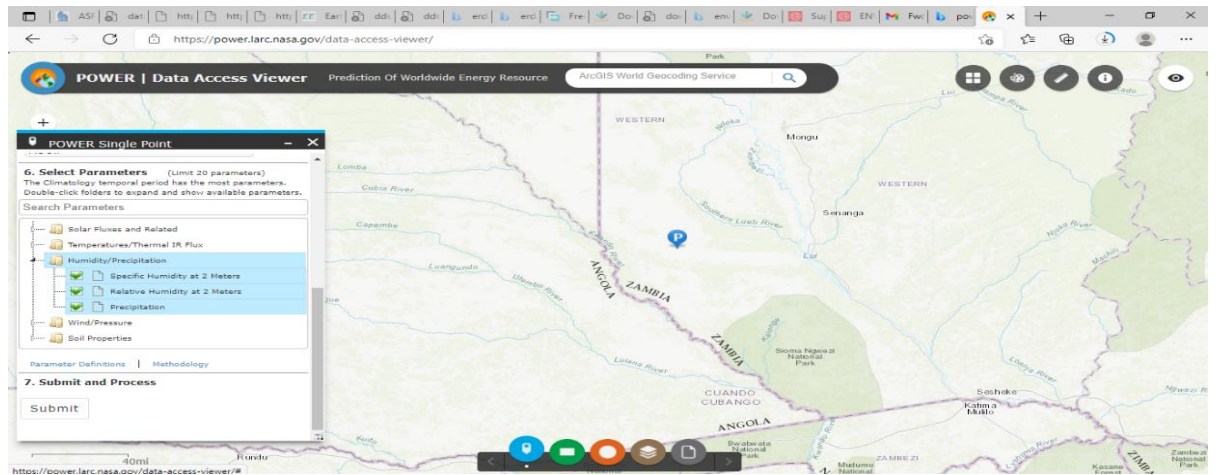


Figure 30: Continued procedure for Acquisition of Climate Data

Table 3: Precipitation data of Matebele Flood Plain 2008-2018 (mm)

YEAR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANN
2008	16.36	15.32	14.16	10.62	8.61	6.35	5.68	4.88	4.33	6.41	13.67	14.47	10.07
2009	15.26	14.95	13.61	9.89	7.87	5.86	5.19	4.15	5.92	7.81	12.88	14.65	9.83
2010	15.87	15.62	15.26	13.92	9.34	5.98	5.98	4.58	5.13	6.59	12.21	14.28	10.38
2011	15.14	13.98	15.08	12.15	7.81	4.82	4.09	4.39	4.58	7.75	12.21	15.5	9.77
2012	14.59	15.32	14.28	9.03	5.68	5.37	3.97	4.64	4.7	8.3	11.72	15.32	9.4
2013	15.93	15.2	12.94	8.3	5.86	4.7	4.64	4.46	5	6.65	11.84	15.32	9.22
2014	15.5	15.01	15.2	12.63	8.36	6.65	5.37	4.94	5.8	6.53	11.78	14.22	10.13
2015	13.79	12.7	11.72	12.08	6.47	5.19	4.39	3.97	5.25	6.47	9.7	15.32	8.91
2016	15.56	15.75	16.05	11.23	6.9	5.55	4.64	4.64	4.82	6.47	11.17	13.73	9.7
2017	15.75	16.24	14.83	12.45	8.85	7.26	5.92	5.31	5.37	8.3	10.5	15.01	10.44
2018	13.49	15.99	15.87	12.88	9.46	6.1	6.35	5.31	5.13	6.53	9.64	11.96	9.89

The data in Table 3 shows the precipitation, in millimetres, received on Matebele Plain from 2008 to 2018. This data was analysed to give a general overview and establish the years in which the area received more precipitation. A Mann-Kendall statistical test was conducted to determine the relationship between rainfall received in the area and flooding events. The Mann-Kendall test statistic is a robust method to analyse trends in time series, used to detect monotonic trends. There was a significant trend in the amount of precipitation received in the area for some months and the expected levels of flooding. Hence, it guides the sampling of images for

analysis. It was, therefore, significant that precipitation as a parameter is analysed to support the observable results in the satellite images.

Table 4 summarizes the Man Kendall trend analysis on the precipitation received on the Matebele flood plain from 2008 to 2018. From the summary of the p-values, it is evident that there were no significant variations in the average amount of rainfall received on the plain. The amount of precipitation received was recorded to be constant, mainly falling in the same range of significance, hence minimal variations.

Table 4: Summary of Statistics on the Trends in Rainfall received on Matebele flood plain from 2008 to 2018.

Summary statistics

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
JAN	11	0	11	13.490	16.360	15.204	0.902
FEB	11	0	11	12.700	16.240	15.098	0.997
MAR	11	0	11	11.720	16.050	14.455	1.300
APR	11	0	11	8.300	13.920	11.380	1.741
MAY	11	0	11	5.680	9.460	7.746	1.342
JUN	11	0	4.700	4.700	7.260	5.803	0.779
JUL	11	0	11	3.970	6.350	5.111	0.815
AUG	11	0	11	3.970	5.310	4.661	0.428
SEP	11	0	11	4.330	5.920	5.094	0.487
OCT	11	0	11	6.410	8.300	7.074	0.786
NOV	11	0	11	9.640	13.670	11.575	1.249
DEC	11	0	11	11.960	15.500	14.525	1.023
ANN	11	0	11	8.910	10.440	9.795	0.473

Significance level (%):5

Series\Test	Kendall's tau	p-value	Sen's slope
JAN	-0.309	0.186	-0.100
FEB	0.257	0.274	0.089
MAR	0.200	0.392	0.113
APR	0.200	0.392	0.185
MAY	0.091	0.697	0.085
JUN	0.091	0.697	0.045
JUL	0.147	0.532	0.067
AUG	0.352	0.137	0.070
SEP	0.220	0.349	0.060
OCT	-0.075	0.753	-0.007
NOV	-0.844	0.000	-0.335
DEC	-0.262	0.270	-0.082
ANN	-0.091	0.697	-0.019

Overall, the results for the Mann-Kendall statistic for 2008 to 2018 (annual) indicate a significant positive trend in precipitation distribution on the plain (Figure 31).

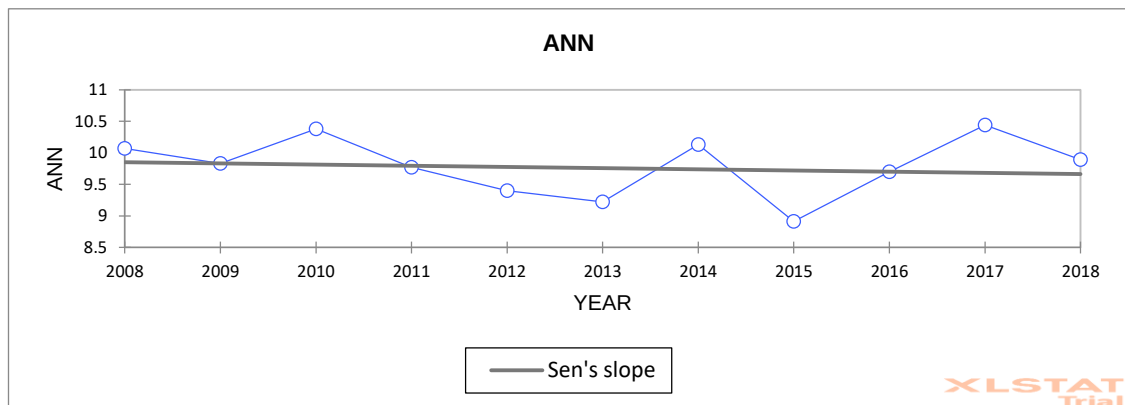


Figure 31: Annual trends in Precipitation on Matebele Plain from 2008 to 2018

Figure 32 shows a graphical display of the average rainfall received in each month for the period 2008 to 2018. During this period, 2008 to 2018, there have been significant variations in the average annual rainfall received in the area. Starting from 2010, there has been a significant decrease in the average precipitation levels recorded in the area. This means the levels of flooding were also significantly expected to reduce as precipitation has been contributing to the flooding extents. Compared to the general overview in the satellite imagery, the appearance of water

in the images for the years 2010 to 2016 were showing a significant reduction. Precipitation has a direct impact on the inundation levels on the plain. This validated the observations in satellite images.

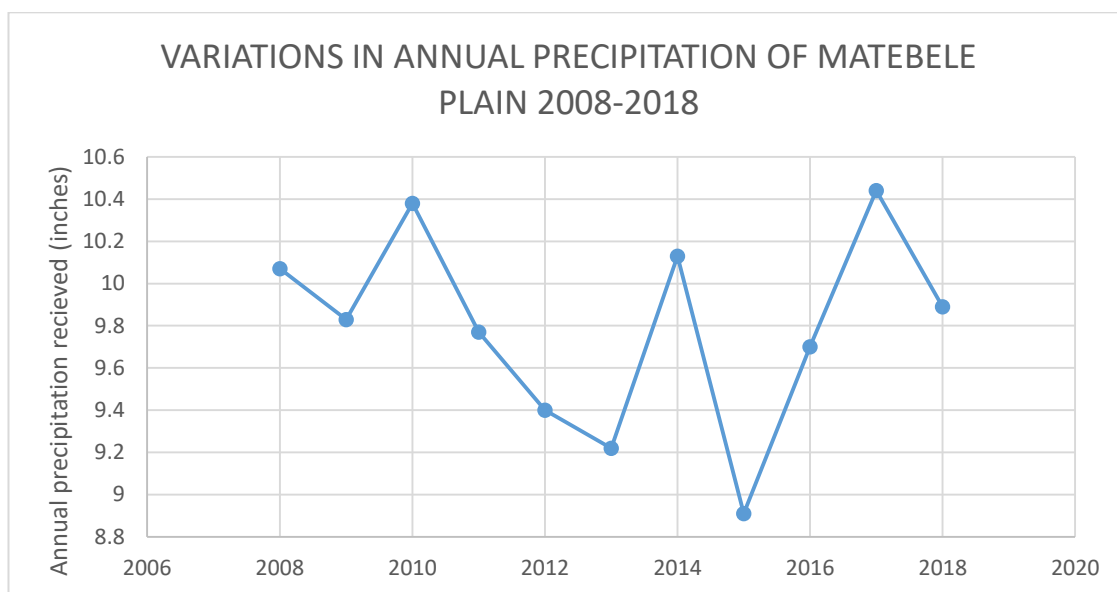


Figure 32: Analysis of Annual Precipitation received on Matebele Plain from 2008-2018

The monthly distribution of average precipitation on Matebele Plain, as shown in Figure 33, indicates an average trend of rainfall received, like other parts of Zambia. Normal rainfall distribution was received from November to March from 2008 to 2018. In addition to the Multi-Criteria Analysis (MCA), the analysis of the rainfall pattern aided in validating the results in the satellite images, indicating that the highest flooding events will be from January to March annually.

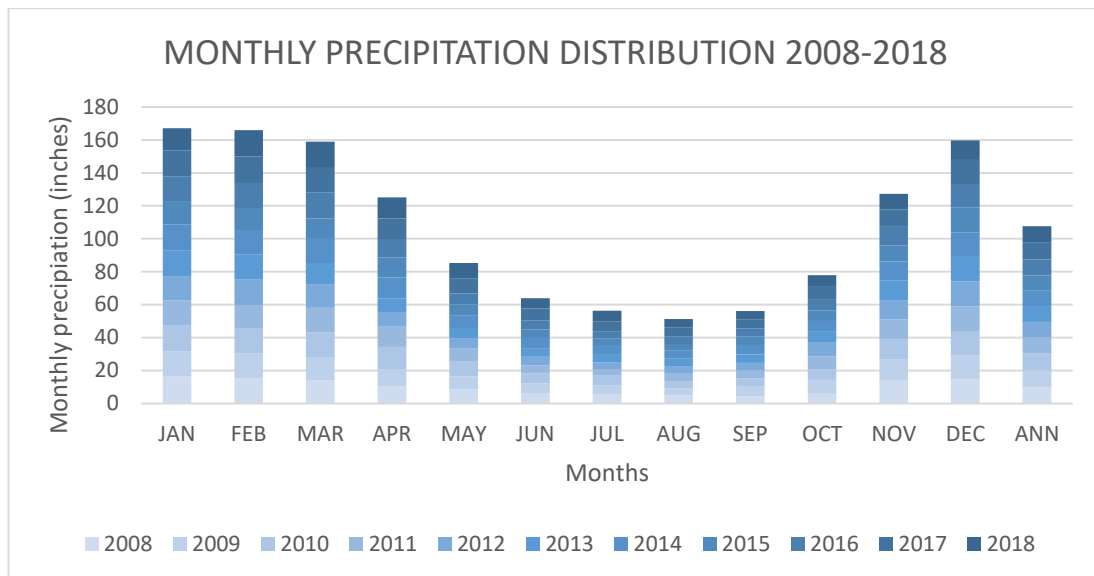


Figure 33: Analysis of average monthly precipitation received on Matebele Plain-2008-2018

Matebele Plain is in Argo-Ecological Region 2b of Zambia's Agro-Ecological Regions (Figure 34). The region covers the Western Province of Zambia, and the average precipitation ranges from 800mm to 1000mm. Matebele floodplain lies within this region of the Agroecological zones of Zambia.

