Seminar series nr 218

Flood Hazard Assessment by means of Remote Sensing and Spatial analyses in the Cuvelai Basin

Case Study Ohangwena Region –Northern Namibia

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2010

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A Master Thesis in Geomatics of 30 ECTS presented to

Department of Physical Geography and Ecosystem Analysis

Centre for Geographical Information Systems

of

by

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in partial fulfilment of the requirements

for degree of Master in Geomatics

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ACKNOWLEDGEMENT

I would like to express my gratitude to all those who gave me the opportunity to complete this Research. I'm deeply grateful to my supervisor Andreas Persson Lund University, who helped me with stimulating suggestions and encouragement. He assisted me during the time of this research and the writing of this report.

I would also like to thank Mr. Van Langenhove Guido from Ministry of Agricultural Water and Forestry, Namibia and Kombada Mhopjeni , from the Ministry of Mines and Energy , Namibia, for their input and for taking some time off their busy schedule to forward me relevant data literature.

Finally yet importantly, I would like to thank Christian Shipena for she has been a great of great assistance during the conduction of the field survey and my fellow student and good friend Maxime Rwaka for his input, assistance, and advices.

Let me not forget my family for their patience and allowing me time to concentrate on my research. I am particularly graceful for my Aunt and Uncle, Mrs. /Mr. Ndaitwah for allowing me to use their car for site visits while conducting the survey.

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ABBREVIATIONS & ACRONYMS

ETM+	Enhanced Thematic Mapper Plus
GIS	Geographical information systems
GPS	Global Positioning System
GRN	The Government of the Republican of Namibia
KM	Kilometre
M	Meter
MAWF	Ministry of Agricultural Water and Forestry
MNDWI	Modified Normalized Difference Water Index
NDWI	Normalised Different Water Index
RS	Remote sensing
SLC	Scan Line Corrector
STD Dev	Standard Deviation

ABSTRACT

Floods are one of the most frequent natural disasters in the world that causes substantial damage to quality of life, livelihood, and properties. Many countries, in particular developing countries, lack knowledge of the phenomenon and infrastructures to deal with the disaster. So they tend to deal with disasters after it has occurred. Recently, there has been major flooding in the central northern Namibia, in the Cuvelai basin. These floods affected about 30% of the population and caused major damage and loss of life and the Government of the Republic of Namibia (GRN) does not have an early warning system for the floods nor mitigation measures in place. Further, post flooding information on the level of damage in specific locations is also not made available. For these reasons, this study aims to assess the impact of floods and determine flood hazard areas in the Cuvelai Basin in the Ohangwena region, using Remote Sensing and Geographical Information Systems (GIS). This was achieved by delineating *Oshana* flood waters from Landsat ETM+ imagery by means of (MNDWI) method. Thereafter, the delineated *Oshana* flood waters were used to determine the flooded homesteads for each year and further assess the impact of flood in each village. Lastly, spatial cluster analysis was applied on the villages, based on the number of flooded homesteads per village, to assess the spatial distribution of the flooded homesteads and create hazard maps.

Based on the delineated *Oshana* flood water, an increase in the water area was recorded as from 2007 to 2010. Major changes in the *Oshana* flood water area were noticeable as from the year 2008 to 2010, specifically the introduction of more water toward the eastern side of the flood area. The number of flooded homesteads increased significantly as from 2008, when compared to previous years. The most affected villages are those that are located on the northern side of the study area. Results show that about 19% of the villages are in high hazard level 1, meaning they have significantly affected by the floods more than other villages as from 2003 to 2010.

Results of this study can be used to identify villages that are severely impacted by flood for humanitarian assistance. The method to assess and identify the impacted areas can be used mainly for post and pre-flood event to identify potentially affected areas and the number of impacted villages and homesteads.

Key words: Flood Hazard Assessments, Remote Sensing, MNDWI, Getis-*Ord Gi** Spatial Analysis

1 INTRODUCTION

Remote Sensing (RS) and Geographical information systems (GIS) have been used all over the world for different applications. They have been applied in application such as environmental monitoring, forest management, surface water detection and analysis, detection of peat soils amongst others (Lillesand, et al., 2008; Gibson, et al., 2000). Remote sensing can be defines as the art of obtaining recording of information of an object without being physical contact with the object (Gibson, et al., 2000; Lillesand, et al., 2008) . On the other hand, GIS can be defined as a system designed to store, manipulate, analyze, and visualize spatial information (Steinberg, et al., 2006). The use of remote sensing has significantly increased in the field of hydrology. It has improved the collection of data, monitoring of hydrological status, such as water quality, floodplains mapping, river flow monitoring, amongst other application (Holden, 2008; Lillesand, et al., 2008; Guo, et al., 2010). Data delivered from remote sensing imagery, such as land cover classification, floodplain areas, can be entered in GIS. These data can be combined with other spatial data containing attribute data such type of land uses, population, for further analysis and manipulation.

Floods are one of the most frequent natural disasters in the world and they can cause substantial damage to quality of life, livelihoods and to properties. Many countries, in particular developing countries lack knowledge of the phenomenon and infrastructure to deal with natural disasters, including floods and they only tend to deal with them after they have occurred (Fuad, et al., 2005). As a result they cause significant damage that could have been avoided. However, with extensive investigation and assessments, proper mitigation and planning beforehand can be adopted to reduce the flood impacts or at least avoid major damages. Flood assessment includes investigation and analysis of the causes of the floods, such as the flood frequency, flood inundation, flood extent and the damage associated with the flooding (Ward, et al., 1995), and many other factors.

In Namibia, there have been floods in the north eastern regions (Kavango and Caprivi) and north central regions (Ohangwena, Omusati, and Oshana). These floods cause significant damage to properties, loss of lives and major destruction to rural people’s quality of life (World Meteorological Organisation, 2009; Consolidated Appeals Process , 2009). The floods within Okavango and Caprivi regions date years back, within the Kwando Zambezi plains. While, in the northern central regions the floods are within the Cuvelai basin, and it only became more apparent in the last 3 to 4 years. The Cuvelai basin stretches from highlands in Angola forming small tributaries locally known as *"Oshanas"* within the Cuvelai basin (Davies, 1994). Large scale flooding within the Cuvelai basin takes place after heavy rainfall in Cuvelai river system in southern Angola (National Planning Commision , 2003; Miller, et al., 2010). However, some areas within the Cuvelai can be heavily flooded, due to heavy rainfall in those areas, thus the water does not flow to other places (Miller, et al., 2010). Large scale flooding affects over 30% of Namibian's population in the central north, either through total homestead destruction or through submerged of crop fields, thus crop productivity is affected. Since the central northern region floods are recent, the Government of the Republic of Namibia (GRN) does not have an early flood warning system for the floods nor mitigation measures in place. However, the GRN and other organisations conducted rapid appraisal assessments during the 2008 and 2009 floods to identify immediate and medium-term humanitarian needs (Consolidated Appeals Process , 2009). Since the floods cover a large area, in some instances the full extent of the damage is not determined until rains and floods have subsided in the areas (The Namibian Newspaper, 2008), as a result some affected people are not assisted on time. During pre and post flooding events some questions might arise in order to mitigate and assist the impacted people or areas. Questions such as, which areas have more flooded homesteads? Which areas need more enforcement to assist the affected people? Which are the potentially affected areas? All these questions require in depth investigation and assessment in order to mitigate the impact of floods. It is against this background that this study tried to answer the following questions: What are the *Oshana* flood areas and what is the extent of the flood?

- How many homesteads are exposed to the flooding for each flood year?
- Which villages have the highest number of flooded homesteads, and which are vulnerable to flooding?
- What are the spatial characteristics of the impacted villages; are they clustered or randomly distributed within the Cuvelai?

2 AIMS AND OBJECTIVES

The aim of the study was to assess the impact of the floods and determine flood hazard areas in the Cuvelai Basin in Ohangwena region, using RS and GIS. Specific objectives of the project were:

- to effectively delineate *Oshana* water body from series of Landsat ETM+ imagery and identify flood water extent and changes ,
- to identify the flooded homesteads, impacted villages and assess their spatial distribution based on the 2003 , 2004, 2005, 2006, 2007, 2008, 2009 and 2010 *Oshana* flood water and,
- to create flood hazard areas based on the number of most flooded homesteads for the past 10 years.

To achieve these, the following main steps were taken; Firstly, *Oshana* flood waters were delineated from Landsat imagery by mean of Modified Normalized Difference Water Index (MNDWI) method. Secondly, the delineated *Oshana* flood waters were used to determine the flooded homesteads for each year. Lastly, the number of flooded homesteads per village was determined and spatial analysis was applied on the villages. The word *homesteads* used in the report refers to the Ovambo traditional houses see *Photo 1* .

Photo 1: Typical traditional Homestead Source: Curtsey of Edward Kuliwoye, 02 June 2010

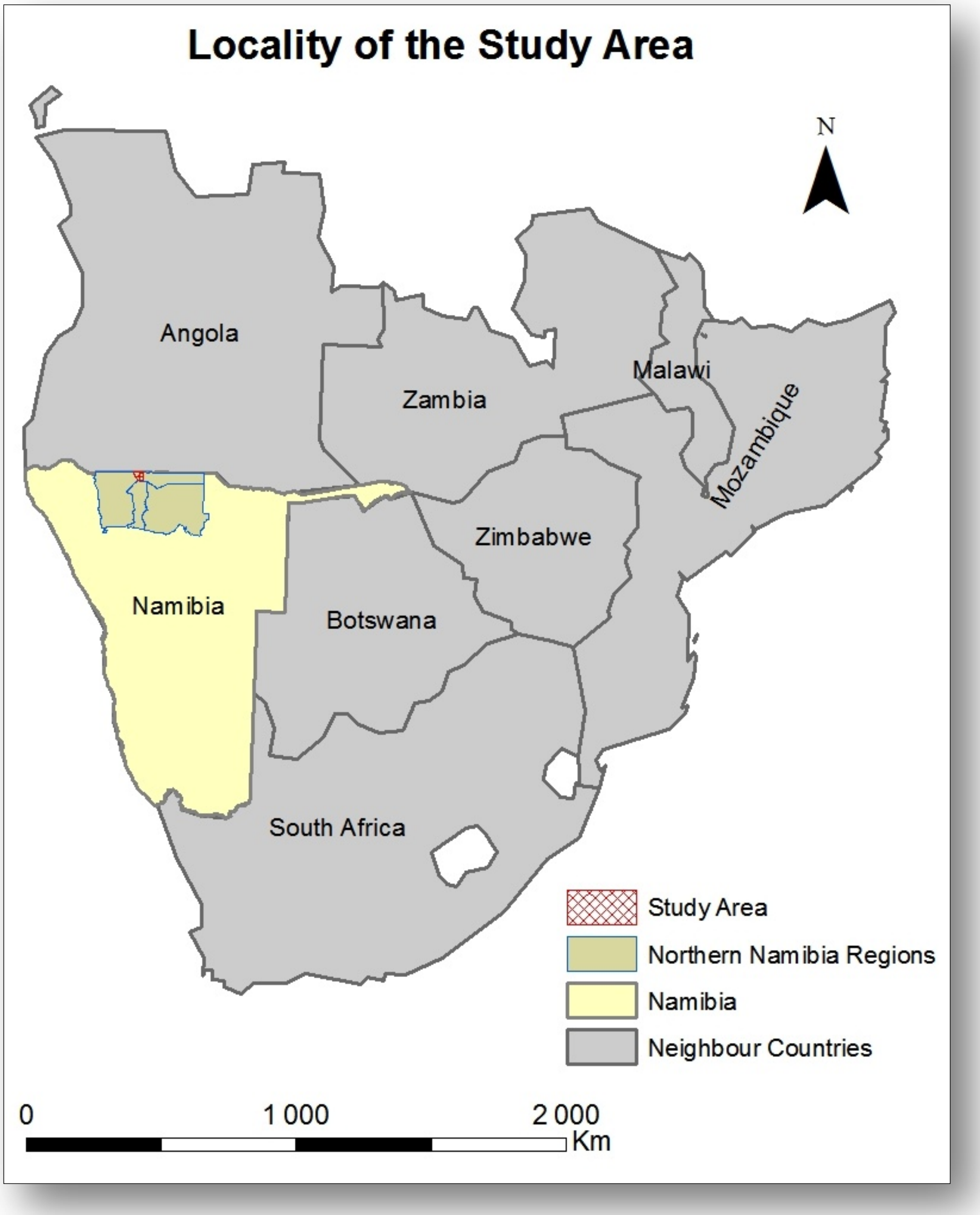
Study Limitations and Errors

The study was hampered by several factors, namely by;

- A lack of sufficient budget to finance the field visit and other necessities for the study
- A lack of a local hydrological data, such as rainfall and water level measurements that would enhance the degree of analysis.
- The efficiency detecting water body from the images might be hampered by clouds, mixed pixels and other atmospheric effects.

3 INTRODUCTION TO THE STUDY AREA

Namibia is an arid to semi-arid country, with high rainfall variations across the country and from season to season. Namibia is bordered by South Africa, Botswana, Zimbabwe, Zambia and Angola, in the south, east, north east and north respectively. Namibia is divided into 13 regions and the regions within the Cuvelai basin are central northern regions namely Ohangwena, Oshana, Omusati and Oshikoto see *Map*.