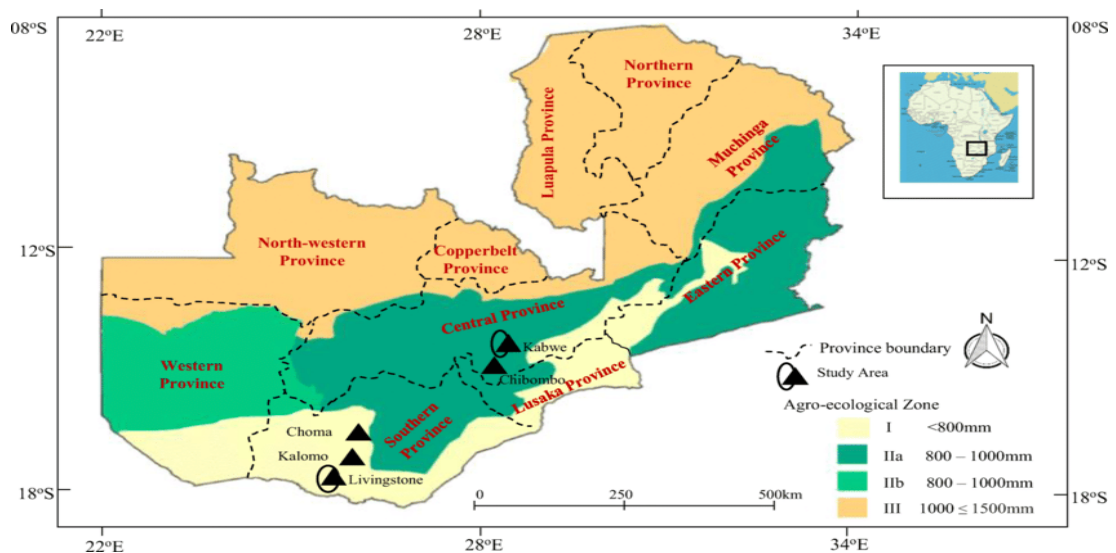


Figure 34: Agro-ecological regions in Zambia and Rainfall distribution.

From Table 5, the computed Z statistic for the trends in wet days for areas in Agro-ecological region 2b gives -0.3 showing the minimal significance in the trends in the precipitation received around this Agro-ecological region.

Table 5: Trend in annual number of wet days and annual rain fall amount for stations in Agro-Ecological zone 2.

Station	Trend (wet days)	Trend in annual rainfall amount (mm/year)
Chipata	-0.4708	-5.72
Choma	-0.25	-2.45
Kabwe	-0.2240	-5.95
Kafue	-0.222	-1.12
Kaoma	-0.3350	-4.35
Mongu	-0.3085	-2.77
MtMakulu	-0.0779	0.8918
Petauke	-0.3387	-1.95

Source: *Rainfall Trends in the Agro-Ecological Zones of Zambia* by Suman Jain
Department of Mathematics and Statistics, University of Zambia.

5.1.2 Download and Analysis of the Digital Elevation Model (DEM)

In addition to satellite image analysis, other Geospatial techniques required to model the flow of water regimes on the plain include a digital elevation model. The digital elevation models DEM are essential in improving the results from SAR image analysis (Brivio, 2002). In this study, the Matebele floodplain digital elevation model was downloaded from satellite data using USGS's Shuttle Radar Topography Mission (SRTM). The results from the Digital Elevation Model (DEM) support understanding the aerial coverage of floods in the study area. There is a meaningful

relationship between the changes in slope and terrain of an area and the potentiality of flooding.

Determination of the trends in the flooding events began with establishing the general elevation of the study area. Elevation analysis gives an overview of the propagation in the flow regimes of the area. This enabled the determining of the stream drainage pattern of the study area. Determination of the DEM of the wetland enabled the study to be focused on understanding which areas were likely to be inundated using the direction of the flows. An aerial satellite terrain image of the study area was extracted from earthexplorer.usgs.gov using the steps in Figures 8,9 and 10 to develop the area's Digital Elevation Model (DEM).

Figures 35, 36 and 37 show the first steps of extracting the area under consideration for the determination of the Digital Elevation Model (DEM). The area in red is the Keyhole Markup Language (KMZ) shapefile of the study area imported into the Earth Explorer for downloading the terrain area to process the DEM.

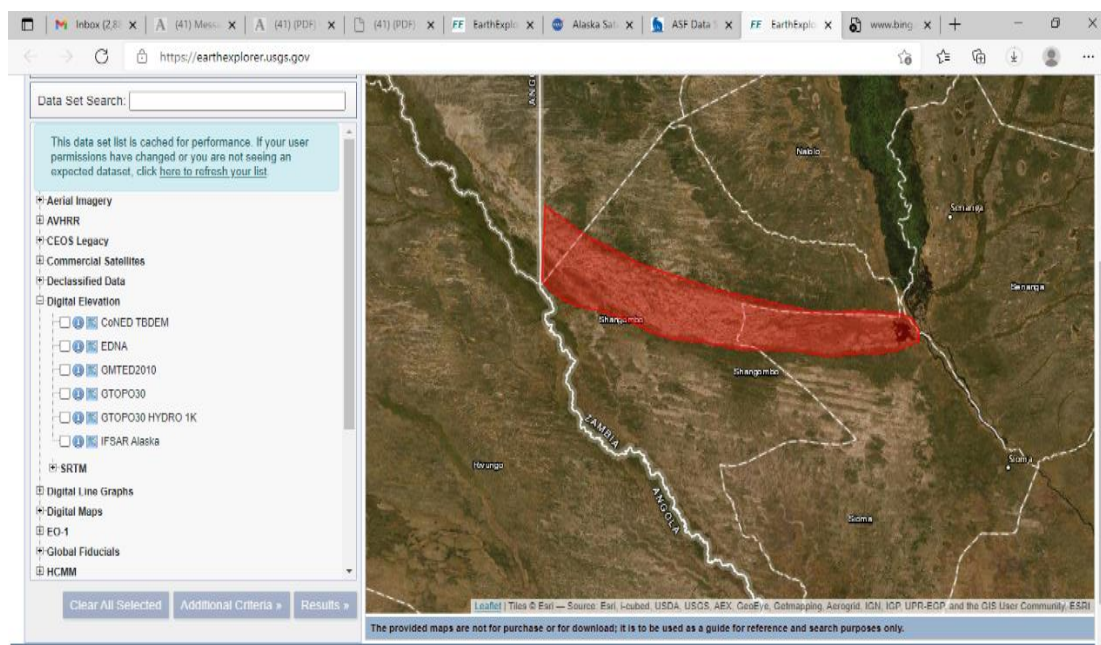


Figure 35: Extraction of the Digital Elevation Model (DEM) for Matebele Plain

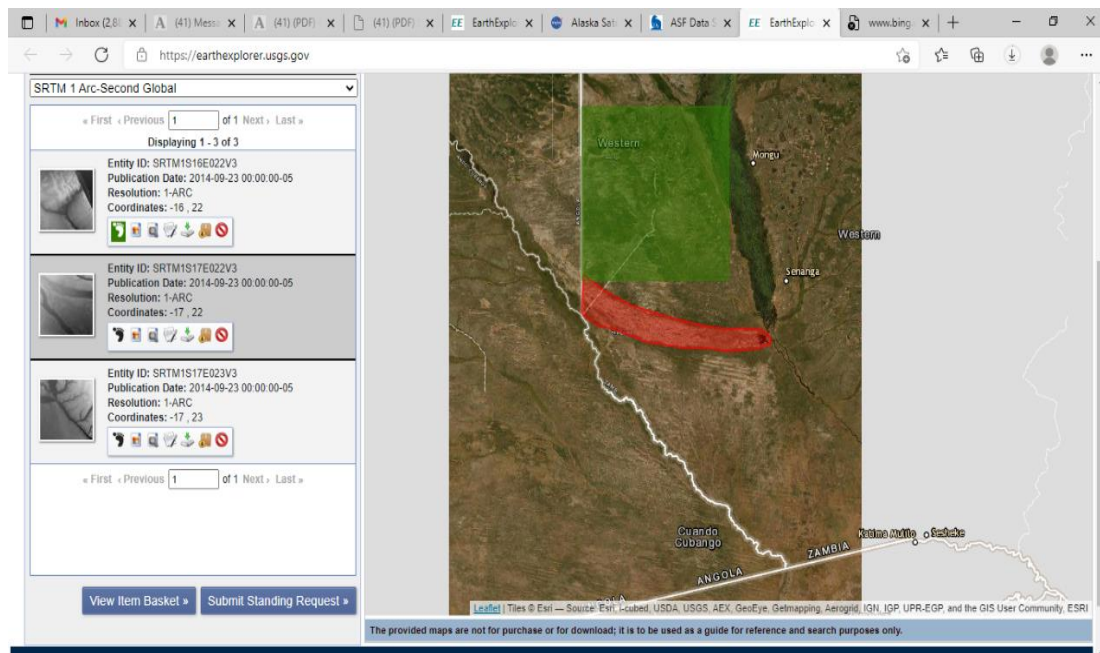


Figure 36: DEM Extraction

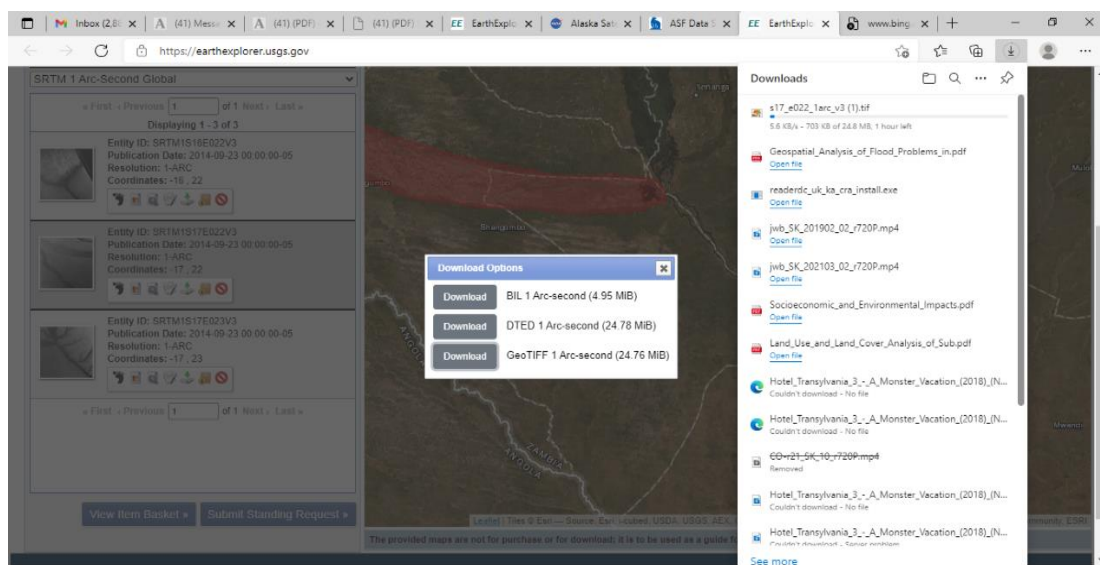


Figure 37: Final acquisition of the DEM.

Figure 38 shows the download process of the areas extracted for the analysis of the Digital elevation models. The model will assist in determining the general flow of the surface streams on the plain. Using the ArcGIS- Arc Hydro Data model, a grid derived from digital elevation model, which is a map flow direction, was developed to show the flow accumulation, stream and catchment areas of the flooding events.

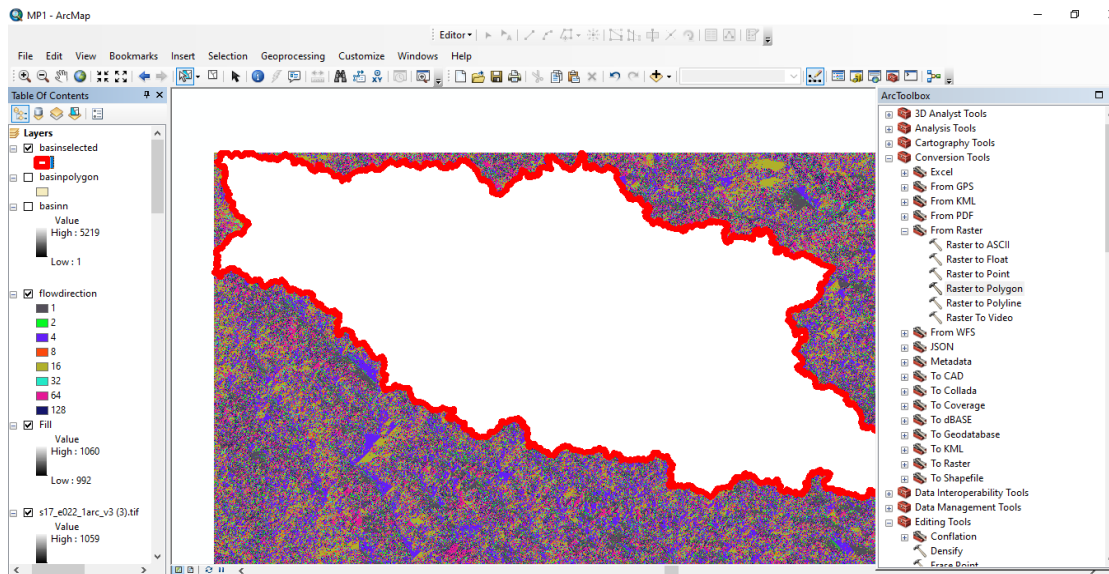


Figure 38: DEM Processing

Figure 39 shows the processing of the drainage pattern of Matebele Plain in ArcGIS using the various spatial analysis tools and results show that most of the surface streams on Matebele plain flow in the west-east direction. In addition, there is a dense distribution of surface streams that distribute flood water over the plain. This validates the results that most the spatial areas on the plain are usually inundated when the plain records the highest flooding events.

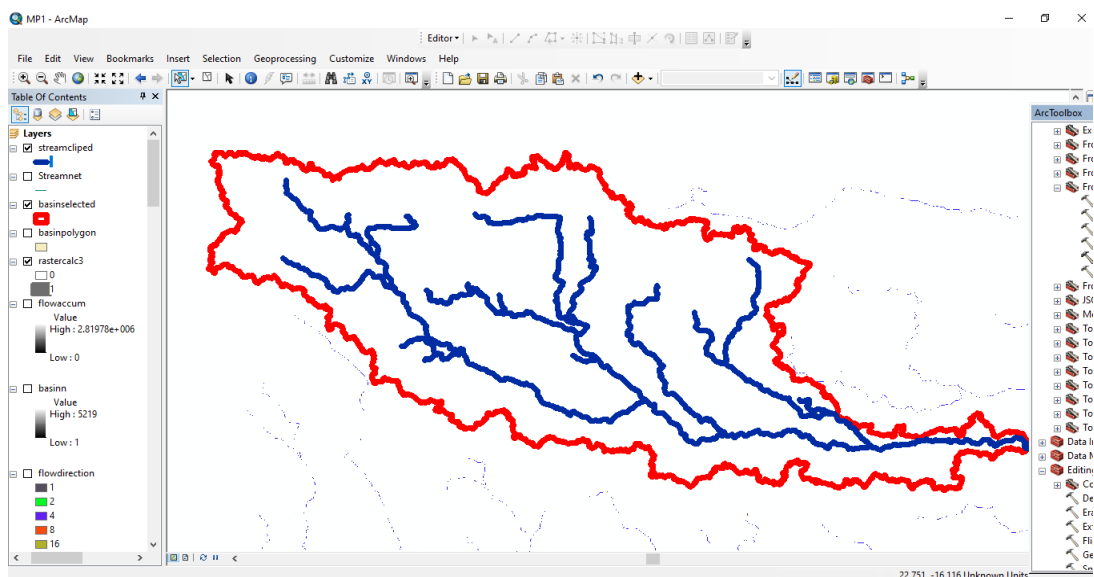


Figure 39: Overview of the drainage pattern on Matebele Flood Plain

The Digital Elevation of the study area shows that Matebele wetland has a dense network of annual surface streams mainly flowing from west to east, connecting flows from the Kwando River in Angola into the Zambezi River (Figure 39). The drainage pattern of the wetland gives an overview of the expected changes in the flooding extent of the area. Areas in the lowest elevation of the wetland experience the earliest inundation and increase outwards to other areas around the plain.

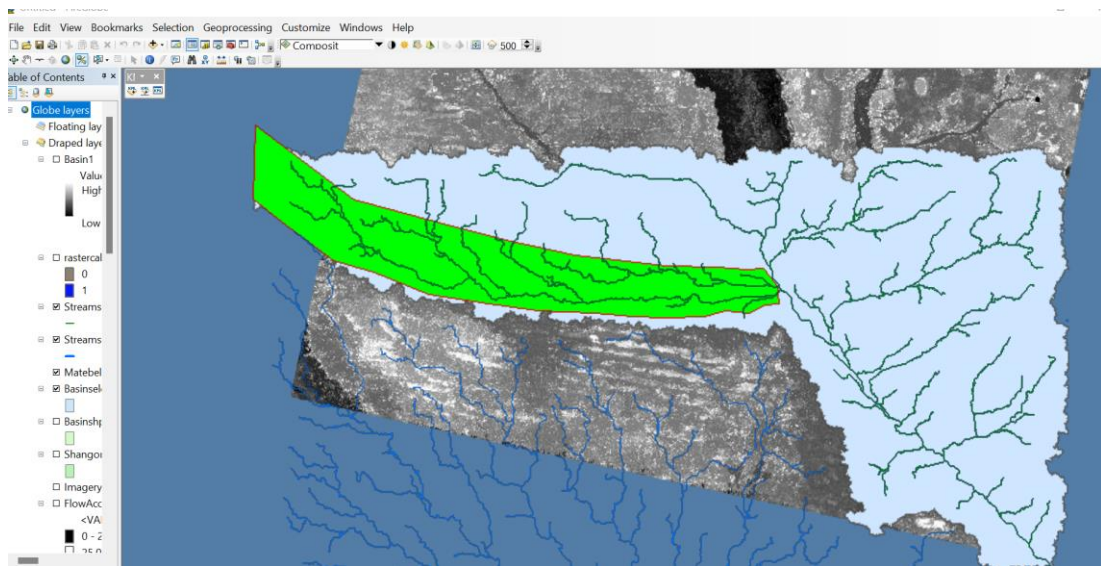


Figure 40: Matebele Drainage Pattern with surrounding wetlands.

The drainage pattern in Figure 40 includes other patterns surrounding the Matebele plain. These were assessed to have an overview of the flows in the general catchment and drainage basin for a clear understanding of the effects of flooding events on the communities and the response strategies indicated by the respondents during field data collection. This supports the results from the aerial satellite images showing that the floods covered almost the entire area. Through interpolation, Figure 40 shows that Matabele Wetland is a watershed whose flooding has direction correlation with the nearby watersheds. The mapping of surrounding watershed aids in making conclusions and recommendations for understanding the extent of flooding events in the general catchment area.

From the total coverage of the wetland (21078km²), the results from an overlay of the image analysis and the drainage pattern of the study area showed that the maximum peak of the flooding events were recorded in 2018 with a percentage of 78%. This saved as the highest hydrological year. Overlaying the results from the image with the highest observed water coverage, the highest pick of the floods (maximum flood extent) on the plain was recorded during the 2018/2019 flood season covering an area of 16,441 square kilometres (Figure 41). Compared to the lowest extent which occurred in the year 2012. And the mean flood extent of 9559.91., the maximum flood extent has a difference of 11347km² over the lowest extent and 5094 km² above the normal, respectively.

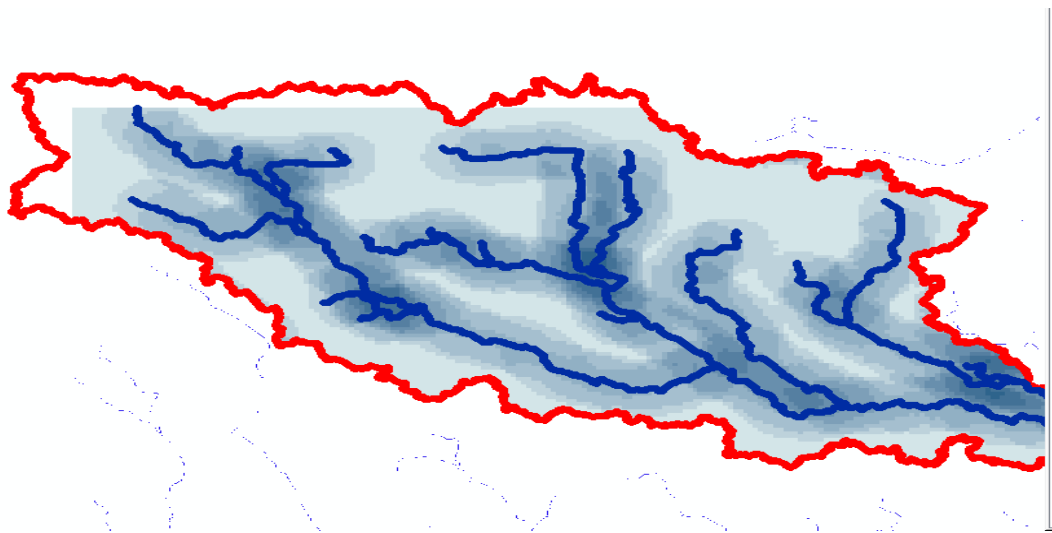


Figure 41: An overlay of the maximum flood extent on Matebele Flood Plain

Figure 42 is an output processed satellite SAR image of July 2018 showing flooding events in the study area. The areas covered by blue-black colour in the shapefile of the study area highlighted in red indicate the pixels for water as it absorbs most of the radiation from the Sun. Light blue pixels represented areas with water (marshlands) having sedimentation such as vegetation while dark blue and grey areas

represented areas open water bodies on the plain. The image was of July 2018, having been processed in ArcGIS.

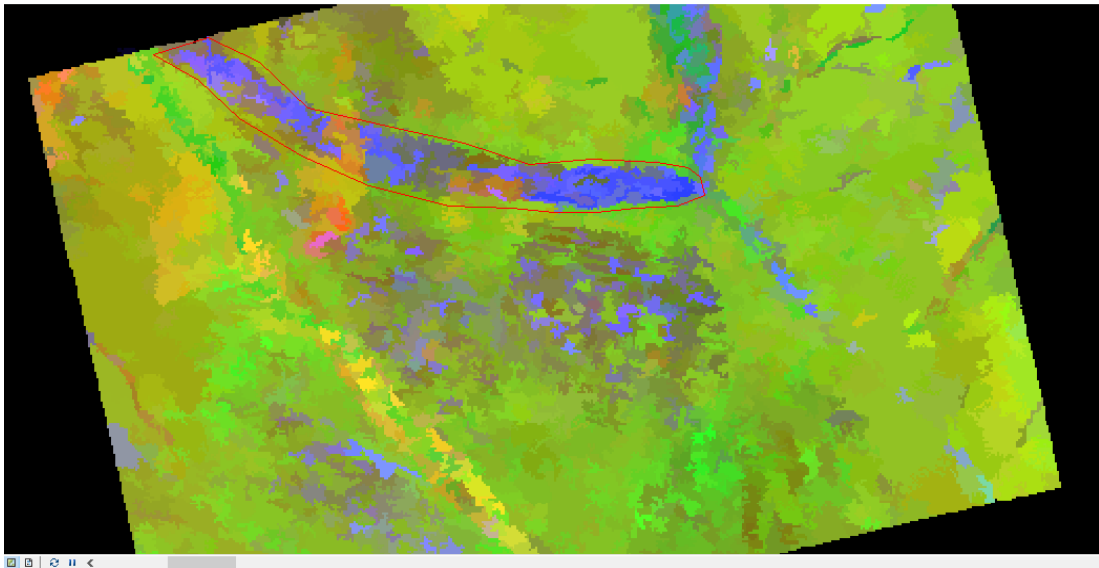


Figure 42: Imagerial analysis of the maximum flood coverage on Matebele Plain

In remote sensing and image interpretation, the reflectance of water surfaces is always high in the Electromagnetic spectrum (EMS) blue bands. This is because water surfaces mainly absorb the green and red bands of the EMS. From Figure 43, the blue band is strongly reflected in the areas that are covered by water. The extract of the study area in Figure 43 shows a high reflectance of the blue band, showing that the area is mainly covered by water during this time of the year. Interpretation of water-covered areas depends not only on the blue pixels in an image. Other factors such as mixed pixels, turbid, or dark are additional guiding factors to consider. In areas where vegetation grows in Marshlands, as with the Matebele flood plain, there was a high percentage of mixing pixels, which required additional criteria to interpret them. These included the use of Digital Numbers (DN) values. A range was determined where pixels with DN values from 0-4 were counted as water-covered areas. In addition, open waterbodies highly absorb all the energy from the Electromagnetic spectrum, resulting in such an appearance. Therefore, in the image

in Figure 43, areas appearing dark grey were verified through field validation as open waterbodies such as swamps. All these dark pixels were summed up to determine the maximum aerial extent of the flooding events in the study area. The pixels covering the blue band were summed up to determine how much area was covered by water. Other environmental factors such as sedimentation, floating vegetation, and buildings that are surrounded by water were in the flooded area. Histogram thresholding was also done in the Sentinel Application Platform (SNAP) to determine the coverage of blue pixels in the image being processed. This, therefore, validates that the Matebele floodplain was largely inundated in that particular year and that the aerial coverage of floods in the area is almost 78%, which was calculated to be an area of 16,441 km².