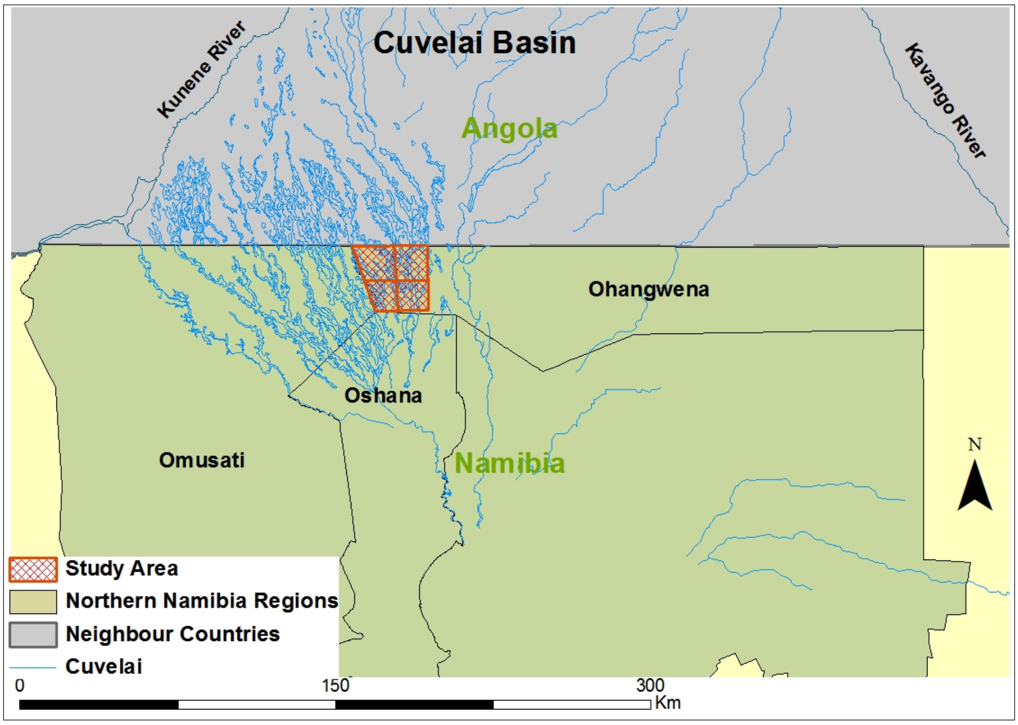


Map1: Locality of if the study area **Data Source: (National Planning Commision, 2010)**

3.1 DESCRIPTION OF THE STUDY AREA

The study area is within the Cuvelai basin, located in the central north of Namibia in Ohangwena region and it is approximately 1 170 km². The Cuvelai basin is shared between Namibia and Angola (*Map 1*), with its main catchment area in the south of Angola. In Namibia, it is within the area between the Okavango and Kunene Rivers (Niipele, et al., 2007), and it is approximately 10 000 km².

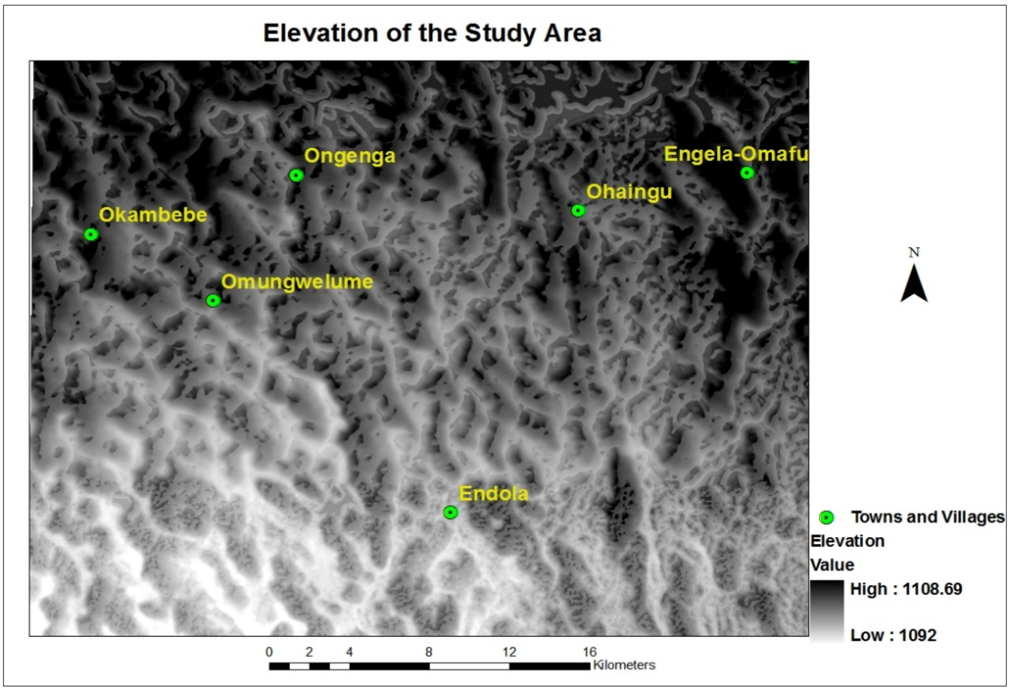
Due to time constrains and budget, the study only covers a part of the Cuvelai basin in Ohangwena region within Ongenga, Engela, Ohangwena, and Oshikango Constituencies.



Map 1: The Cuvelai Basin **Data Source: (National Planning Commision, 2010)**

3.1.1 Geology and Hydrology

The study area is within an altitude approximately 1 092 meters and 1 110 meters (*Map 2*) above sea level (Christelis, et al., 2001; Davies, 1994). The slope is gently flat stretching towards the south spreading across the Kalahari sands into the Etosha Pan (Christelis, et al., 2001). In the northern part the elevation it is slightly higher and decreases down south towards. In the north east and eastern part of the study area the slopes are slightly steeper and streams are narrower than in the west (Miller, et al., 2010). The west part is within the centre of the Cuvelai basin and the slope is gently more flat than northern and eastern areas.



Map 2: Elevation of the study area represented by a 50m interval Digital Elevation Model. **Data Source: (National Planning Commision, 2010)**

The area is within an alluvial plain made up of Eutric Cambisols dominant soils type (Mendelsohn, et al., 2002). This soil is made up of sedimentary sands and clays washed and blown in from the higher grounds in Southern Angola (National Planning Commision , 2003). Over thousands of years, the Cuvelai was once one big Cuvelai flood plain (Hahn, et al., 1928). As it went through many years of dry seasons, slow water flows sands started to form sand bars and later these sand bars became vegetation bars or islands (Miller, et al., 2010). These vegetation islands divide the Cuvelai plains into *Oshana* tributaries, and it is on this islands the natives set up their crop fields and homesteads close to the *Oshana*.

The mean annual rainfall in the region varies between 300 mm per year in the west and 650 mm per year in the east (Christelis, et al., 2001). On an average of over two-thirds of the annual rainfall is concentrated in November to March, (National Planning Commision , 2003).

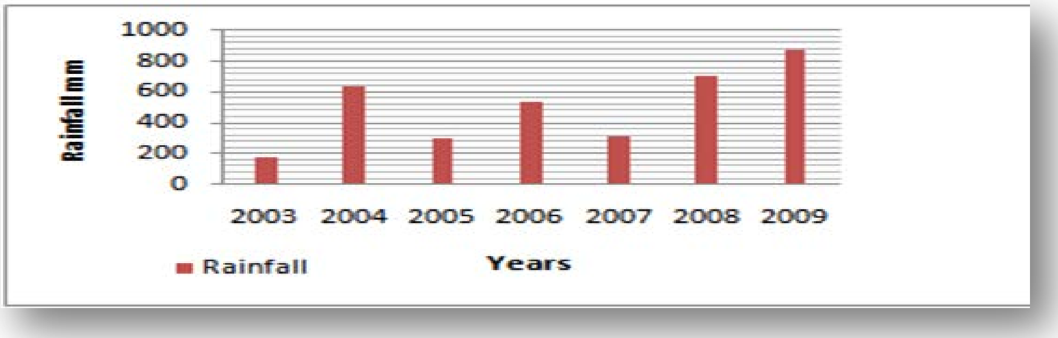


Figure 1: Estimated Annual average rainfall in the Cuvelai at one station.

Data Source: (Meteorological Service of Namibia, 2010)

Currently there is no operational rainfall measurement station in the area, the one used to be there stopped operation in 1972. The rainfall data in *Figure 1* was estimation from a rainfall measurement station that is about 20 km from the study area.

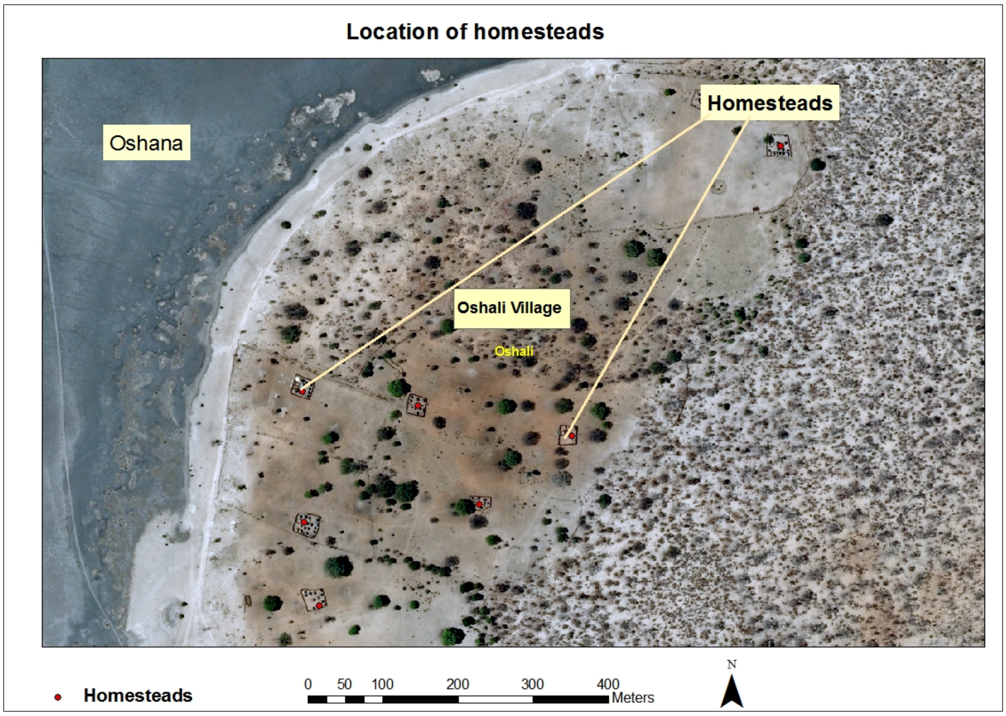
As mentioned earlier the Cuvelai is made up of *Oshana* and pans. *Oshana* made up of ephemeral shallow streams inter-linked water courses and grass covered. The pans are also grassy, but circular shaped and hold water temporary (Miller, et al., 2010). In events of heavy rainfall or heavy surface water flow these lakes join forming steady streams (Miller, et al., 2010; Davies, 1994; Christelis, et al., 2001). These streams flows southwards into the Etosha Pan, and as they move toward Etosha pan they form less wide streams that become less wider before reaching into the Etosha pan (Davies, 1994). Surface water dries out after two to three months or even longer, after the rainfall season depending on the depth of the pan or lake (Miller, et al., 2010). The pans and *Oshana* are generally not deep, they ranges from one to two metres in depth. However, there are some pans and streams that are about 4 meters (Miller, et al., 2010).

3.1.2 Vegetation

The study area is characterized by woodland based on landscape called Cuvelai drainage, which is characterised by mopane scrub (*Colophospermum mopane*) and sparsely various larger trees and shrubs. During the rainfall season *Oshana*s are covered by grass, which disappears slowly due to animal grazing (National Planning Commision , 2003). Due to a high population density in the area, most of the vegetation has been swept away for firewood and building homesteads and overgrazing (National Planning Commision , 2003).

3.1.3 Population and Social status

Ohangwena region is the most densely populated region in Namibia with an average of 21.3 persons per square km, with the highest average population density, of 40 persons per square km within the study area (National Planning Commision , 2003). The exact number of homesteads within the study area was not known, however based on the 2007 orthophoto visually confirmation outlines that there were approximately 11656 homesteads within the study area. The homesteads are uniformly distributed within the study area, within the study area *(see Appendix II Distribution of homesteads).*



Map 3: Location of homesteads approximately to the oshana in Oshali village

Data Source: (MLRR, Directorate of Survey and Mapping, 2010)

Most inhabitants of the Ohangwena region depend on the subsistence agricultural farming, which is the highest source of food and income, (Central Bureau of Statistics , 2003). The subsistence farming in Ohangwena region is made up of small crop fields of average 2.4 hectares (Mendelsohn, 2006). Within each crop field there is a homestead mainly built from woods that are surrounding several huts. The homesteads are set up within the Cuvelai, around the *Oshanas* see Map 3 (National Planning Commision , 2003).

4 LITERATURE REVIEW

4.1 FLOOD HAZARD

Floods are natural disasters that causes significant damage to buildings and infrastructures, drown humans and livestock, spread diseases, contaminate water supplies and damage crops (Holden, 2008). Floods can be attributed to heavy rainfall, heavy overflow, or human modification of floodplains that can lead to change in flood frequency and magnitude (Holden, 2008). Some of the major floods include those recently in Malaysia Sensual 2006 which resulted in evacuation of over 100 00 people and the Mozambique floods that killed thousands of people in 2000.

The *Oshana* in the Cuvelai basin are generally known for their rainfall season small scale flooding, depending on the magnitude of the rainfall (Miller, et al., 2010). However, recently there have been several large scale floods, forcing a number of people to be evacuated, noticeable in years 2008 and 2009 (Consolidated Appeals Process , 2009).

Photo 2: *Oshana* floods in 2009 Source: Courtesy of MAWF

The Cuvelai system is known to floods at an interval of four to six times in every ten years (Miller, et al., 2010). These floods are induced by water emanating from the Cuvelai basin river system in southern Angola and by heavy local rainfall within Namibia (The Namibian Newspaper, 2008; National Planning Commision , 2003; Miller, et al., 2010). Heavy rainfall in some parts of Cuvelai results in floods only in that area, hence several *oshana* within the Cuvelai could be flooded while other might not be flooded (Miller, et al., 2010) (National Planning Commision , 2003). Moreover, for heavy floods within the Cuvelai basin to occur there must be heavy wide spread rainfall, especially from the highland in southern Angola. This occurred in 1953/54, 1956/57 and 1960/61 seasons were there was widespread rains in Angola and extensive flooding in Namibia but, the local rainfall was low (Miller, et al., 2010).

In 2008, it was estimated that about 406 households and about 1 258 people were affected by the rain and floods in Ohangwena Region (The Namibian Newspaper, 2008) . Several roads, bridges and other vital infrastructure were also destroyed or severely damaged. While in 2009, 16.6% the population was affected and about 13,000 persons were displaced from their houses (Consolidated Appeals Process , 2009).