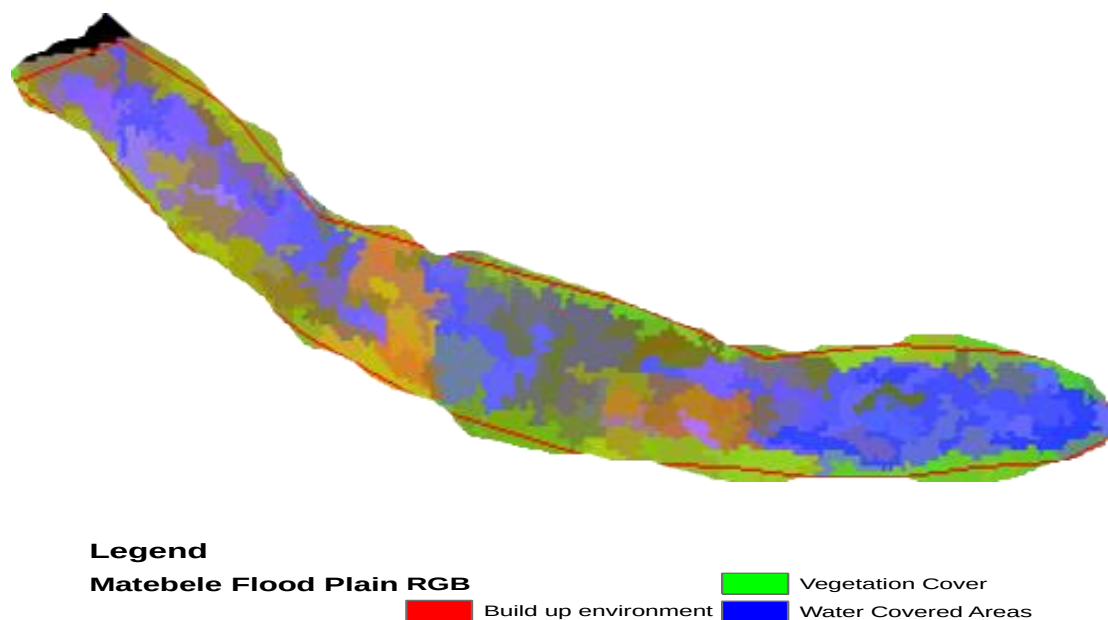


Figure 43: Extract of the Matebele Flood Plain showing the distribution of floods during the highest peak.

5.2 Spatial Variations of flooding extents on Matebele Flood Plain

Geospatial techniques combined with Environmental Remote Sensing (ERS) techniques have been pertinent in determining the historical variations in flooding events and providing near-real-time flood information. Geospatial variations, mainly determined through analysis of temporal satellite images, have provided aerial extents of spatial flood coverage. Geospatial variations of the flooding events on Matebele Plain was the second objective, which required analysing each image sampled from each particular year. Upon analysis of each image, the area covered by water pixels represented by blue colour was calculated to give the maximum flood coverage in that particular year. From processed images, variations could be determined as shown in Figures 44 and 45.

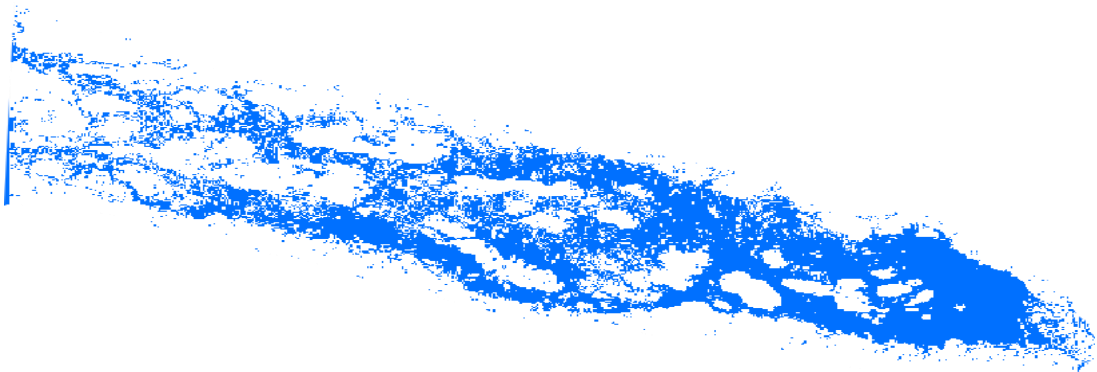


Figure 44: Flood coverage for June 2010 on Matebele Flood Plain

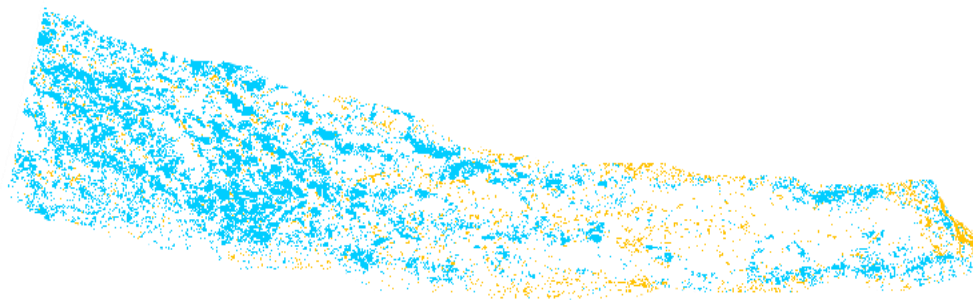


Figure 45: Flood Coverage for July 2012 on Matebele Flood plain.

Table 6 shows that the extents of flooded areas in each respective year started increasing from 2009, compared to the previous year, with coverage of 14936km² and started reducing from 2011 until 2015 which recorded a spatial coverage of 5733km². Table 7 gives the differences in extents of the flooding events during the study period.

Table 6: Spatial Coverage of Floods on Matebele Flood Plain, 2008-2018

S/N	Year	Maximum Area covered by floods (km ²)
1	2008	9431
2	2009	14936
3	2010	11320
4	2011	6571
5	2012	5094
6	2013	6021
7	2014	5733
8	2015	7542
9	2016	9425
10	2017	12645
11	2018	16441

Table 7: Annual Differences in Flooding Events (2008-2018)

S/N	Period	Annual Difference (Km ²)
1	2008-2009	5505
2	2009-2010	-(3616)
3	2010-2011	-(4749)
4	2011-2012	-(1477)
5	2012-2013	927
6	2013-2014	-288
7	2014-2015	1809
8	2015-2016	1883
9	2016-2017	3220
10	2017-2018	3796

Statistical significances in the spatial variations were determined through statistical tests conducted on the same results. The study employed Linear Regression and ANOVA tests, which were conducted at $p = 0.005$. The tests were conducted on the results of variations of flooding events using ANOVA and Linear Regression Analysis. This was, among other statistical reasons, the statistical differences in the flooding events, concluding the observed changes and determining how far each recorded event was from the other. ANOVA was conducted on the mean estimates of the extent of flooding.

Table 8: Statistical Analysis Results from ANOVA

SUMMARY

<i>Groups</i>	<i>Count</i>	<i>Sum</i>	<i>Average</i>	<i>Variance</i>
Year	11	22143	2013	11
Maximum Area covered by floods (km2)	11	105159	9559.909	14902128

Analysis of variance (Y):

Source	DF	Sum of squares	Mean squares	F	Pr > F
Model	1	313257102.545	313257102.545	42.042	<0.0001
Error	20	149021388.909	7451069.445		
Corrected					
Total	21	462278491.455			

Computed against model $Y = \text{Mean}(Y)$

According to the statistical interpretation of the *p-value*, when it is less than the alpha, we reject the null hypothesis; if it is greater than the alpha, we accept the null hypothesis. In this study, our null hypothesis stated no significant variations in the extent of flooding events on the Matabele Flood Plain. To interpret the results in a table, when the *F* static is greater than the *F* critical, there is a significant difference, and the null hypothesis is rejected. Another way to interpret our results is using the *p-value*. In the results in Table 8, the *p-value* (<0.0001) is less than 0.005. We reject the null hypothesis and conclude that there is a significant difference in the spatial variations in the flooding events on the Matabele Flood plain.

A linear regression analysis of the results on the variations in flooding events on Matabele Flood Plain was conducted, and the results were as follows.

Table 9: Statistical Results from Linear Regression

S/N	Year	Maximum Area covered by floods (km ²)	Precipitation (mm)
1	2008	9431	10.07
2	2009	14936	9.83
3	2010	11320	10.38
4	2011	6571	9.77
5	2012	5094	9.4
6	2013	6021	9.22
7	2014	5733	10.13
8	2015	7542	8.91
9	2016	9425	9.7
10	2017	12645	10.44
11	2018	16441	9.89

**Regression of variable
Year:**

Goodness of fit statistics
(Year):

Observations	11
Sum of weights	11
DF	8
R ²	0.070
Adjusted R ²	-0.162

MSE	12.786
RMSE	3.576
MAPE	0.128
DW	0.229
Cp	3.000
AIC	30.529
SBC	31.722
PC	1.627

Table 9, R square (R^2), which tells how variance the dependent variable can be accounted for by the independent variable, is 0.070. This is calculated to percentage form as 0.70×100 giving us 70%. This means 70% in the variations can be accounted for by change in years during the study period.

Table 10: ANOVA Results from Linear Analysis

ANOVA					
	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	4718359	4718359	0.2942	0.60066445
Residual	9	1.44E+08	16033658		
Total	10	1.49E+08			

From Table 10, the main interest is the significance *of* which is 0.60. In the analysis, the alpha was 0.05 which means if the significance *F* is greater than the alpha meaning the null hypothesis indicating that there are variations in the flooding extents on Matebele Plain can be accepted.

Figures 46, 47 and 48 show linear regression analysis of the trends in the flooding events on Matebele flood plain. Observations from Figure 46 indicate a downward trend beginning 2009 with a significant increase starting from 2015 ($r=1.01$, $p=.005$).

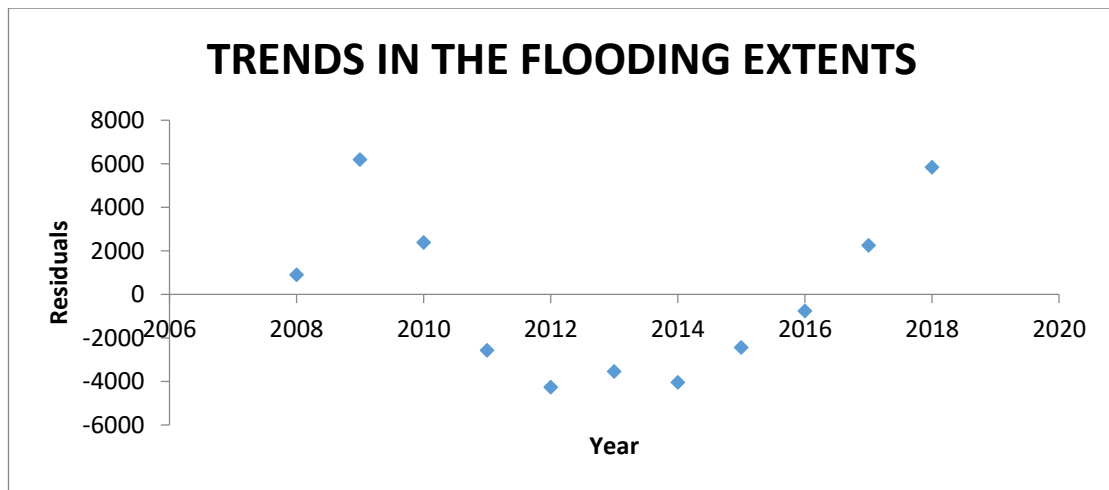


Figure 46: A linear regression analysis of the trends in the flooding events on Matebele flood plain.