Photo 3: Homestead flooded in 2009 **Source: Courtesy of MAWF**

People were affected either through homestead completely flooded or crop fields submerged, see *Photo 3.* The 2009 flood was considered the highest and most damaging for all regions, *(personal communication: Mr Van Langenhove Guido by email on 01 December 2010).* There were about 21 relocation camps in six regions to host the displaced and many of the camps were overcrowded and lacked adequate access to safe water and sanitation facilities (Consolidated Appeals Process , 2009).

4.2 WHAT HAS BEEN DONE SO FAR

The study area lack information on the number of affected homesteads, people per village and the most affected areas. An attempt was made to acquire information on the most impacted villages, locations of camps and specific number of people given shelter; unfortunately there was no data available. However, the GRN is currently conducting large scale flood mapping project in the Cuvelai (*confirmed by Mr Van Langenhove Guido, personal communication).*

In addition effective and efficient data that might enhance the degree of flood hazard assessments such as local rainfall in the area and water level measurements were also unavailable during the commencement of this study. However, several daily flood level measurement stations has been set up within the Cuvelai as from 2008.

4.3 WATER DETECTION

Delineation of surface water from satellite imagery can easily be completed, since water has a unique spectral signature and can readily be differentiated from other objects, especially clear water (Pietroniro, et al., 2002). Clear water less reflects radiant energy within the blue and green wavelength, while absorbing it in the near infrared band (Lo, 1986; Lillesand, et al., 2008). On the other hand, with turbidity, sediments, and other organic matters in the water, it can have high reflectance in the visible wavelength (Lo, 1986; Liu, et al., 2003). However, in near infrared and mid infrared these water body still have lower reflectance of these wavelengths (Lillesand, et al., 2008; Lo, 1986). In these wavelengths radiant penetrates clear water resulting in very dark image tones of even shallow water bodies (Lillesand, et al., 2008).

Several methods have been used to delineate water body from satellite imagery; such as density slicing, threshold approaches and band combinations, adopted by researchers such (Tan, et al., 2005; Sanjay K, et al., 2005; Wang, 2004). Density slicing has been applied in many studies successfully, however since it uses a single band, in most cases thermal infrared or mid- infrared, it is ineffective in classifying mixed pixels and turbid water (Sanjay K, et al., 2005).

The method used in this study to delineate *Oshana* water area from the Landsat ETM+ imageries was the modified normalized difference water index (MNDWI). MNDWI method is an enhancement of the normalised different water index (NDWI) and was developed to delineate water body from imagery with the formula

Since the physical properties of the study area consists of sand soils and grass during the rainy season, which tends to have high reflectance in Mid-IR and low in green band. This method was considered suitable for this purpose. In addition, several researchers (Hui, et al., 2008; Soti, et al., 2009) have also utilised MNDWI method to delineate water properties from Landsat 7 Thematic Mapper imagery effectively. This method was also considered effective for delineation of water and flood water, since floods consist of clear water and turbid water. Of relevance to this study, is a study by Soti, et al., (2009) conducted in arid area in Senegal, where it was determined that MNDWI from Landsat ETM+ was effective in delineation of water area in arid areas.

4.4 SPATIAL CLUSTER ANALYSIS

Spatial analysis is a method that aims at grouping similar features based on their location, and attributes values (Rogerson, 2001). There are many spatial methods for cluster analysis, such as the Local *Moran I nearest neighbour analysis*, however this study adopted *Getis-Ord Gi** cluster analysis. This method tests statistical significance of a particular value of a feature in a surrounding and its surrounding variable consists of higher or lower values than the surrounding average values (Rogerson, 2001). The method considers the distance between the features, which determines whether the feature will be included in the surrounding features or not. For example, a low spot clustering will depend on whether a feature with low value is surrounded by other features with low values as well. The *Getis-Ord Gi**statistic local clustering is given as:

5 DATA AND METHODS

This section outlines methods and materials used for this study. Section 0 outlines the primary materials used, while section 5.2 outlines the method employed. The diagram in *Figure 2* show the primary tasks carried out.

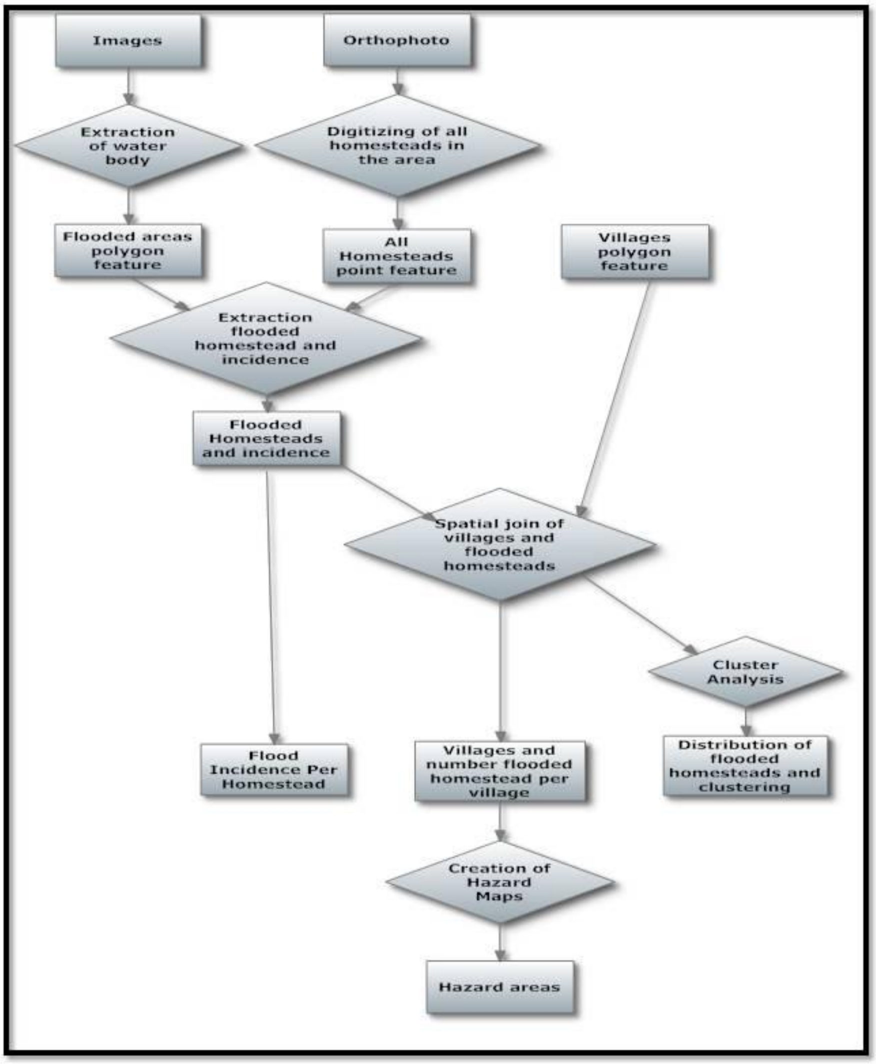


Figure 2: Conceptual Diagram of the main task undertaken

5.1 Data

5.1.1 Imagery Data

The Landsat 7 Enhanced Thematic Mapper Plus (ETM+) imageries were acquired dating from 2003 to 2010 to detect *Oshana* water area. Year 2001 and 2002 was omitted due to heavy clouds in all the imagery that could be obtained. As mentioned earlier, generally rainfall season in Namibia is from November to March, and it is mostly cloudy during these months, thus most of the images in these months are not cloud free. As a result, only daily images of the month of April were adopted for water body delineation for all years. However, year 2009 April month imagery are not cloud free, as a result imagery from March has been used as replacement.

Table 1: Landsat ETM+ Band Parameters **Data Source: (USGS, 2010)**

LandSat7 bands:	wave range μm	Nominal spectral	Spatial Resolution
Band 2	0.53-0.61	Green	30meters
Band 5	1.55-1.75	Mid-IR	30meters

Landsat ETM+ scene for study area was scene path= 180 and row = 72. Only band 2 and 5 were required for this study, see their parameters *Table 1*. For all imagery parameters *see Appendix I Imagery Parameters.*

All the images used were acquired between February, and April, and since they are all from one scene they all have the same sensor capture time.

Since May 2003, an instrument malfunction on board of Landsat ETM+ resulted in all Landsat imagery from that period to present to be captured with *Scan Line Corrector* (SLC)-off mode. As a result all the imagery acquired after 2004 have gaps at the edge of the each scene (USGS, 2010) and they are distributed with these gaps. Therefore, the user has to fill the gaps before any processing can be done. Landsat ETM+ imagery that has SLC-off has been successfully applied in several researches (U.S. Geological Survey, 2003). However one should need to ensure the method used to fill the gaps is effective and will hail the required result.

5.1.2 Orthophotos and Village data

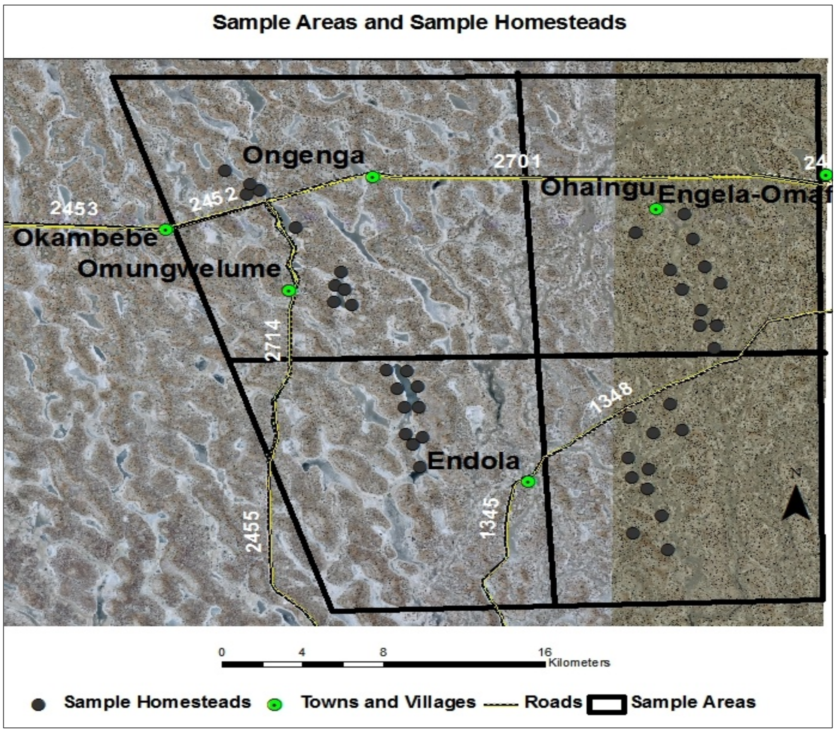
Orthophotos of 2007 of 1 meter resolution and 1 kilometre by 1 kilometre scenes of the where used to identify and digitize the homesteads in the area (*vector points feature*).

The village data is presented as polygons, and they were obtained from (Mendelsohn, et al., 2002). This data was used to assess the number of flooded homesteads per village and to assess the spatial distribution of the villages by means of spatial cluster analysis.

5.2 METHODS

5.2.1 Field survey

The field survey was conducted from the 21st of August to the 31st August 2010. The primary aim of the field study was to obtain information for accuracy assessment and for field reconnaissance purposes. Moreover to obtain information from those homesteads that are in close proximity to *Oshana* floodplains. The study area was divided into two sample areas; one on the western side of the study area and the other on the eastern side of the study area (*Map 4*). This is because slight heterogeneity in the topography and landscape within the Cuvelai basin from east to west. The sample areas were further divided into four randomly subareas. In these random areas, 10 homesteads were selected onsite based on those that are within visible sight from *Oshana* floodplains.



Map 4: Sample area divided into 4 subareas with the homesteads surveved

Data Source: (National Planning Commision, 2010)

The surveying tools were aerial photographs of the study area and Global Positioning System (GPS) receiver. GPS receiver was used to mark the coordinates of the homesteads, while the aerial photographs were used to mark the homesteads surveyed as a backup for GPS points. Due to time and budget limitation, only 80 homesteads were targeted for surveying, about 5% of the estimated number of homesteads in the study area. However, due to some technical problems during the survey only 75 homesteads could be surveyed.

5.2.2 Delineating of Water Body

The purpose for delineating *Oshana* flood waters was to determine the extent of the *Oshana* water body for the past 10 years, and to use it to determine the flooded homesteads. The Oshana flood water was delineated as follows.

Firstly, the gaps in the images were filled by means of kriging interpolation. This was carried on images captured from 2004 to 2010. After the gap filling, majority filtering was applied to each band, to reduce the number of noise and random single pixels in the bands.

Thereafter the MNDWI method was applied to band 2 and band 5 to delineate water body, with the formula were never flooded is considered as the high priority than those homesteads that stated that they were flooded.

5.2.3 Digitizing of homesteads and extraction of flooded homesteads

The purpose of the extraction of flooded homesteads was carried out for two reasons: One was to determine the number of homesteads, flooded homesteads and illustrate their spatial distribution. Two, it was to obtain the number of flood incidences per homestead. These reasons were achieved as follows:

- Firstly, all homesteads within the study area were digitized from the 2007 one meter resolution orthophoto. Homesteads digitized were represented as point feature, and the point was placed inside each homestead in the study area. About 11 656 homesteads were indentified and digitized. **(*Appendix II*** Distribution of homesteads**)**.
- Secondly, the flooded homesteads were extracted from the none flooded homesteads for each years, 2003 to 2010. The flooded homesteads were determined by means of overlaying delineated *Oshana* flood water (*polygon features*) and homesteads (*point features*), see (***Appendix IV*** Homesteads Intersection with water bodies). Those homesteads covered by delineated water, were referred to as flooded homesteads.
- Thirdly, the number of times a homesteads intersected with the oshana water polygons, was summed up to give the flood incidences per homesteads from 2003 to 2010.