Table 11: Coefficient Statistic Table

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	-407351	768536.1	-0.53003	0.60891	2145900.1	1331199	2145900	1331199
Year	207.1091	381.786	0.542474	0.60066	656.55077	1070.769	656.551	1070.769

Regression equation: $y = mx + b$

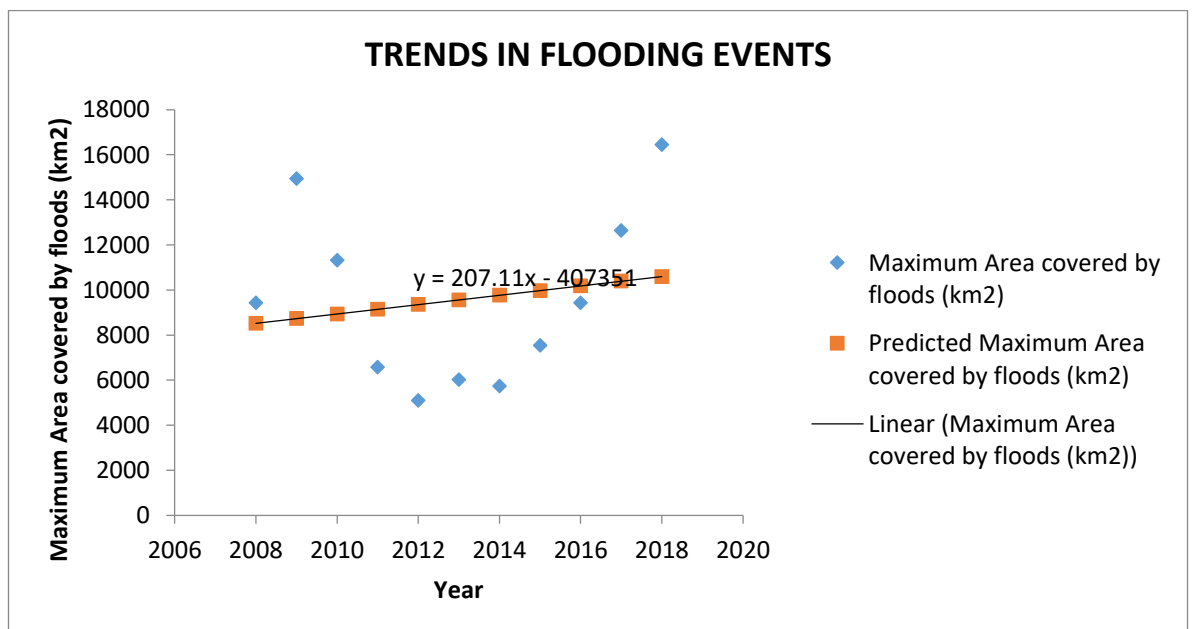


Figure 47: A regression analysis of the trends in flooding events on Matebele flood plain.

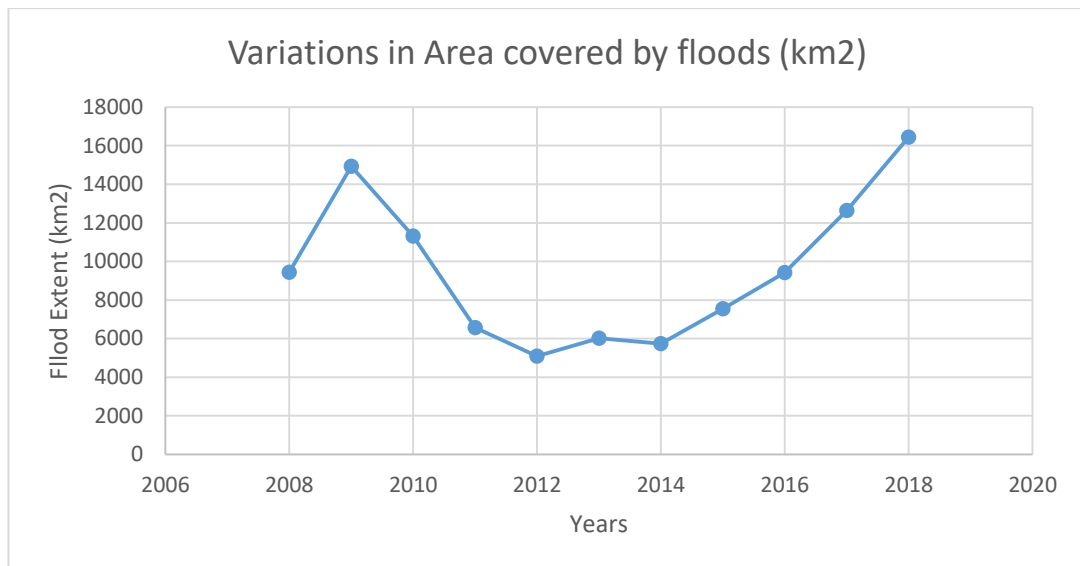


Figure 48: Annual variations in flooding events on Matebele Plain 2008-2018

Figure 49 indicates significant variations in the flooding events on Matebele plain. A downward trend is significantly observed from 2009 when the area experienced the second highest flooding event in the ten-year flood cycle. The variations indicate that the area has been experiencing low extents in the flooding events.

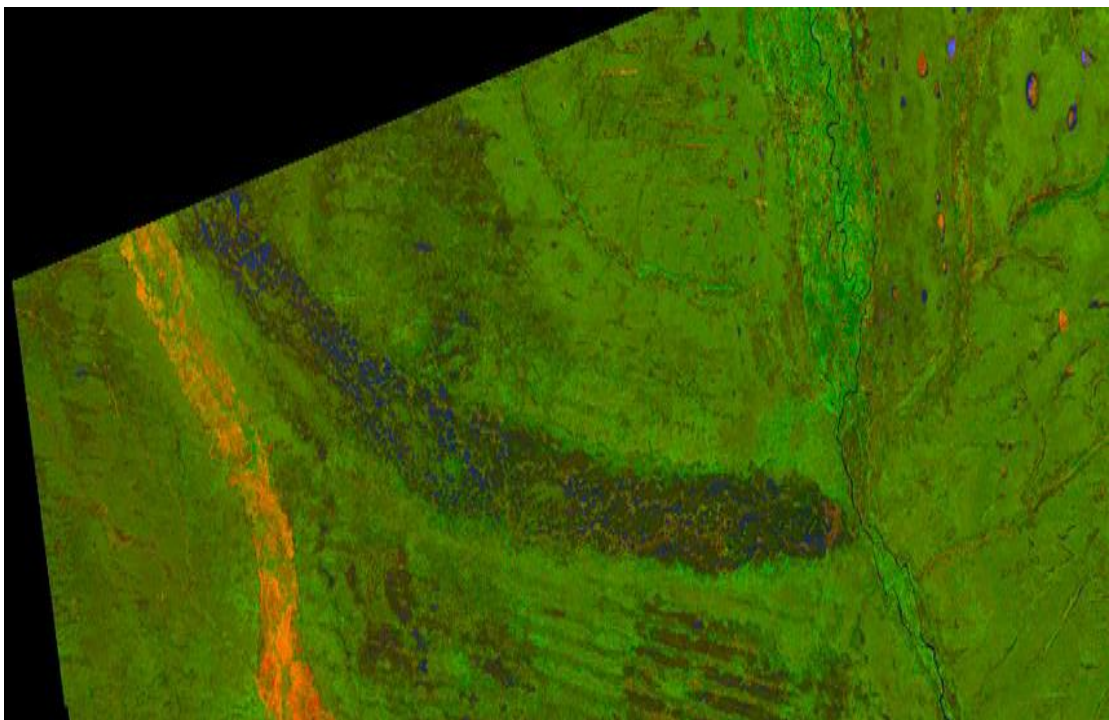


Figure 49: An aerial view of the flooding extents on the plain, (October 2017)

The image in Figure 50 depicts the variations observed in the flooding events on Matebele wetland. The image of the mid-year justifies the results of the variations in the flooding extents and the changes in the area covered by water. Figure 51 indicates a reduction in the general coverall of water in the study area through the observed reduced coverage in the blue pixels. Visual analysis of the images indicated that there were significant changes in the aerial coverage of the floods on the plain when analysed annually.

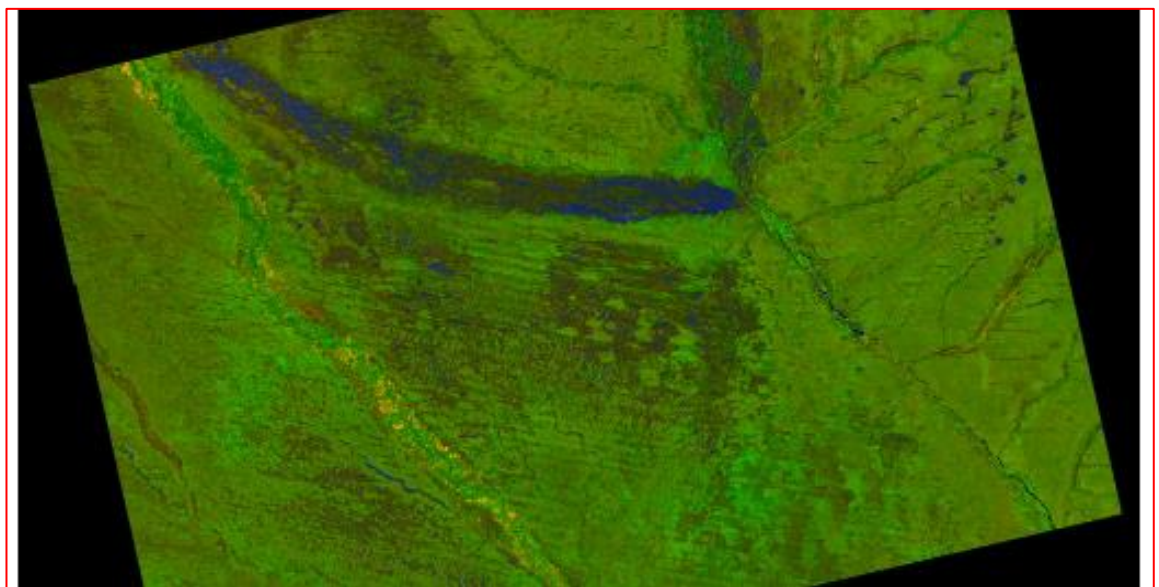


Figure 50: An image taken in November 2017.

Compared to the satellite image of October 2017 in Figure 30, the image in November 2017 in Figure 50 shows an increase in the amount of water covering the study. This is seen through the increase in the blue colour, representing the blue pixels of water. Based on the spatial threshold used to determine the spatial variations from the central blue band pixels, there was a significant variation in the flooding events during the study period, and the floods reached a maximum in a 10-year flood cycle. The variations in flooding extents were established to be caused by changes in weather conditions, land use/cover changes, and disturbances upstream in the neighbouring country from which part of the flows are received.

5.3 Identification of affected land use/land cover types

It was identified that the area is covered by various land use activities. These range from agricultural activities to other related human activities such as settlements. The area, among others, is covered by agricultural farmlands, settlements such as villages, schools, health centres, and development projects under implementation (Figure 52).

Figure 51 shows the various human settlements on the Matebele plain and the variations in the intensity of the flooding events on the Matebele Flood Plain.

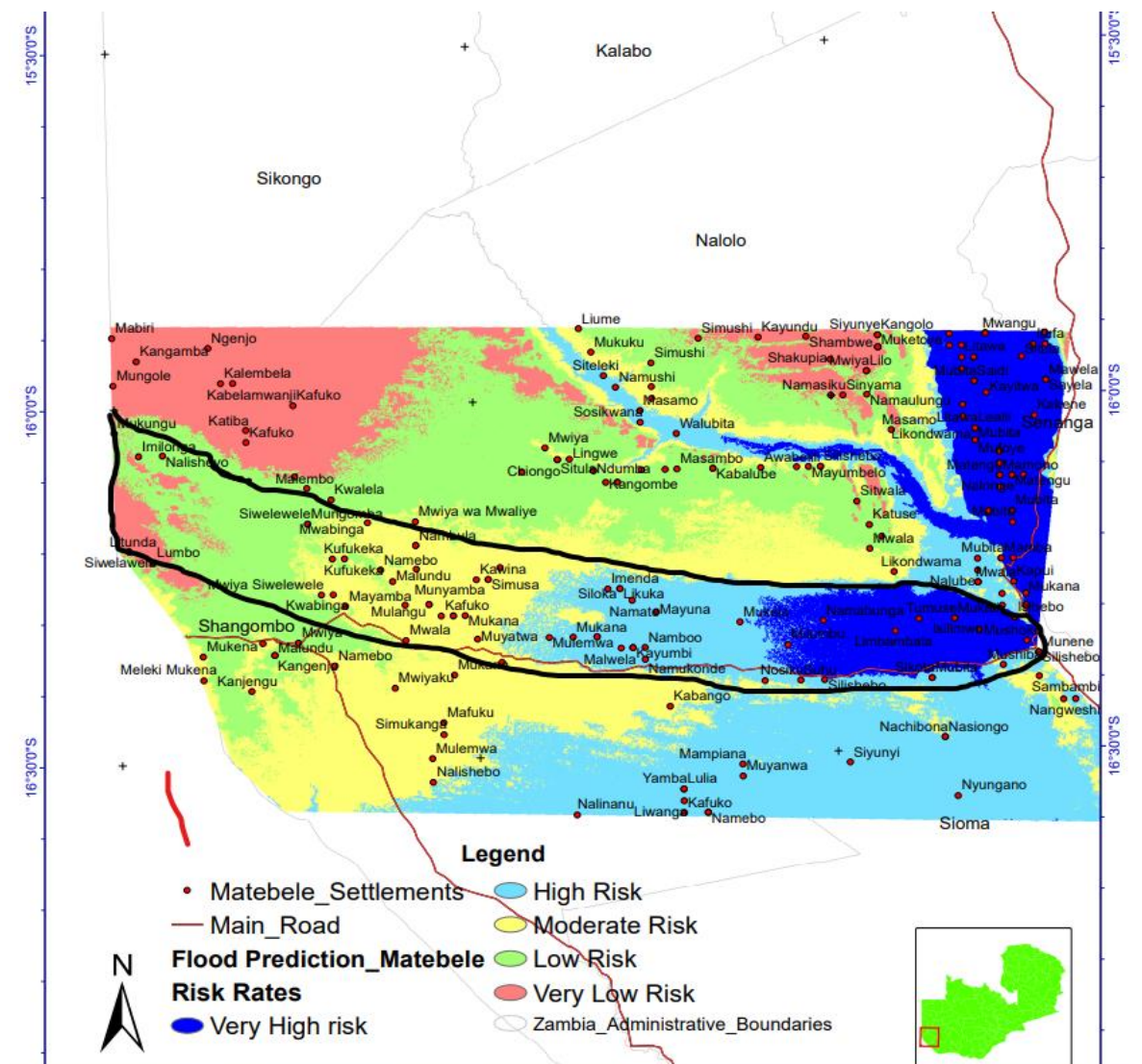


Figure 51: Human settlements and flood risk areas.

As mapped in Figure 52, the highest floods are experienced in the South-eastern part of the plain. This part of the plain receives flows from the Zambezi plain and those flowing from Western part of the plain hence increased records of the floods. The map shows the areas where the floods are highly concentrated during the year and when they are at their highest peak as well as the levels of intensity in relation to the expected risks.

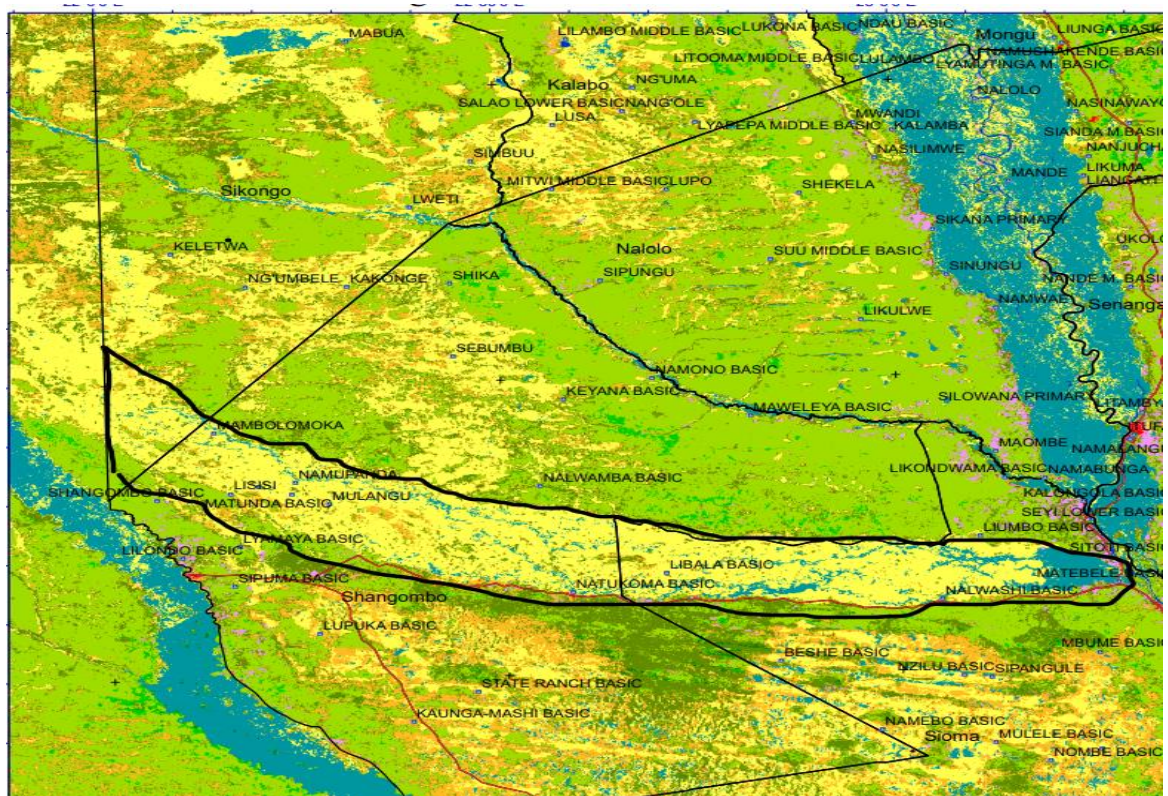


Figure 52: Schools on Matebele Flood Plain

Figure 53 shows some of the public institutions that are in the study area and validates the results that these are usually affected by flooding events when the area is at its pick of flooding.

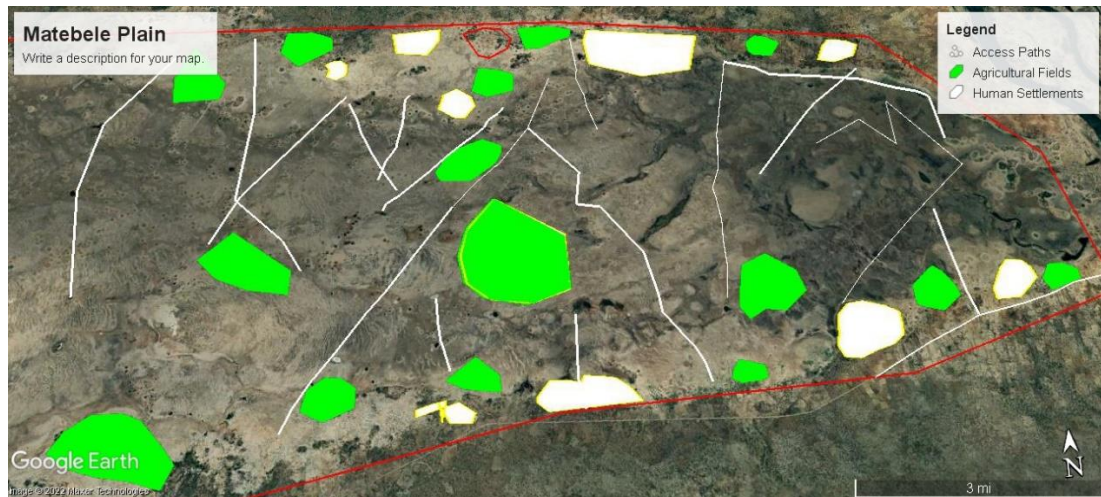


Figure 53: Partial Digitized Land use/Landcover map of Matebele Plain

As earlier indicated in Figure 52 above, the South-eastern part of the plain is at highest risk of the floods. Figure 54 shows a digitized part of the Matebele plain of the human activities that affected by the flooding. This, therefore, concludes that all the digitized human activities, settlements, agricultural fields in Figure 55 are usually affected by the flooding events. The image in figure 55 is showing even the access routes used by the local people to reach their productive centres. All these routes are affected by the flooding events when the area is completely flooded.

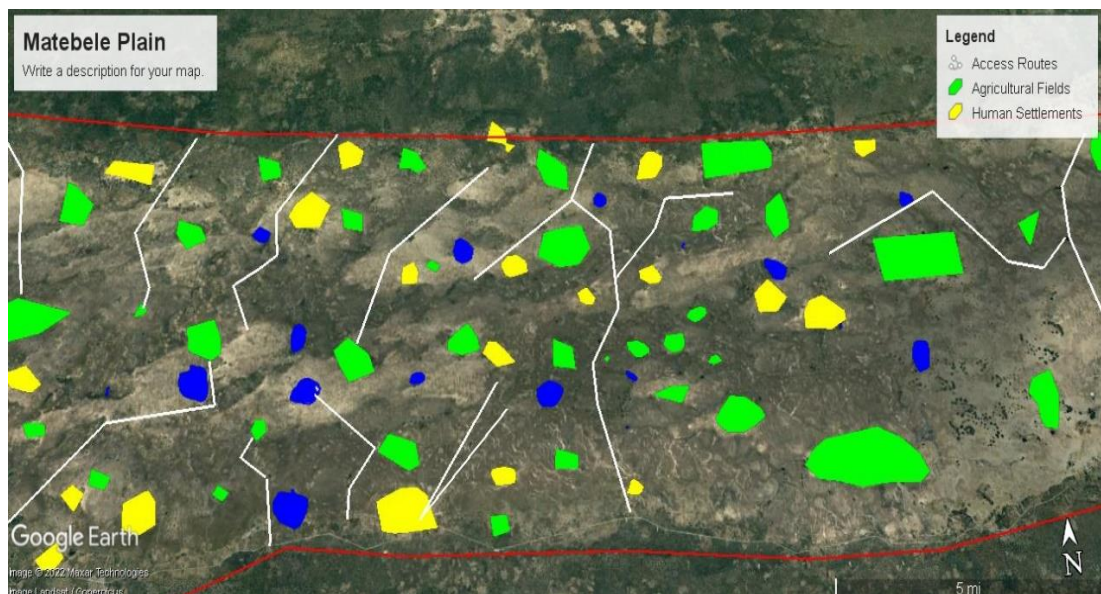


Figure 54: Distribution of Human Activities in the middle part of Study Area.

Figure 55 shows the distribution of the various activities in the moderate-risk area of the Matebele Flood Plain. When this area is covered with floods, the result is that the human activities in the area are affected by the events. Among the notable ones include human settlements, which are houses, sources of water, and access routes to productive centers. These are human activities such as settlements, social structures such as schools, health centres, water points, access routes, and other land uses such as crop fields. All the various land uses are affected in the three regions identified with flooding risks. Most land uses are concentrated in regions with high and moderate flood risk.

The study employed interviews with key informants who have witnessed the flooding of the study area and managed to experience the effects of the floods. This was mainly to triangulate the results from image analysis and increase the reliability of the results. Through discussion with them, the following results were arrived at.

From the five wards sampled on Matebele Plain, 94.8% of the respondents indicated that floods affect land use activities such as villages, crop fields, productive centres, socio-economic facilities, education centres, health centres, and access routes. At the same time, 5.2% of the respondents responded negatively to the effects of flooding on the plain.

The respondents were requested to provide information on the months in which floods are mainly experienced on the plain. From the total sample size of 160, a response of 156 respondents indicated that the plain has flooded from April, May, June, and July every year. This represented 97.7% of the total respondents.

Table 12 gives a general overview of the effects of flooding events on various landcover/land uses on Matebele Plain.

Table 12: Effects of Floods on the Land use/land use on Matebele Plain

Identified land use/land cover	How affected by floods	Severity score of the effect	Possible mitigation measures
Settlements (Villages)	Submerging settlement areas, eroding the walls,	High	Opening canals to divert flood water from reaching the settlements, use of water-resistant materials for buildings.
Farmlands	Submerging of the crops in the fields,	High	Digging canals around fields to divert the flood water, planting early before floods affect crop fields, relocating the fields to areas that are not highly flooded.
Grazing lands	Submerging grazing areas	High	Opening canal on the plain to control the flows and reducing on flooding.
Water Points	Contamination, eroding shallow wells, blocking access to the wells	High	Opening canal on the plain to control the flows and reducing on flooding.
Social Infrastructure	Damaging buildings, washing away building made of pole and mud, damaging bridges	High	Diverting the waters from the building through construction of canals and use of water-resistant

			materials for construction.
Access routes	Blocked and flooded	High	Opening canal on the plain to control the flows and reducing on flooding.
Wildlife habitats	Flooded and displace wildlife	Moderate	Opening canal on the plain to control the flows and reducing on flooding.

From the selected respondents, about 97% indicated that the flooding events affected various human activities in the area. Generally, the floods have been affecting settlements, houses, social infrastructure, accessibility roads and other areas that are important for human and biodiversity.



Figure 55: Field visits to areas affected by flooding on Matebele Plain

Figure 58 was mainly the validation process of the observations in the satellite images. Visits were made to the areas depicted in the images to have floods covering some parts of the study area. Validation of the observed changes in satellite images is cardinal to support the authenticity of the results.

5.4 Flood Management on Matebele Plain

Flood management on Matebele plain is mainly the responsibility of the people living in the plain and both the local and central government authorities. The study established that several local methods such as evacuation, locating settlements of uphill and the use canoes are among the mechanisms they use to manage their activities. However, through interviews and field observations, the study established and proposed for mechanisms to manage the floods. Flood management mechanisms were established through understanding the how much the floods affect the communities.