5.2.4 Determination of impacted villages

After the flooded homesteads were determined, they were spatial joined to the villages polygon feature. The resulting feature was village polygon feature with attributes of the number of flooded homesteads per village. The villages had different number of homesteads, ranging from 10 to 348 homesteads.

Impacted villages were only calculated based on the 2008, 2009, 2010 floods. This is because from 2003 to 2007 there were no major floods and that the number of flooded homesteads is minimal in each year. The impacted villages were categorised into two groups, they are assessed as fallows;

- Firstly, **villages with a high number of flooded homesteads assessed**, based on the number of flooded homestead per village.

- Secondly, **percentage of flooded homestead per village was assessed,** based on the total number of homesteads in the villages. This was carried out in order to determine which villages were significantly impacted by the floods based on the number of homesteads in that village.

The percentages of the flooded homesteads in a village were further divided into 3 categories as follows;

- The Villages with less than 5% flooded homesteads, "**Low impacted**"
- The villages having above 5% and less than 10% flooded homesteads, "**Medium impacted"**
- The villages with more than 10% flooded homesteads, "**Significantly impacted**"

5.2.5 Assessing the Spatial Distribution

The aim of the spatial analysis was to assess spatial distribution of the flooded homesteads, to determine whether the villages are clustered or randomly distributed throughout the study area. If affected village are clustered, this will aid in further assessing why they are together and affected by the floods. The *Getis-Ord Gi** spatial clustering analysis was applied on villages polygon features based on the number of flooded homesteads from 2003 to 2010. A 1500m threshold distance was applied, meaning only villages within a distance of 1500m will be considered in the calculation of the clusters.

5.2.6 Hazard Areas

The flood hazard villages were created based on the combined number of impacted homesteads per village as from 2003 to 2010 floods. The impacted villages were categorised in hazard levels as follows;

- High hazard (level 1), villages with more than 10% flooded homesteads, based on the combined flooded homesteads. These villages were greatly impacted by the *Oshana* floods.

- Medium hazard (level 2), villages with having above 5% and less than 10% flooded homesteads up to 10% flooded homesteads.

- Low hazard (Level 3) less than 5% flooded homesteads. These villages were not largely impacted by the *Oshana* floods.

6 RESULTS

6.1 *OSHANA* WATER AREA CHANGES

Visual presentation of the extent and changes of the delineated water indicates an increase in *oshana* water. The highest noticeable change in the *Oshana* flood water and extent was from 2007 to 2008 see *Figure 3* below. Before 2008 floods, the *Oshana* flood waters were mainly distributed toward the west and central of the study area, see *Map 5* and *Map 6.* However since 2008 more water bodies were visible throughout the study area with noticeable change toward the east of the study area, see *Map 8.* In year 2003 to 2007 water was not detected in some villages, for e.g. in Ohaingu village compare *Map 6* and *Map 8*, however from year 2008 significant water is visible.

Extend in the flood water area also created an increase the number of flooded homesteads as from 2008, *see Figure 3.* The total homesteads flooded as from 2003 to 2010 were 925 within the study area. The most number of flooded homesteads were in 2010, which is double the number of homesteads flooded in 2004 and 2005. The highest change in flooded homesteads was in from 2008 to 2009, with 200 flooded homesteads.

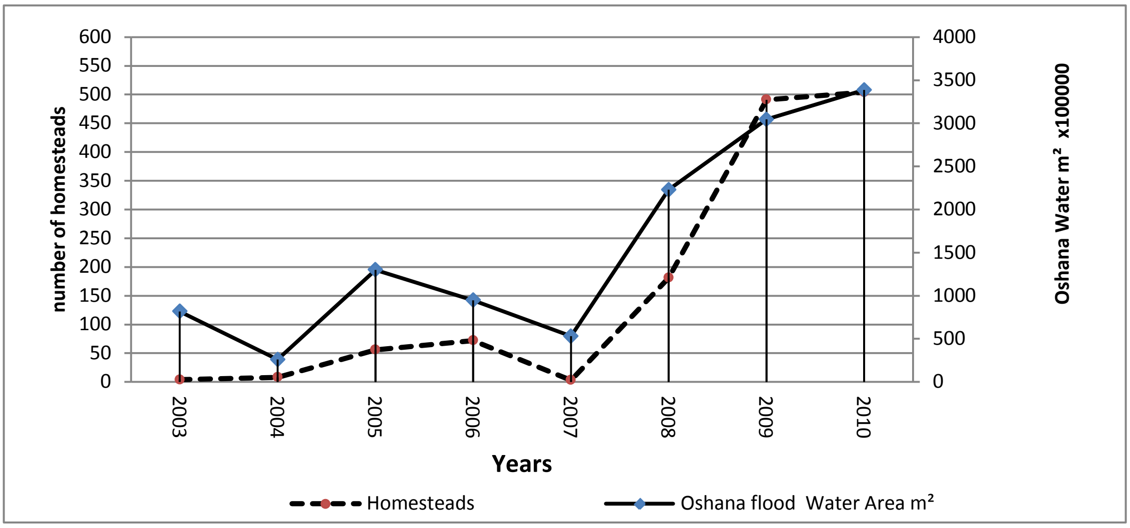
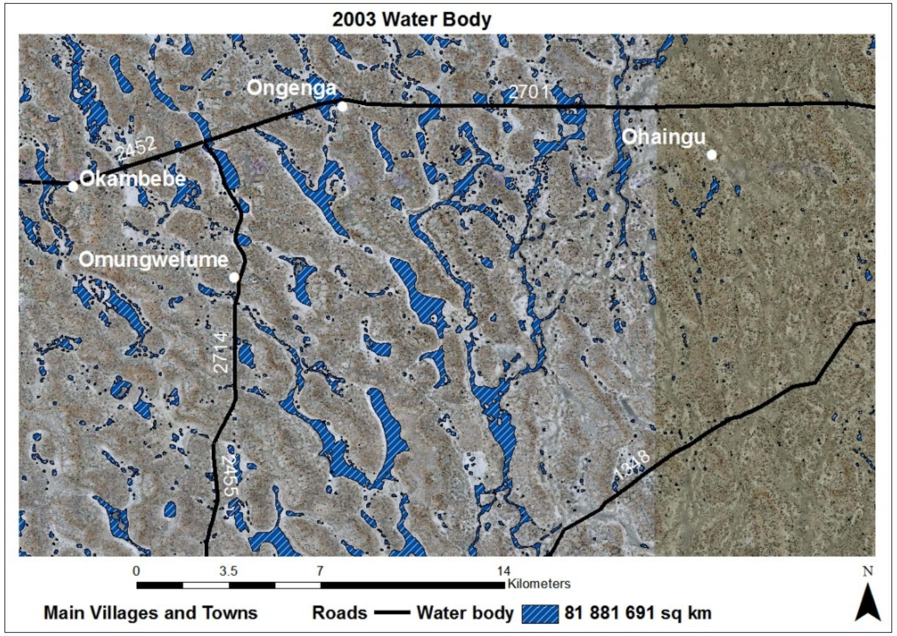
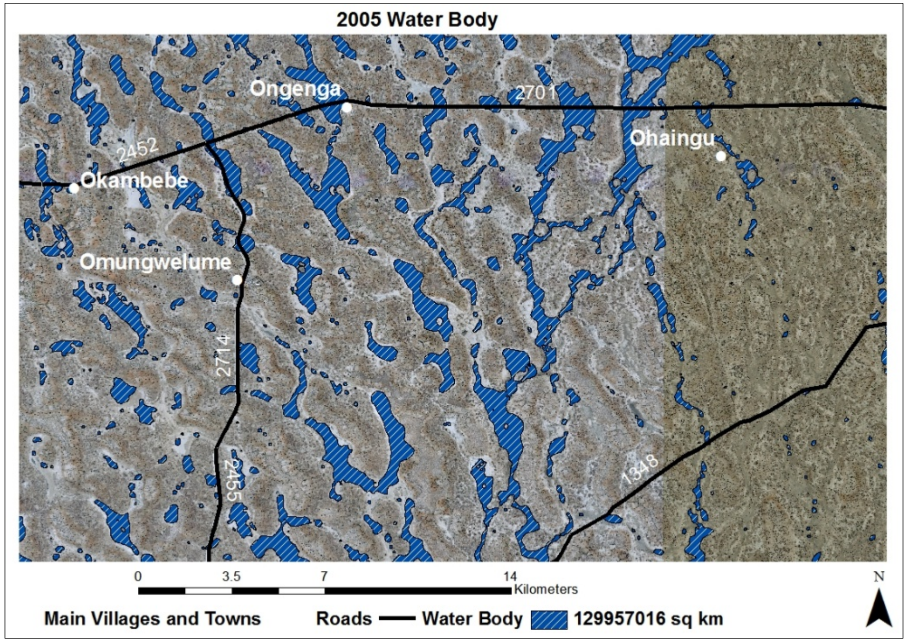


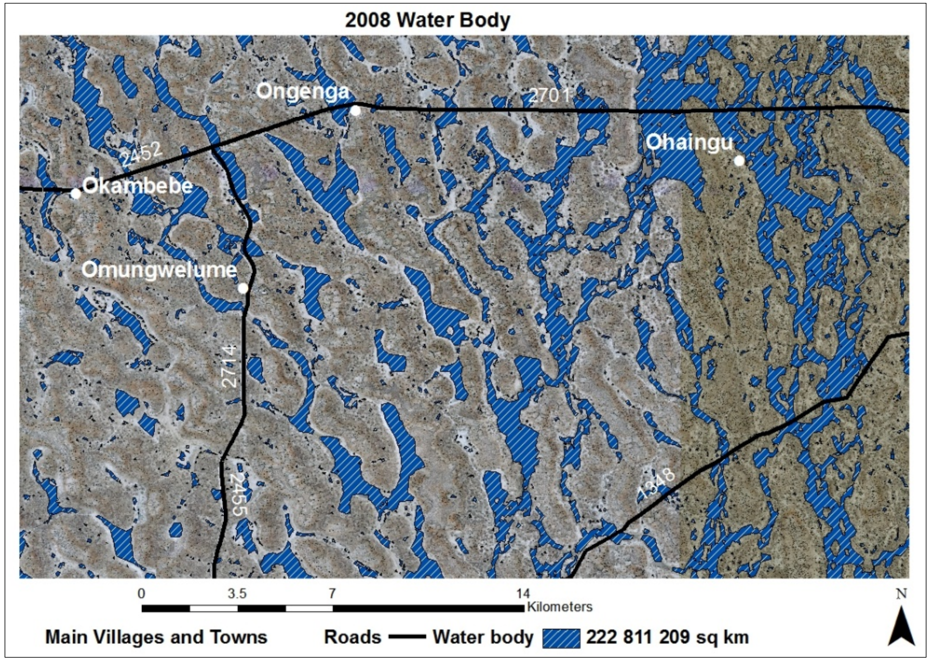
Figure 3: Areas that were delineated as water bodies and the number of homesteads covered by the water area.



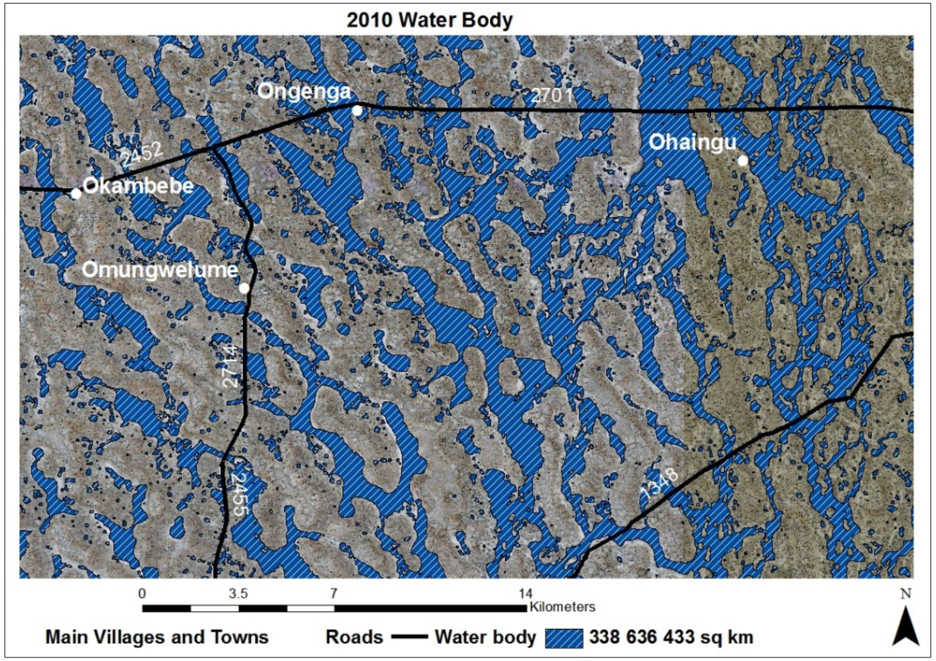
Map 5: 2003 water bodies, which can be said is the common flood areas