Figure 56 shows the responses of how the flooding events on Matebele Plain affected various human activities and property. Loss of lives is leading with 93%. This means that flooding events have been a severe problem for lives, so there is a need to understand these events to develop effective mitigation measures. The area's food security is also affected during these flooding events, as can be seen with a percentage of 15.

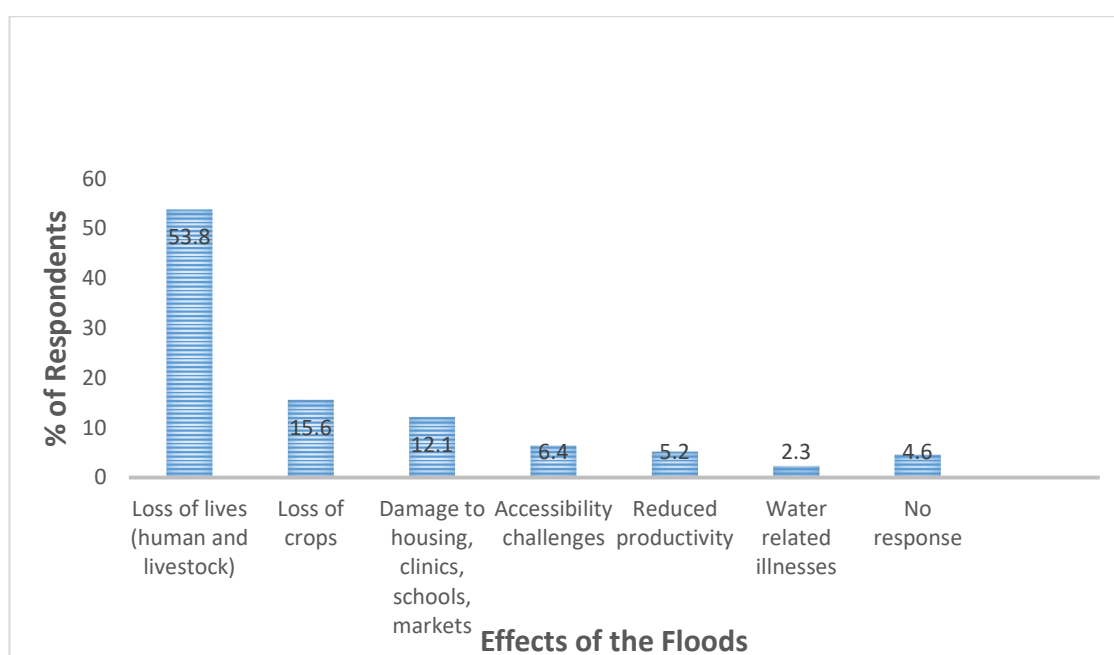


Figure 56: The effects of flooding events on Matebele Plain

Based on the analysed responses presented in Figure 56, the loss of human and livestock lives has significantly affected the floods during the study period. The changing extents of floods in the wetland have also been affecting people's location of crop fields and the change of crops being grown. The communities practiced rice farming during the flood periods and changed to maize, sorghum, and millet when the area was not flooded. The increase in floods in the area has affected people's livelihood through crop changes and farming strategies. with a high loss of lives, primarily for livestock. Most livestock were affected by the introduction of diseases such as blackleg, worm infestations, and cattle ticks. The floods also reduce the availability of suitable land for grazing, resulting in livestock movements to upper lands and low returns from animal husbandry.

The flood events on the Matebele Flood Plain affect livelihoods in many ways, and the severity varies according to the livelihood's vulnerability, sensitivity, and exposure. A numerical rating scale was adopted to rate the effectiveness of the flood management mechanisms and ease the participants' responses in the data collection.

Table 13 gives a summary of the results.

Table 13: Effects of Floods on Livelihoods and Management Mechanisms

Effect of Flood on livelihoods	Severity of the effects	Flood management Mechanism	Rating method effectiveness
Increased health hazards	High	Evacuation of families from flooded areas to reduce flood related hazards	1
Increased health costs	High	Evacuation of families from flooded areas to reduce flood	1

		related hazards	
Increased cost of farming inputs	High	Relocating of farming fields to uplands	1
Increased cost of farming	High	Opening canals to divert water from fields	2
Low returns from animal husbandry	High	Relocation the animals to uplands to increase on the returns.	1
Loss of important natural sources of livelihoods	High	Developing mechanism to harvest natural resources in flooded areas. Mechanisms include canoes and diverting waters from the sources.	3
Increased socio-economic transport costs	High	Using water transport such as the use of canoes	3
Reduced financial income	Moderate	Investing the financial income into buying farming inputs	3
Reduced crop production	High	Introduction of crops such as rice farming. Relocating other crops to uplands	2
Collapsing of Houses	High	Construction of houses using flood resilient materials, relocating settlements	1

Rating: 1 =Very Effective, 2= Effective, 3= Average

Table 13 shows the effects of floods on the livelihoods and the mechanisms that were being deployed to manage the floods during the study period. The International Labour Organization (ILO) defines a livelihood as comprising the capabilities, assets, and materials required for a means of living (ILO;2006). Carney (1998) further adds that livelihoods comprise human, natural, social, financial, and physical capital. Many people's lives in developing countries depend on these as livelihood-supporting assets. The people living on Matebele plain mainly depend on farming and small financial activities for their livelihood. Farming activities and economic activities are affected by flooding events, as shown in the table above. Management strategies include relocating to uplands where flood waters cannot reach to continue their activities. Fields where farming is done have been affected by water submerging the crops before they reach maturity. Table 7 above shows that most of the significant livelihoods are affected by floods. The results have been affecting the health of the communities by contaminating water sources, flooding fields in areas that get flooded, resulting in loss of crops and food insecurity, and an increase in the cost of carrying out farming activities. The floods have also been affecting the socio-economic activities of the people in the area, resulting in reduced economic activities. These could result from accessibility challenges to the areas where socio-economic activities are done. As summarized in Table 13 further, the respondents indicated that natural forests have also been significant in supporting livelihoods. They support the communities with wild fruits, roots, and other critical natural things. Flooding of the area affects the accessibility to these livelihoods support assets.

The communities have devised several mechanisms to mitigate the effects of floods on their livelihoods. Among them is determining the areas that get heavily flooded

on the plain so that their fields can be located strategically. Other farmers try to dig canals around their crop fields to divert the water from their fields.

Figure 57 validates some of the responses from interviews on the impacts of the flooding events to the provision of social services and access to social economic centres. During the visit to the study area, the researcher could witness the challenges in accessibility and the coverage of flooding events.



Figure 57: Accessibility challenges due to flooding.

From the interviews conducted with key informants, the research revealed that floods have been affecting most land use and land cover activities in the area. A school called Mambolomoka has been annually affected by floods. About 300 villages on the plain have been displaced from their original settlement areas during the study period. In a village called Musa, field crops were swept by the floods of 2009, resulting in the community becoming food insecure. In an interview conducted with a key informant who resides in the study area, he observed that in 2009, 2016, and 2018, due to flooding in our area, Learners could find it challenging to reach the school.” Another respondent from Musa Village, Mr Sepiso said, “our village has been shifting every year as the water have been reaching our homes, washing away some important items and even washing the walls of our houses.”

CHAPTER SIX: DISCUSSIONS

6.0 Introduction

This chapter gives an analysis of the key findings of the research in relation to the aim and the objectives as outlined in the first chapter and the results chapter of the report. The study aimed at determining the extents of flooding events on Matebele Plain for the development of the flood management strategies on the affected land use/land cover in the area.

6.1 Mapping of Flooding Extents using Geospatial Technologies

Geographic Information Science (GIS), remote sensing and satellite data have proven to be effective techniques for establishing flooding events and extents on large areas as the study results indicate for an aerial coverage of 16,441km². This confirms and validates scientific findings which indicate in-situ and traditional methods such as ground surveys and aerial observation of determining extents of floods on large areas are time consuming, costly and delay in providing the much-needed information for decision making (Ramsewak, 2019). Results from this study coincides with other studies conducted by other researchers (Phiri, 2021; Dhanabalan, 2021; Baghdadi, 2001) whose findings strongly concluded that satellite data provides easy acquisition and access to data for timely provision of results. Despite this scientifically appreciated advantage, research has also identified challenges in the process and techniques such as limitations owing to the availability of satellite data, the hardware processing capacity, human capacity among others (Ramsewak, 2019).

6.3 Determination of trends in flooding extents in Matebele Flood Plain

Significant trends in the levels and extents in flooding events are common as established by the study results which strongly coincide with similar research (Zimba, 2018). Several factors are responsible for the stimulating the trends, and among them include climatic factors, the formation of the landscape, drainage pattern, the soil type, human activities and precipitation. These factors, as indicated

in this study have had effects on flow regimes around the wetland. Precipitation significantly contributed to the variations in the extents of flooding annually. This findings supports the findings of Breugem (2020) who established the impacts of Meteorological aspects of heavy precipitation in relation to flooding. However, the geomorphological factors on the wetland, the soil type and drainage pattern play a significant role in sustain water levels. As Wang (2016) indicates that there is strong relationship between rainfall and flood occurrence. Through correlation analysis of rainfall data acquired for the study area, as the rainfall increased, there was a positive increase in the spatial coverage of floods. However, the amount of rainfall has a significant determinant to the Agro-ecological region in which the Matebele flood plain lies.

6.4 Flooding Events and Landcover/Landuses on Matebele Flood Plain

The findings of this study compare well with reports on the impacts of flooding events on the people living on Matebele Flood plain in Shangombo District (GRZ;2009, Wakumelo; 2012). The results have clearly indicated that flooding events in Shangombo District during the study period have had negative impacts on several land use activities. Affected mostly are crop fields, access roads, livelihood activities among other key land use activities. The effects begin from loss of lives for humans and livestock, destruction of housing units, flooding of crop fields, blocking access routes to productive centres, submerging grazing land, contaminating water points and other flood related hazards. The results, furthermore, strengthen the surveys from Flood Analysis conducted in the same are (GRZ;2009) on the impacts of the flooding events in the area. This support other research conducted on the Zambezi Basin. As a response to the impacts, communities must put measures such as relocating to uplands, relocating their livestock to uplands and change in crops that are being grown. Others include opening canals to divert the flood waters from

the villages. The findings have established areas of serious impacts require the establishment of significant information to enhance planning for future floods in the area.

6.5 Development of a flood information system about Matebele Flood Plain

The findings of the study found that Matebele flood plain has no reliable and effective flood information system. As Mabuku (2018) indicates, rural areas without information systems on flood warning and response, adding to observations by Wakumelo (2021), have results in huge losses of lives, property and other livelihood activities. This, therefore, calls for response in supporting the development of such systems to mitigate the adverse impacts of the flooding events especially among rural communities. Flood Information system contains a flood map showing the coverage of floods during the highest peak, information about the main sources of the flooding events, the risk areas, the major flow areas of the floods, months in which the floods have been identified to reach their peak, a general overview of the flooding situation in terms of reduction and increase, the most affected land use/cover in the area, potential evacuation points, possible mitigation measures and the period in which floods last on the plain.

CHAPTER SEVEN: CONCLUSIONS AND RECOMMENDATIONS

7.0 Introduction

This section gives the conclusions of the overall study and proposed recommendations.

7.1 Conclusions

Based on the study findings, it can be concluded that geospatial techniques are reliable, significant and timely in determining the maximum aerial extents of flooding events on large wetlands like the Matebele floodplain. This validates scientific research indicating that geospatial technologies coupled with remote sensing provides a quick and reliable source of information for mapping large areas affected by flooding events. From results, indicating that Matebele plain experienced the highest percentage of 78% of inundation in the period 2008 to 2010, provides a general conclusion that communities and socio-economic activities on the plain are highly affected by the flooding events, and therefore, the need for stronger interventions.

7.2 Recommendations

The study, based on the findings, strongly recommends that the following.

- (i) The Zambian Government, through the National Policy on Wetlands and Ramsar Convention, to recognize Matebele Plain as one of the critical wetlands in Zambia.
- (ii) The Government of Zambia, through the Disaster Mitigation and Management Unit (DMMU), should consider providing early warning and support to the affected communities on the plain, provide an effective early warning system for communities living on the plain.
- (iii) Government and Research Institutions to profile the flooding events on Matebele plain as Climate Risks for development of response strategies.

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APPENDICES

APPENDIX 1: Questionnaire for Local People Living on Matebele Flood Plain THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

SCHOOL OF NATURAL SCIENCES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Dear respondent,

I am a postgraduate student from the University of Zambia pursuing a master's Programme in Geographic Information and Earth Observations. I am carrying out research in partial fulfilment of the master's degree on the flooding extent of the Matebele Flood Plain in Western Province of Zambia. The study also aims at identifying land uses affected by the floods on the plain from 2008 to 2018.

You have been randomly chosen to take part in this research. You are requested to take part through answering the questions below. This is academic research, and all your responses will be used only for academic purposes and nothing else.

Your co-operation will be highly appreciated.

Thanking you in advance.

SECTION A: GENERAL AND PERSONAL INFORMATION

1. Date of interview:
2. Place of interview.....
3. Sex: Male {} Female {}
4. Age: (i) 1-19 {} (ii) 20-39 {} (iii) 40- 59 {} (iv) 60-79 {} (v) 80 + {}
5. Education: (i) Primary {} (ii) Secondary {} (iii) Tertiary {} (iv) None {}
6. Occupation: (i) Farmer {} (ii) Teacher {} (iii) Health Worker {} (iv) Unemployed {} (v) Other {}
7. Locational Information
 - (i) Community/ Village name..... (ii) Zone.....
 - (iii) Ward..... (iv) District.....

(v) GPS Points: E.....
S.....

8. How long have you been living in this community?

(i) 1-10 {} (ii) 11-20 {} (iii) 21- 30 {} (iv) 31-40 {} (v) 41 + {

9. How knowledgeable are you about Matebele Flood Plain?

Excellent {} Good {} Average {} Other
(specify).....

10. Has your community ever experienced flooding? Yes {} No {}

12. What are the major sources of floods in your community?

.....

11. In which years have you experienced floods in your community?

(i) 2008 {} (ii) 2009 {} (iii) 2010 {} (iv) 2011 {} (v) 2012 {} (vi) 2013 {}

(vii) 2014 {} (viii) 2015 {} (ix) 2016 {} (x) 2017 {} (xi) 2018

12. Rate the magnitude of flooding in each year in the table below

YEAR	LOW	MODERATE	HIGH
2008			
2009			
2010			
2011			
2012			
2013			
2014			
2015			
2016			
2017			
2019			

13. How long do floods last in your community?.....

14. How often do floods occur in your locality?

(i) Annually {} (ii) Biennial {} (iii) Other.....

15. List the areas on the plain that are annually flooded?

- (i).....
- (ii).....
- (iii).....
- (iv)

SECTION B: PARTICIPATORY GIS USING AREA MAP

(Kindly refer to the attached map of Shangombo)

6. Identify the location of your village/community on the map.
7. Identify any areas around your village that are annually flooded.
8. Has there been variations in the flooding extents in your community? Yes {} No {}
9. Draw on the map provided the boundaries of the highest flood you experienced in the period 2008 to 2018 in your area.
10. Draw on the map provided the boundaries of the lowest flood you experienced in the period 2008 to 2018 in your area.
11. What have been the causes of the variations/changes in the flooding extents?
.....

SECTION C: IMPACT OF THE FOODS ON LAND USES

12. What land uses are present in your area? (tick below)
 - (i) Crop fields {}
 - (ii) Other Settlements {}
 - (iii) Pathways {}
 - (iv) Roads {}
 - (v) Water points (shallow wells, dams, boreholes) {}
 - (vi) Villages {}
 - (vii) Productive centres {}
 - (viii) Any other (s).....
13. Which land uses are affected by floods in your area?

- (i) Crop fields {}
- (ii) Settlements {}
- (iii) Pathways {}
- (iv) Roads {}
- (v) Water points (shallow wells, dams, boreholes) {}
- (vi) Villages {}
- (vii) Productive centres {}
- (viii) Any other (s).....

14. What is the level of impact of floods on the items listed below?

Area	Level of effect 1=No effect 2=Low impact 3= Moderate impact 4= High impact	Comments
Water sources/points		
Crop fields		
Villages		
Roads		
Pathways		
Productive centres		
Others		
Sources of livelihood		
Other settlements		

15. State any recorded negative impacts of floods in your area?

.....

16. What measures were employed to mitigate the impacts of floods experienced in your area?

.....

THANK YOU FOR YOUR COORPERATION

APPENDIX 2: Interview Guide for Government Officials in Shangombo District

THE UNIVERSITY OF ZAMBIA

DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

SCHOOL OF NATURAL SCIENCES
DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

Dear respondent,

I am a postgraduate student from the University of Zambia doing a master's Programme in Geographical Information and Earth Observations. I am carrying out research in partial fulfilment of the master's degree on the flooding extent of the Matebele Flood Plain in Western Province of Zambia. The study also aims at identifying land uses affected by the floods on plain from 2008 to 2018.

A BRIEF OF THE STUDY AREA

The Matebele Floodplain is situated on the upper course, southwest of the Zambezi River and covers Sioma and Shangombo Districts of Western Province. The floodplains lie on Kalahari sands and the river bottom is predominantly composed of shifting sand. It includes a system of arable land, canals, lagoons and swamps. Its area is broadly estimated at 550,000 hectares, with a total wetland area of 1.2 million hectares (Turpie et al., 1999). The flood plain gets flooded after the main rainy seasons when the Kwando River in Angola overflows, with floods peaking in April and receding by July.

You have been chosen to take part in this research. You are requested to take part through answering the questions below. This is an academic paper, and all your responses will be used only for academic purposes and nothing else.

Your co-operation will be highly appreciated.

Thanking you in advance.

SECTION A: GENERAL AND PERSONAL INFORMATION

1. Date of interview:
2. Place of interview.....

3. Sex: Male {} Female {}

4. Age: (i) 1-19 {} (ii) 20-39 { } (iii) 40- 59 { } (iv) 60-79 { } (v) 80 + { }

5. Education: (i) Primary {} (ii) Secondary { } (iii) Tertiary { }

6. Occupation:

7. Locational Information

(i) Name of Institution..... (ii) Department.....

(v) GPS Points: E..... S.....

8. How long have you been working in this institution?

(i) 0-9months {} (ii) 1-5 years { } (iii) 6-10years { } (iv) 11-15years { } (v) 16years + { }

9. What are the functions of your department?.....

10. How knowledgeable are you about Matebele Flood Plain?

Excellent {} Good {} Average{ } Other (specify).....

11. Which areas on the Matebele plain have been affected by floods in the past years?

.....
.....

12. What are the major sources of floods on the plain?

.....
.....

13. Have there been variations in the extents of flooding on the plain?

Yes {} No { }

12. In the table below, indicate the extent of floods in each year?

YEAR	LOW	MODERATE	HIGH
2008			
2009			
2010			
2011			
2012			
2013			
2014			
2015			
2016			
2017			
2019			

13. How long do floods last on the plain?.....

14. How often do floods occur on the plain?

(i) Annually {} (ii) Biennial { } (iii)

Other.....

15. List the areas on the plain are usually covered by floods?

(i).....

(ii).....

(iii).....

(iv)

SECTION B: PARTICIPATORY GIS USING AREA MAP

(Kindly refer to the attached map of Shangombo)

6. Identify the areas you're that get flooded on the map provided.

7. Have there been variations in the flooding extents on the plain? Yes {} No { }

8. Draw on the map provided the boundaries of the highest flood you experienced in the period 2008 to 2018.

9. Draw on the map provided the boundaries of the lowest flood you experienced in the period 2008 to 2018.

SECTION C: IMPACT OF THE FOODS ON LAND USES

12. What land uses are present in your area? (tick below)

- (i) Crop fields { }
- (ii) Other Settlements {}
- (iii) Pathways {}
- (iv) Roads {}
- (v) Water points (shallow wells, dams, boreholes) {}
- (vi) Villages { }
- (vii) Productive centres { }
- (viii) Any other (s).....

13. Which land uses are affected by floods in your area?

- (i) Crop fields { }
- (ii) Settlements {}
- (iii) Pathways {}
- (iv) Roads {}
- (v) Water points (shallow wells, dams, boreholes) {}
- (vi) Villages { }
- (vii) Productive centres { }
- (viii) Any other (s).....

14. What is the level of impact of floods on the items listed below?

Area	Level of effect 1=No effect 2=Low impact 3= Moderate impact 4= High impact	Comments

Water sources/points		
Crop fields		
Villages		
Roads		
Pathways		
Productive centres		
Others		
Sources of livelihood		
Other settlements		

15. State any recorded negative impacts of floods in your area?

.....
.....
.....

16. What measures were employed to mitigate the impacts of floods experienced in your area?

.....
.....
.....

THANK YOU FOR YOUR COORPERATION

APPENDIX 3: ETHICAL CLEARANCE



THE UNIVERSITY OF ZAMBIA DIRECTORATE OF RESEARCH AND GRADUATE STUDIES

Great East Road Campus | P.O. Box 32379 | Lusaka 10101 | Tel: +260-290 258/291 777
Fax: (+260) 211 290 258/253 952 | Email: director.drgs@unza.zm | Website: www.unza.zm

APPROVAL OF STUDY

IORG No. 0005376
HSSREC IRB No. 00006465

30th May, 2022

REF NO. NASREC-2022-MAR-005

Mr. Morris Manyika
The University of Zambia
School of Natural Sciences
P.O. Box 32379
LUSAKA

Dear Mr. Manyika

RE: "FLOOD EXTENT MAPPING AND MANAGEMENT ON MATEBELE PLAIN IN SHANGOMBO, ZAMBIA"

Reference is made to your protocol dated as captioned above.

NASREC resolved to approve this study and your participation as Principal Investigator for a period of one year.

REVIEW TYPE	ORDINARY REVIEW	APPROVAL NO. NASREC-2022- MAR-005
Approval and Expiry Date	Approval Date: 30 th May, 2022	Expiry Date: 29 th May, 2023
Protocol Version and Date	Version - Nil.	30 th May, 2022
Information Sheet, Consent Forms and Dates	• English.	To be provided
Consent form ID and Date	• Version - Nil	To be provided
Recruitment Materials	• Nil	Nil
Other Study Documents	• Questionnaire.	

Towards Improving Service and Excellence in High Education Beyond Fifty Years

Specific conditions will apply to this approval;

As Principal Investigator it is your responsibility to ensure that the contents of this letter are adhered to. If these are not adhered to, the approval may be suspended. Should the study be suspended, study sponsors and other regulatory authorities will be informed.

Conditions of Approval

- No participant may be involved in any study procedure prior to the study approval or after the expiration date.
- All unanticipated or Serious Adverse Events (SAEs) must be reported to NASREC within 5 days.
- All protocol modifications must be approved by NASREC prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address.
- All protocol deviations must be reported to NASREC within 5 working days.
- All recruitment materials must be approved by NASREC prior to being used.
- Principal investigators are responsible for initiating Continuing Review proceedings. NASREC will only approve a study for a period of 12 months.
- It is the responsibility of the PI to renew his/her ethics approval through a renewal application to NASREC.
- Where the PI desires to extend the study after expiry of the study period, documents for study extension must be received by NASREC at least 30 days before the expiry date. This is for the purpose of facilitating the review process. Documents received within 30 days after expiry will be labelled "late submissions" and will incur a penalty fee of K500.00. No study shall be renewed whose documents are submitted for renewal 30 days after expiry of the certificate.
- Every 6 (six) months a progress report form supplied by The University of Zambia Natural and Applied Sciences Research Ethics Committee as an IRB must be filled in and submitted to us. There is a penalty of K500.00 for failure to submit the report.
- When closing a project, the PI is responsible for notifying, in writing or using the Research Ethics and Management Online (REMO), both NASREC
- and the National Health Research Authority (NHRA) when ethics certification is no longer required for a project.
- In order to close an approved study, a Closing Report must be submitted in writing or through the REMO system. A Closing Report should be filed when data collection has ended and the study team will no longer be using human participants or animals or secondary data or have any direct or indirect contact with the research participants or animals for the study.
- Filing a closing report (rather than just letting your approval lapse) is important as it assists NASREC in efficiently tracking and reporting on projects. Note that some funding agencies and sponsors require a notice of closure from the IRB which had approved the study and can only be generated after the Closing Report has been filed.
- A reprint of this letter shall be done at a fee.

- All protocol modifications must be approved by NASREC by way of an application for an amendment prior to implementation unless they are intended to reduce risk (but must still be reported for approval). Modifications will include any change of investigator/s or site address or methodology and methods. Many modifications entail minimal risk adjustments to a protocol and/or consent form and can be made on an Expedited basis (via the IRB Chair). Some examples are: format changes, correcting spelling errors, adding key personnel, minor changes to questionnaires, recruiting and changes, and so forth. Other, more substantive changes, especially those that may alter the risk-benefit ratio, may require Full Board review. In all cases, except where noted above regarding subject safety, any changes to any protocol document or procedure must first be approved by NASREC before they can be implemented.

Should you have any questions regarding anything indicated in this letter, please do not hesitate to get in touch with us at the above indicated address.

On behalf of NASREC, we would like to wish you all the success as you carry out your study.

Yours faithfully,

Dr. M. Kaonda

**VICECHAIRPERSON
THE UNIVERSITY OF ZAMBIA NATURAL AND APPLIED SCIENCES RESEARCH
ETHICS COMMITTEE - IRB**

cc: Director, Directorate of Research and Graduate Studies
Assistant Director (Research), Directorate of Research and Graduate Studies
Assistant Registrar (Research), Directorate of Research and Graduate Studies
Acting Senior Administrative Officer (Research), Directorate of Research and Graduate Studies