Map 6: 2005 water bodies, slightly more than the 2003 water bodies



Map 7: 2008 water bodies, showing an increase toward the north east

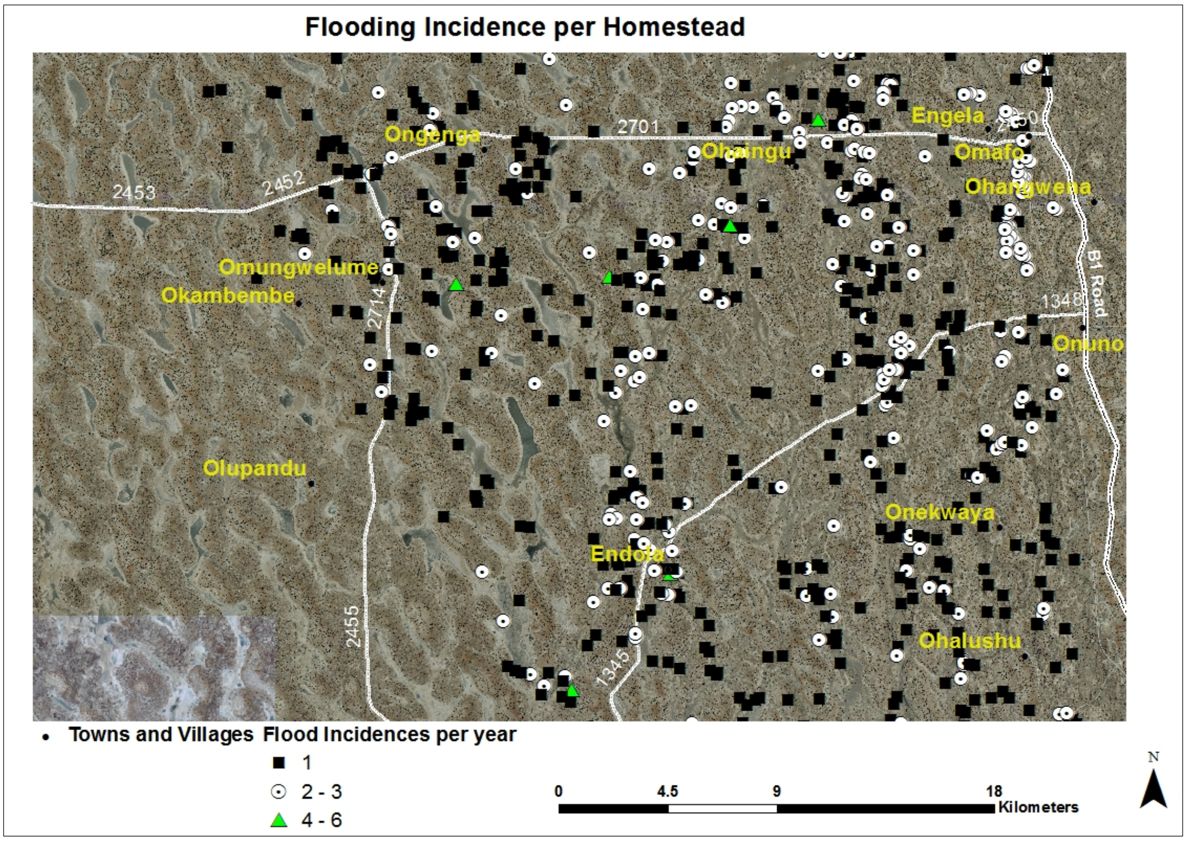


Map 8: 2010 water bodies, showing an increase toward the east

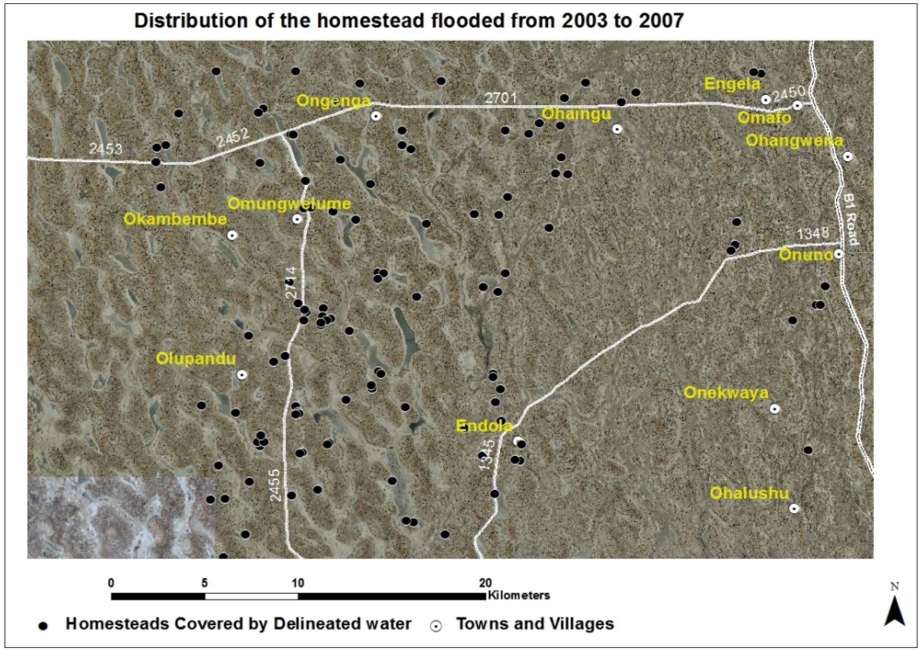
6.2 DISTRIBUTION OF THE FLOODED HOMESTEADS AND FLOOD OCCURRENCES

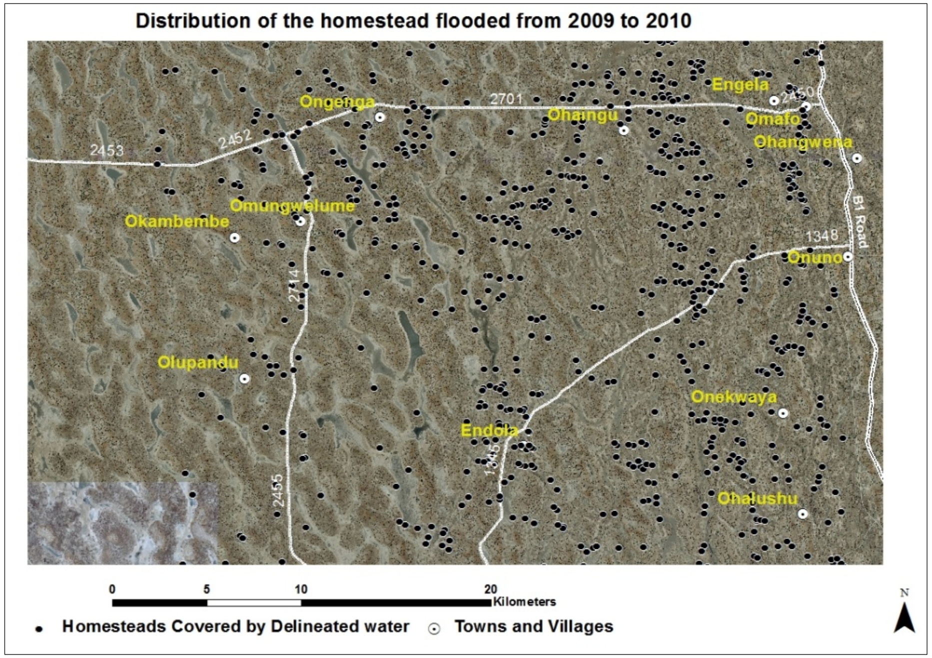
Based on the visual presentation the flooded homesteads are mostly distributed toward the west from year 2003 to 2007 *Map 11*. As from year 2008 the number of homesteads increased significantly toward the east shown in *Map 10*.

The frequent numbers of a homestead flooded recorded was 2 and 3 times see *Map 9*. Nearly all the homesteads flooded between 2-3 times are situated at the northeast of the study area, most of them flooded mostly as from 2008. While, those homesteads that were flooded only ones are located evenly throughout the study area, see *Map 9*.



Map 9: Flood frequency on homesteads for the past from 2003 to 2010





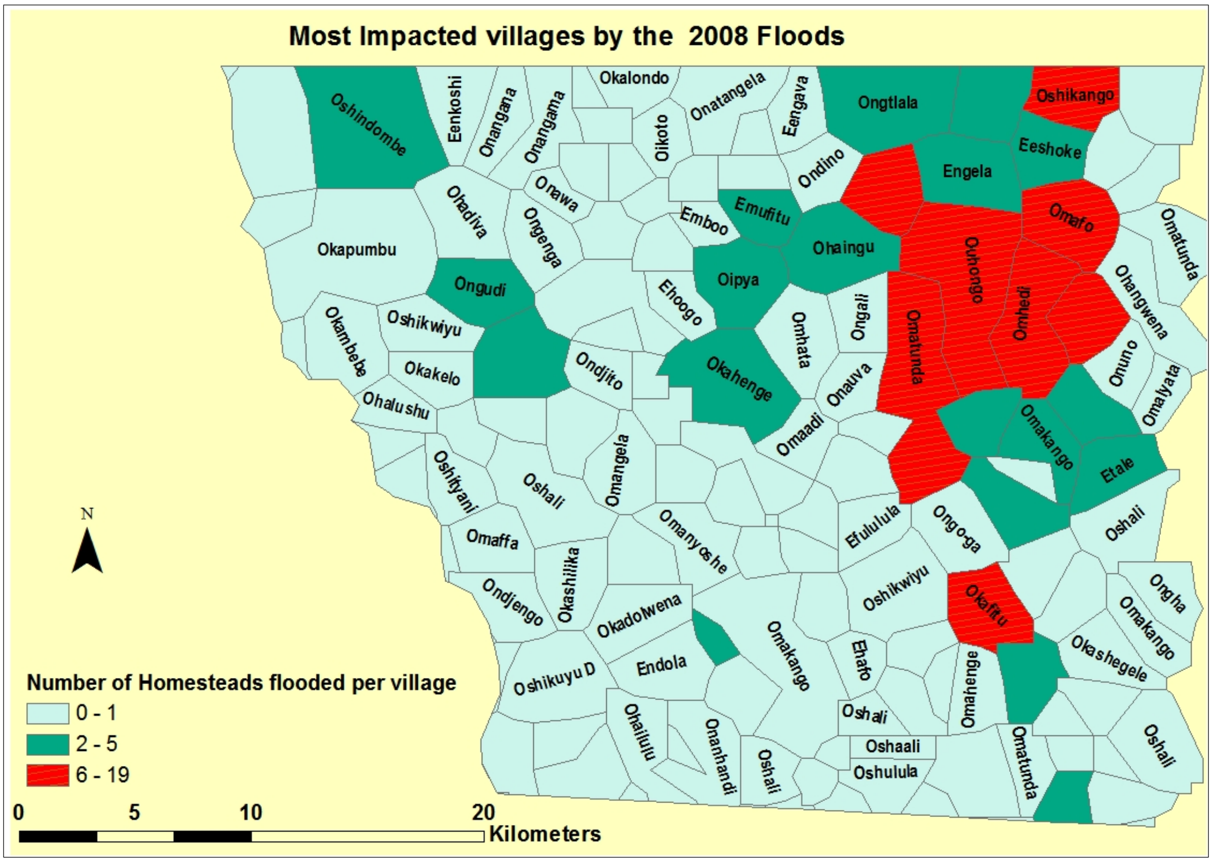
Map 11: Distribution of the homestead flooded from 2003 to 2007

Map 10: Distribution of the flooded homesteads from 2008 to 2009

6.3 IMPACTED VILLAGES

6.3.1 Impacted Villages by the 2008 Floods

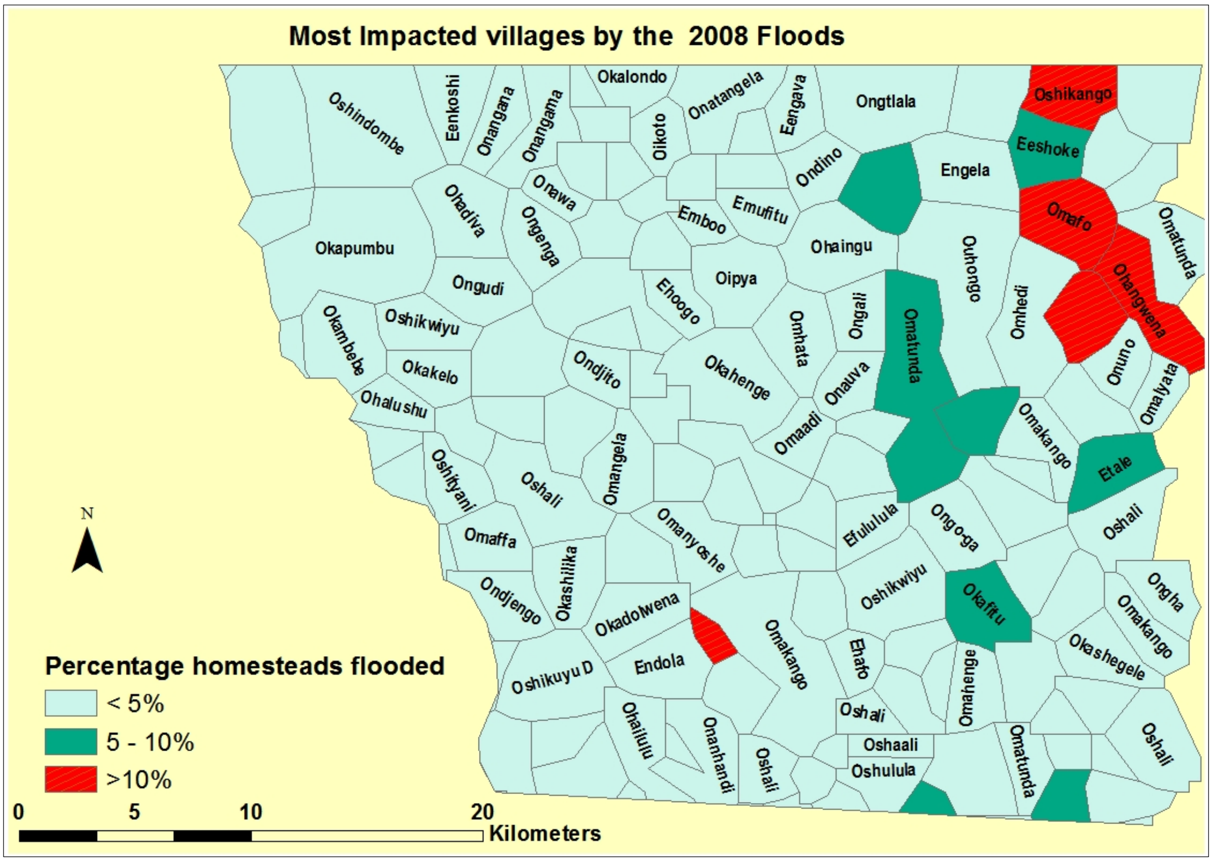
The villages that are impacted the year 2008 flood water are situated on the northeast of the study area *Map 12*. Most of the impacted villages have between 2-5 flooded homesteads. Eight villages have 6-9 flooded homesteads *Map 12*, which is the highest. These are namely Oshikango, Omatunda, and Omafo. The villages that have more than 2 flooded homesteads are 15. The total numbers of impacted villages that have more than 2 flooded homesteads are 15.



Map 12: 2008 Impacted villages based on the number of flooded homesteads

Percentage of flooded homestead per village

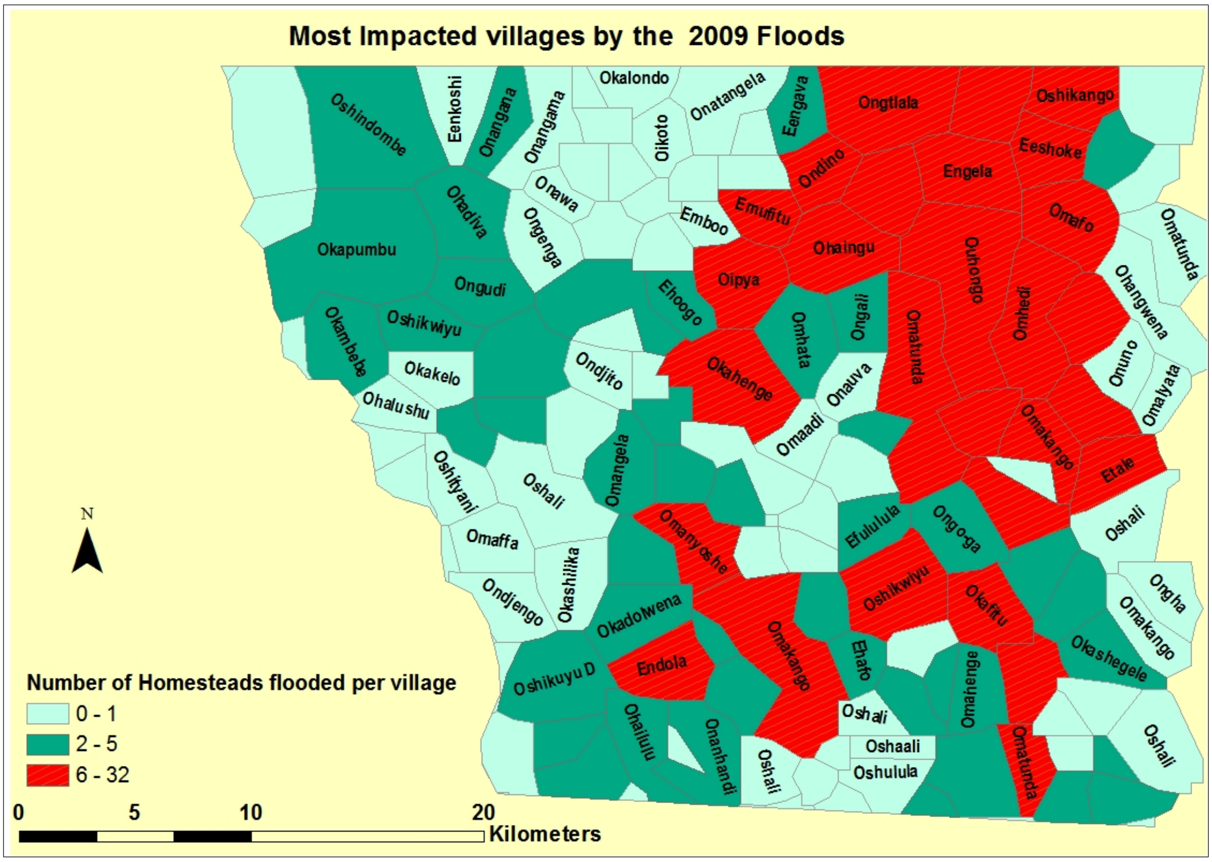
Most of the villages fall within the low impacted category, were only less than 5% of the total homesteads are affected. Only 7 villages fall within this medium impact category see *Map 13*. Those villages that fall within the significantly impacted category are 5 namely Oshikango, Omafo and Ohangwena see *Map 13*. These villages have more than 10% of their total homesteads flooded in 2008, and they are situated on the northeast.



Map 13: Most impacted villages in 2008 based on the percentage number of flooded against the number of homestead in the village

6.3.2 Impacted villages by the 2009 floods

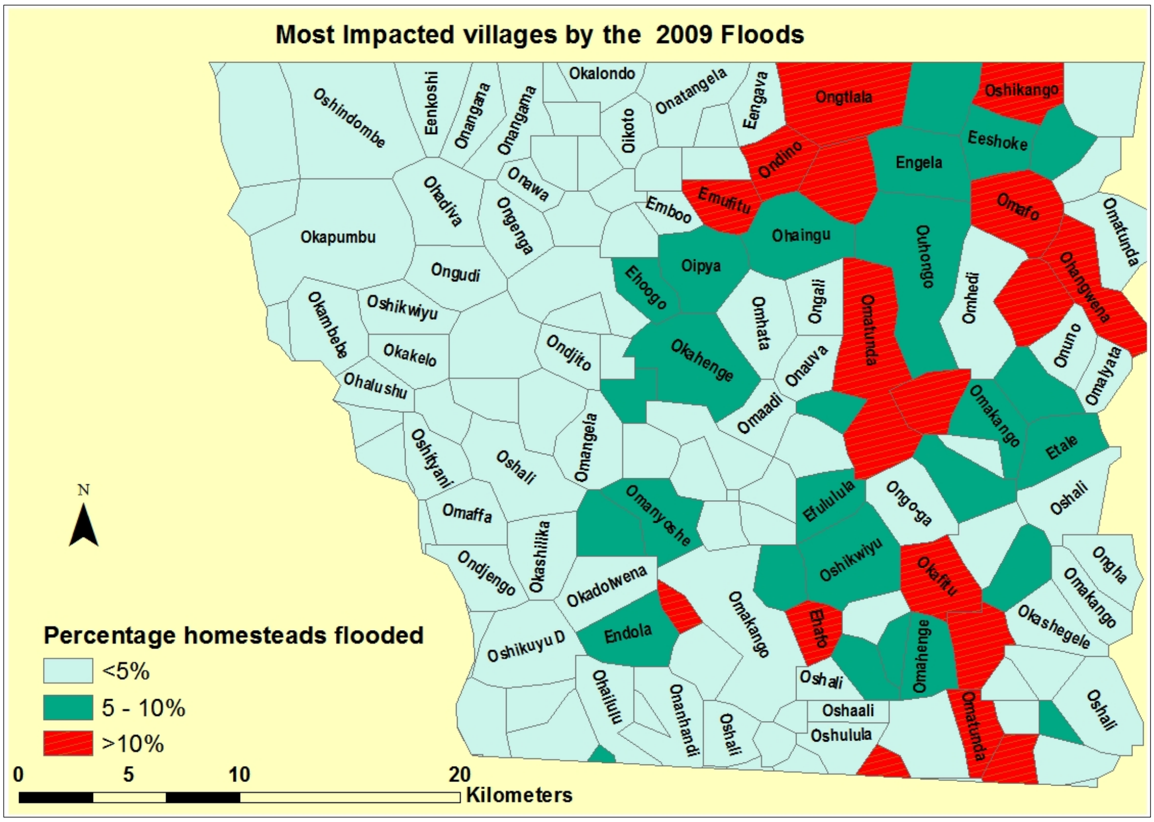
The impacted villages are situated toward the northeast of the study area, *Map 14*. These villages have 6 to 32 flooded homesteads. While, the other affected villages have 4 to 10 flooded homesteads. The villages with the most flooded homesteads are namely Omatunda, Okafitu, Omafo and Okahenge amongst others see *Map 14* . The 2009 floods have the highest number of flooded homesteads per village compared to year 2008 and 2010. The total numbers of impacted villages that have more than 2 flooded homesteads are 32.



Map 14: 2009 Impacted villages based on number of flooded homesteads

Percentage of flooded homestead per village

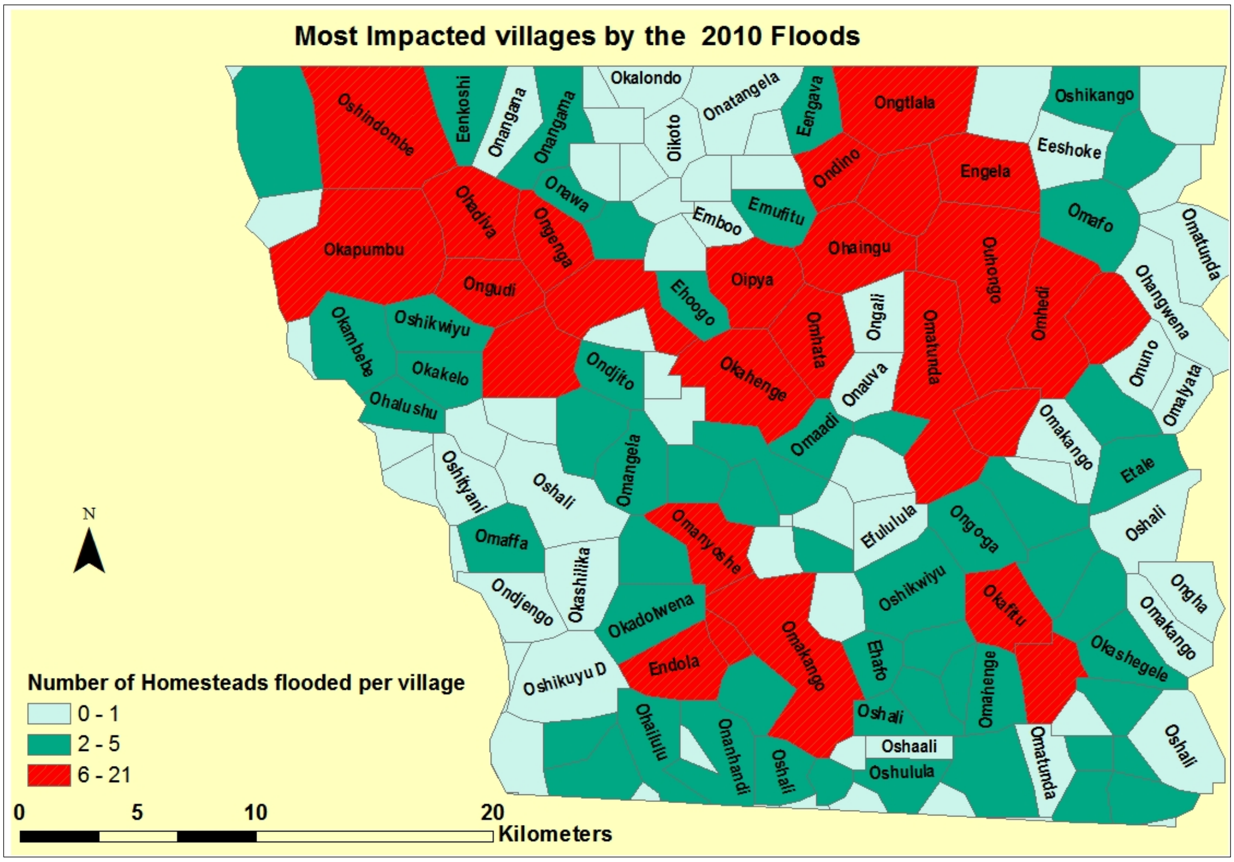
Based the percentage of flooded homestead per village, most villages have less than 5% of the homesteads flooded *Map 15*. The significantly impacted villages increased compared to year 2008, and they are mostly situated on the east. These are villages such as Omatunda, Omafo to mention a few, see *Map 15*. An increase in the medium impacted villages is also apparent on the east compared to year 2008. These are villages such as Engela Ouhongo, which have more than 5% and less than 10% flooded homesteads *Map 15*.



Map 15: Most impacted villages in 2009 based on the percentage number of flooded against the number of homestead in the village

6.3.3 Impacted Villages by the 2010 floods

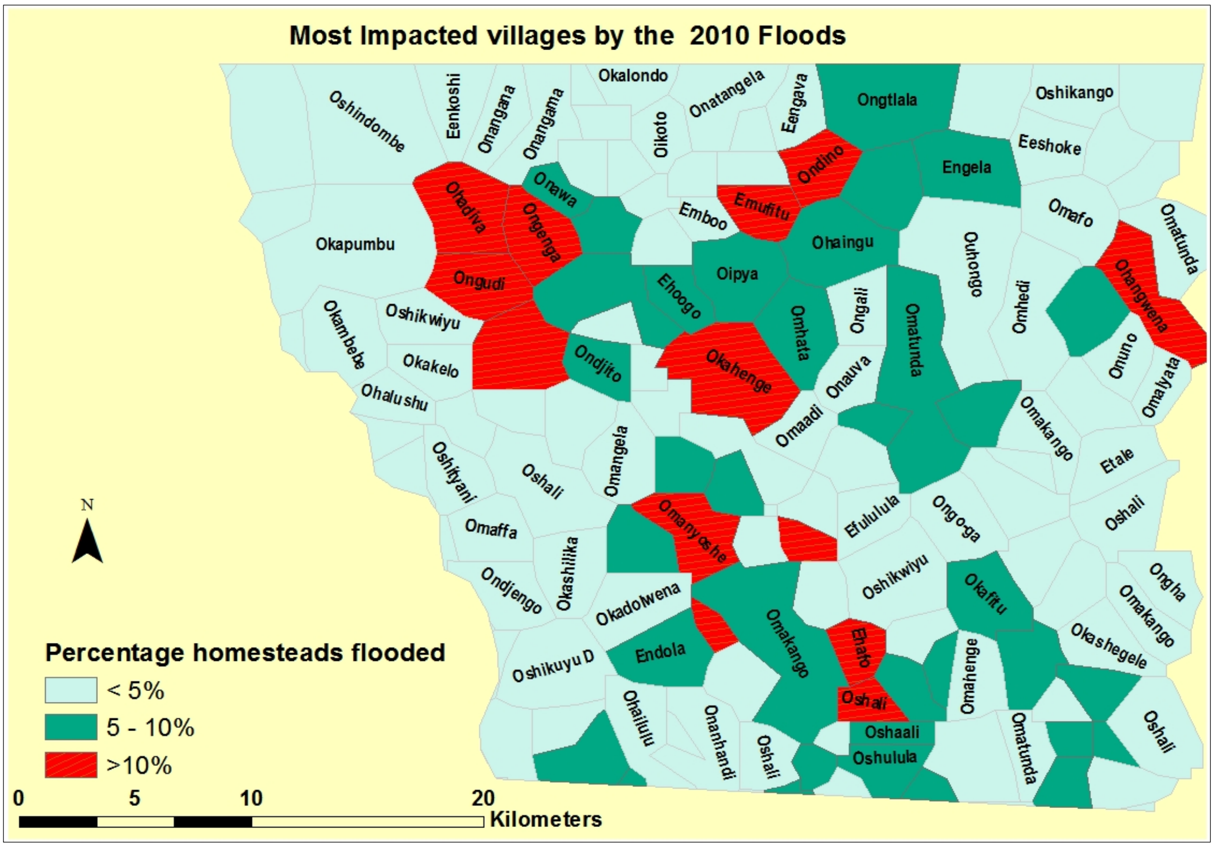
Based on the 2010 *Oshana* flood water, the impacted villages are distributed evenly within the area see *Map 16*. The villages 6 to 21 flooded homesteads are situated on the north of the study area *Map 16*. While the second affected villages that have 2 to 5 flooded homesteads, are distributed unevenly in the area. The villages with high number of flooded homesteads are mainly Omakango, Engela, Oshidombe, Ohandiwa, Ongudhi, and Omatunda *Map 16*.



Map 16: 2010 Impacted villages based on the number of flooded homesteads

Percentage of flooded homestead per village

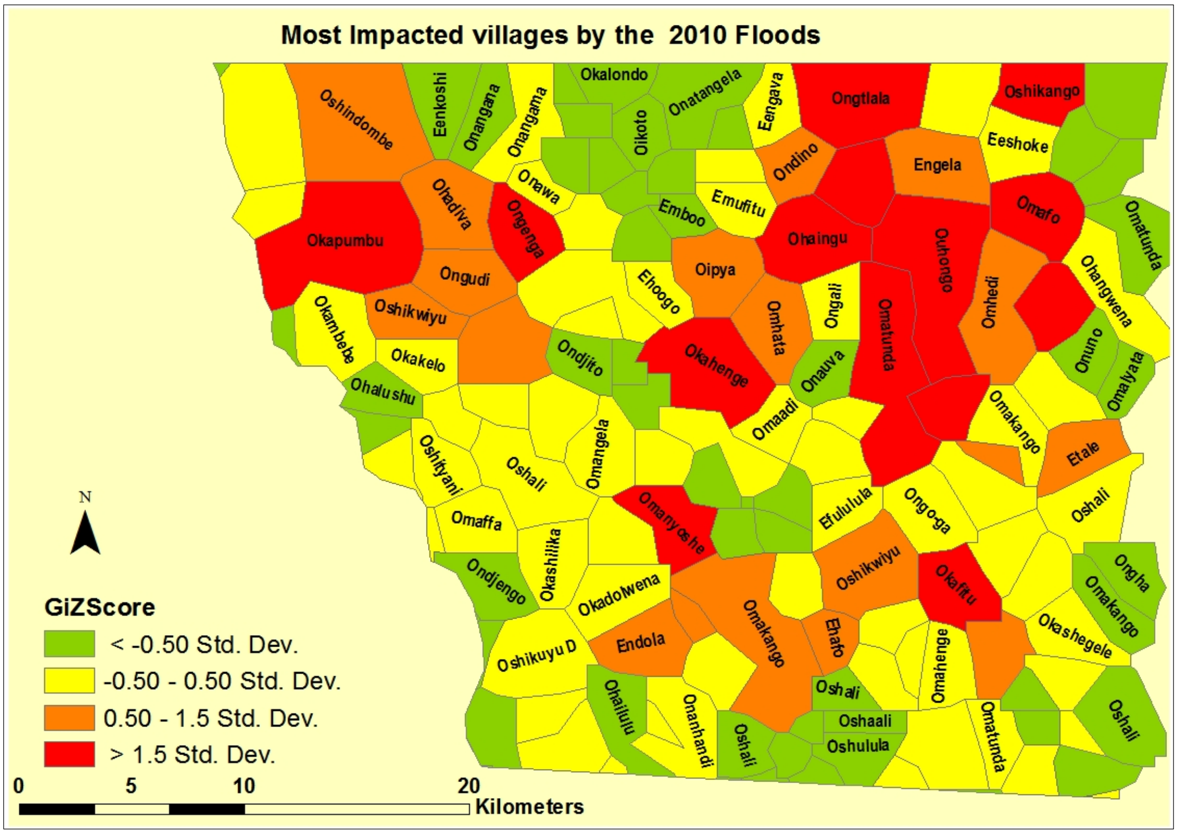
Based on the 2010 floods, 13 villages are significantly impacted and they are situated centrally and northwest. These are villages such as Ohandiwa, Ongudhi, and Ongenga, to mention but few, see *Map 17*. While, other villages such as Engela Onawa, Okahenge have between 5% to 10% homesteads flooded, and they are situated around the centre of the study area.



Map 17: Most impacted villages in 2010 based on the percentage number of flooded against the number of homestead in the village

6.4 SPATIAL CLUSTER ANALYSIS OF THE IMPACTED VILLAGES

The Gi* statistic returned for each feature in the dataset is GiZ-Score, in which the positive GiZ-Score or larger shows intense clustering of high values. While, the smaller the z-score means there is a clustering of low values. The GiZ-Score results displayed on the map based on the Standard Deviation (STD Dev) classification.



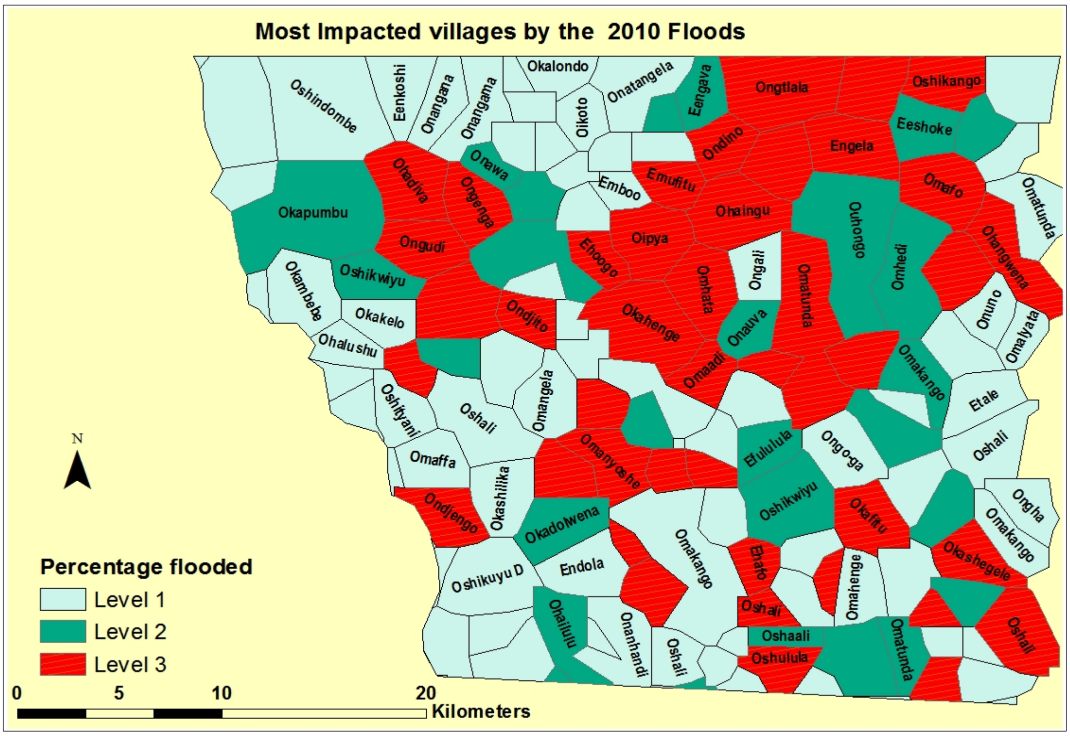
Map 18 Cluster of the flooded homesteads based on villages with highest number of flooded homesteads

Two areas can be said to have clusters of the most affected villages, they are areas toward the northwest, and northeast, see *Map 18*. These areas have GiZ-Score between the 0.50 STD Div and higher, thus they have a high number of flooded homesteads within 1500m surrounding, see *Map 18*. While the other areas have GiZ-Score of 1.50 STD Dev and high represents villages highest affected. These villages are Omakango, Ohandiwa, Ongudhi and Ongenga on the northwest, while on the northeast are villages such as Omatunda, Okandombe, Ongudhi, Omafo, Engela, and Ohaingu, see *Map 18*.

6.5 FLOOD HAZARD VILLAGES

The flood hazard villages were created based on the combined number of impacted homesteads per village as from 2003 to 2010 floods. Based on Map 19, the result is as fallows;

- High hazard (level 1), which consists of the highest impacted villages, includes villages such as Omakango, Ohandiwa, Ongudhi and Omatunda, Ouhongo, Okahange and Omafo, see *Map 19*.
- Medium hazard (level 2), which consist of villages that have less than 10 flooded homesteads. These villages are displayed in blue, on *Map 19.*
- Low hazard Level 3 consists of villages that have 2 or 1 flooded homesteads. Thus, these villages were not largely affected by the *Oshana* floods.



Map 19: Flood Hazard Villages, showing those villages vulnerable to floods based on the past 10 years

7 DISCUSSIONS

7.1 *OSHANA* WATER AREA CHANGES AND IMPACTED HOMESTEADS

The delineated water body shows a visual increase and increase in area in sq km *Figure 3*. A noticeable visual increase is between year 2003, *Map 5* and year 2008 and 2010 *Map 7* and *Map 8*. Before 2008, the water body was mainly at the west and central of the study area, *Map 5*. However, as from 2008 the water bodies were detected toward the northeast and the east side of the study area (*Map 7, Map 8*), this also increased the number of flooded homesteads within the area, and most specifically within the northeast area. Based on the area covered by the water, *Figure 3*, the highest increase was from year 2007 to 2008, which increased seven times, with year 2010 having the highest water coverage of 35000 sq km. The increase in the water area from 2008 also caused an increase in the flooded homesteads by 60%, *Figure 3* and this is highlights why most homesteads were flooded twice or three times, *Map 9*. As from 2003 to 2007 less than 1% of the homesteads in the area were impacted by the floods each year. However, as from 2008, more than 350 homesteads were impacted, which is 3% of total homesteads in the study area, with year 2010 with the highest number of flooded homesteads.

Based on visual assessment, the delineated *Oshana* flood waters overlay with the *Oshana* floodplains areas. However, even after filtering, some single water pixels were still apparent. This could be the small water ponds within the study area. Based on the error- matrix accuracy assessment the MNDWI method effectively delineated the water body. The lowest overall accuracy was 69% while the highest was 82%. The producer accuracy and user accuracy for both years for the none-flood homestead was above 80%, thus none-flooded homesteads were mostly categorized as none-flooded homesteads. Based on this, it was deemed that the delineated water would be effective enough to be used in extraction of flooded homesteads.

7.1.1 Possible Errors

The delineated *Oshana* flood water and number of flooded homesteads were hampered mainly by the fact that it was not known whether the images used represent the highest flood peak or not. As a result it could not be concluded which year had the highest and the lowest water area and flooded homesteads. For instance the images used for year 2010 had the highest *Oshana* flood water area (*Map 8*) and most flooded homesteads (*Figure 3*). Yet, it was confirmed that the highest and most damaging flood since 2003 in the Cuvelai was in 2009(*confirmed by Mr Van Langenhove Guido, personal communication).* In addition, the highest rainfalls in this area since 2003 was recorded in 2009 February month see *Figure 1.*

On the technical point of view, conversion of the water polygon feature might reduce the detected water or increase the extent it extent, as a result the number of flooded homestead might increases or decrease.

7.2 IMPACTED VILLAGES

The villages with the highest number of flooded homesteads for year 2008 and 2009 are both situated toward the north east of the study area; see *Map 12* and *Map 14.* Moreover, based on the delineated *oshana* water body this area showed more water bodies as from year 2008, see *Map 7*. Even thought year 2010 has most flooded homesteads in this area, year 2009 has the highest number of flooded homesteads per village, which were 32 in Omatunda village. The year 2010 on the other hand, has unevenly distributed flooded homesteads within the study area *Map 16,* compared to year 2008 and 2009.

The significantly impacted villages are toward the north and north east, for both year 2008 and 2009; see *Map 13* and *Map 15.* However, even thought year 2010 have the highest number of flooded homesteads; year 2009 has more significantly impacted villages *Map 15* and Map 17. Most of the significantly impacted villages are situated toward the northeast, for both year 2008 and 2009 see *Map 13*and *Map 15.* The year 2010 on the other hand, has unevenly distribution of the significantly impacted villages within the study area *Map 16* and *Map 17* compared to year 2008 and 2009. Villages impacted in both years were for e.g. Okahange, Ongudhi, Ouhungo, Omatunda, and Ohaingu. However, the highest impacted village was Omatunda, with 14% of homesteads impacted by the floods, which 32 homesteads out of 228 affected in 2009.

7.3 CLUSTER AFFECTED VILLAGES AND HAZARD LEVELS

The highest cluster of villages is toward the north east of the study area. However, cluster of 5 villages is apparent toward the north west of the study area, see *Map 18.* The impacted villages that are clustered together can indicate either that they have high homesteads density or they are close to one of the streams flows.

Based on the hazard level, 19% of the villages are in high hazard level, thus they have the highest number of flooded homesteads. Compared to other villages these villages are vulnerable to flooding, e.g. villages such as Okandombe, Ongudhi Ohandiwa Omafo, Engela and Ohaingu, see *Map 19*. The combination of the cluster and hazard village's analysis, one can know which area mostly affected and further study these villages on a local scale, to assess why they are highly impacted than others. One noticeable pattern from the results is that the eastern side only started flooding as from 2008 *Map 8*. Moreover, it is also the area with high cluster and having the majority of villages in a classified as high hazard village.

7.3.1 Usefulness and Drawbacks of the impacted village assessments

The method of identifying the flooded homestead can be used to answer questions during the flooding or post flooding for pre-flooding planning in terms of understanding which areas are more prone to floods? Which areas need more mitigation strategies to cater for the affected people flooded? Considering the availability of the satellite imagery, the method can be adopted during pre and post flooding, to determine most impacted areas and potentially affected areas. The method used to assess the impacted villages can be used to identify which villages have highest number of flooded homesteads, while calculating the percentage of flooded homesteads per village would cater for identifying which villages are highly impacted based on the number of homesteads in the village.

The main disadvantage or limitation of the results presented here is that, the number of homesteads flooded per villages or a relative number was unknown to validate the result. Further, it depends mainly on satellite imagery, thus during the floods, satellite imagery might not be available on time. In addition, satellite imagery might be hampered by cloud covers that might make the assessment cumbersome, also the imagery might not represent flood peaks. Alternatively imaging radar can be used to detect water bodies to ease the problem of clouds. Since radar remote sensing data can be used to map areas that have persistent cloud covers (Lillesand, et al., 2008).

8 CONCLUSIONS AND RECOMMENDATIONS

The *Oshana* flood water areas show major changes for the past 10 years. Major changes in the *Oshana* flood water areas are noticeable as from year 2008 to 2010, specifically the introduction of more water towards the east side of the flood area. The number of flooded homesteads increased significantly from 2003 to 2008. However, the drawback is that the number of flooded homesteads might be under represented.

The common impacted villages for all years were mainly Okahange, Ongudhi, Ouhungo, Omatunda, and Ohaingu. However, the highest impacted village was Omatunda, with 19% of homesteads impacted by the floods (i.e. 32 homesteads out of 228). On cluster analysis, the most affected villages cluster toward the northeast and northwest of the study area. On the hazard villages, about 19% of the villages are in hazard level 1. The villages in the high hazard levels are such as Okahange, Ongudhi, Ouhungo, Omatunda, and Ohaingu. These are villages that can be said to be are vulnerable to flooding more than other flooded villages.

The method to assess and identify the impacted areas can be used mainly for post and pre-flood event to identify potentially affected areas and the number of impacted villages and homesteads. However, it can also be used during flooding or few days after flooding, depending on the availability of the satellite imagery. The main drawback of this method is that it does not cater for alleviation of impact before the flood strikes to reduce the impact on time, or allow for evacuation on time. Thus, further studies still need to be conducted to identify the flood frequency and trend, etc, in order to have a timely flood forecast that might significantly reduce the impact. Nonetheless, there are hardly any studies done on the Cuvelai floods, these results can still be used to allocate small scale projects on the most impacted villages by the past floods.

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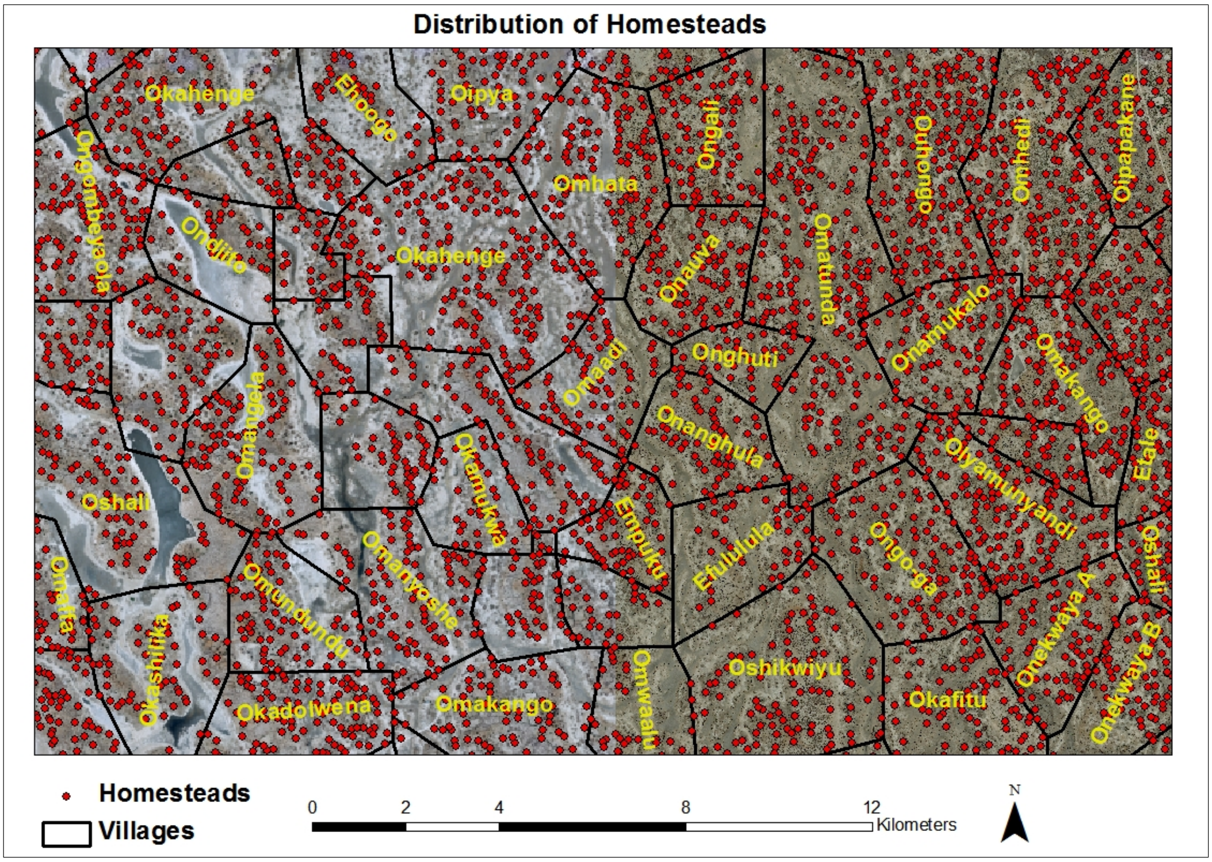
APPENDIX I IMAGERY PARAMETERS

Year	Date captured	Time	Cloud Covers%	Quality
2000	2000/04/29	8:54:02.4467929Z	0	9
2001	N/A	N/A	N/A	9
2002	N/A	N/A	N/A	9
2003	2003/04/22	08:50:27.4970079Z	0	9
2004	2004/04/24	08:50:51.9422476Z	1%	9
2005	2005/04/11	08:51:19.7969565Z	0	9
2006	2006/04/30	08:51:46.6663582Z	15%	9
2007	2007/04/01	08:52:16.1891806Z	0	9
2008	2008/04/03	08:51:52.8428051Z	14%	9
2009	2009/03/21	08:51:56.0898954Z	0	9
2010	2010/04/09	08:53:56.9578697Z	1%	9

APPENDIX II DISTRIBUTION OF HOMESTEADS

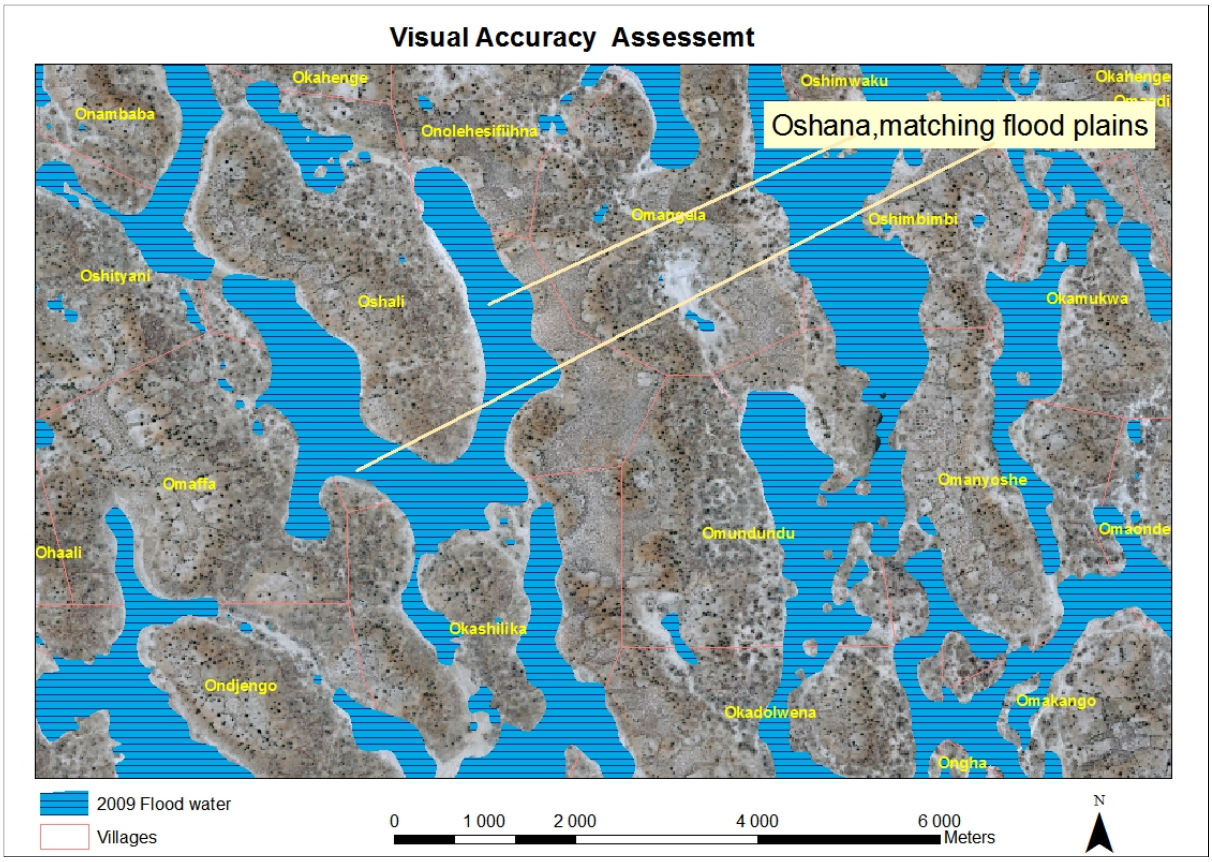


Distribution of flooded homesteads within the study area

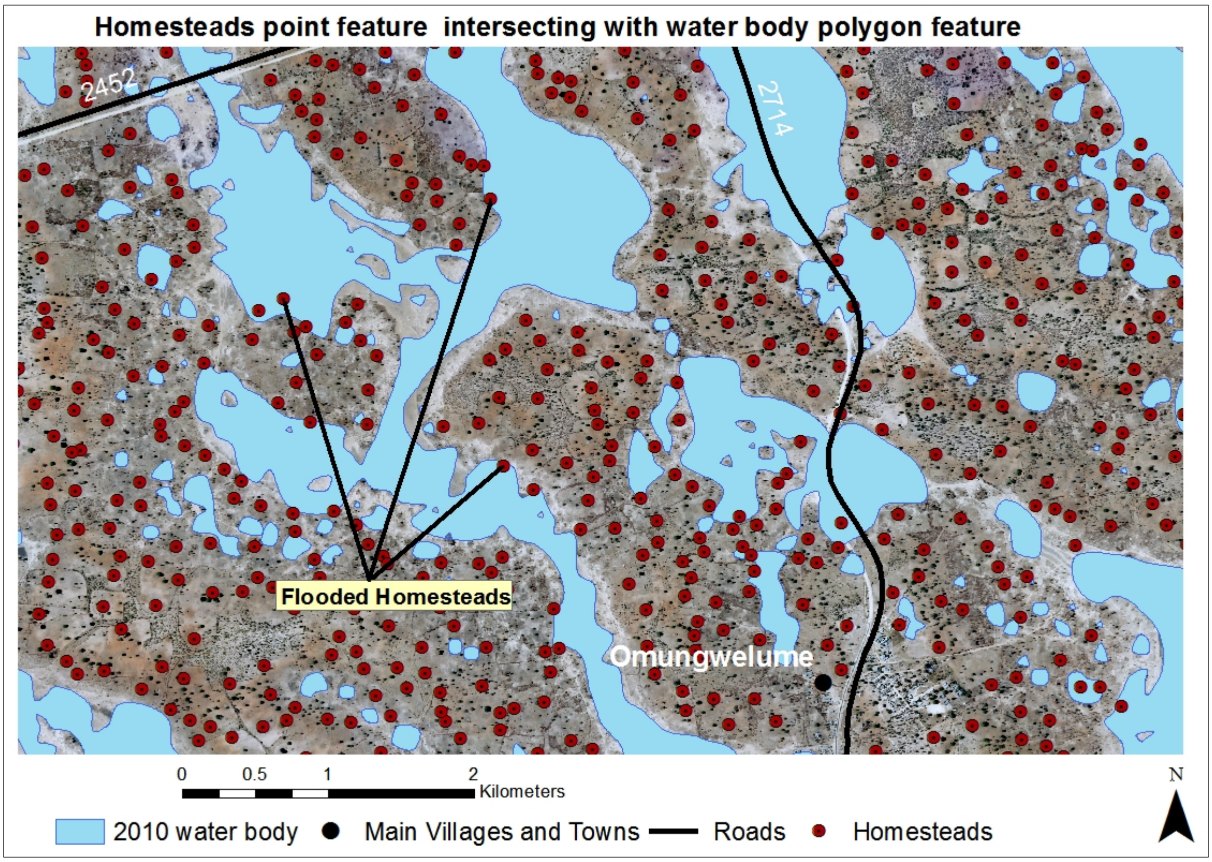
APPENDIX III ACCURACY ASSESSMENT

The 2008, 2009, and 2010 overall accuracy was 80%, 69%, and 82% respectively. While, the producer and user accuracy for homestead flooded and not flooded for each year was above 80%.

	2008	**2009**	**2010**
Producer Accuracy Flooded	46%	50%	54%
Producer Accuracy Not flooded	94%	88%	91%
User Accuracy Flooded	75%	60%	70%
User Accuracy not Flooded	81%	82%	91%



APPENDIX IV HOMESTEADS INTERSECTION WITH WATER BODIES



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