ASSESSMENT OF FLOODWATER HARVESTING INFRASTRUCTURES IN THE NAMIBIAN CUVELAI-ETOSHA BASIN

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Declaration

I, Emeritha Niipare hereby declare that this research project is the result of my own investigation and research and that it has not been submitted in part or full for any other degree or to any other institution and the work of other researchers and authors have been herein acknowledged accordingly.

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Student signature **Date**

Dedication

I dedicate my research project to God, my dearest family and friends. To God- His grace has been sufficient for me, His love and kindness has carried me through. All glory belongs to Him! To my greatest motivator, my father Leopold Niipare- it is because of his coaching, upbringing and mentorship that I have come this far. To my loving mother, Gertrud Shivolo- Thank you for your love, support and encouragement. Your life’s journey gave me the inspiration and determination not to give up. I was content and at peace knowing you were praying for me. To my brothers, sisters and friends who shared their words of advice and encouragement to finish this study.

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Abstract

The Cuvelai-Etosha Basin lies in north-central Namibia and due to the prevailing climatic situation, the basin is dominated by strong seasonal and annual variations of either very dry conditions with drought or heavy flooding in certain years.

A growing population in the Cuvelai-Etosha Basin has resulted in increased demand for water for daily use and agricultural activities. Floodwater Harvesting Infrastructures are considered to be a more effective way to solve those problems. Hence the current status of the initiatives taken to harvest floodwater for use in the dry seasons needs to be determined by means of remote sensing, secondary data and field validation.

The main objective of the study was to assess the condition and performance of Floodwater Harvesting Infrastructures in the Cuvelai-Etosha Basin. The Ministry of Agriculture, Water and Forestry constructed 34 earth dams in this Basin from 2008 to 2011. Out of these newly constructed earth dams, 18 were randomly selected for the study. The research design was based on using both qualitative and quantitative data on a completely randomised basis. Sentinel data was used to identify the water bodies by means of remote sensing. Information was gathered by means of structured interviews from the locals or people acquainted with the sites. The results from the interviews taken among 96% of the participants showed that the highest usage of earth dams is livestock watering while few people use them for irrigation purposes.

Due to sedimentation in the earth dams, depth has reduced and surficial area has increased; hence the dams can no longer retain the quality and quantity of water they were designed for. In conclusion, the method developed from GIS successfully identified 94% of the existing earth dams.

Key Words: earth dams, burrow pits, flood water harvesting, remote sensing, sentinel images.

Table of Contents

List of Figures

List of Tables

List of abbreviations

CEB Cuvelai-Etosha Basin

ESA European Space Agency

ENVI Environment for Visualizing Images

GPS Global Positioning System

RWH Rain Water Harvesting

SASSCAL The Southern African Science Service Centre for Climate Change and Adaptive Land Management

UNICEF United Nations International Children's Emergency Fund

USGS United States Geological Survey

WNDWI A Weighted Normalized Difference Water Index

1. Introduction

1.1 Orientation of the study

Namibia is the most arid country south of the Sahara with little and unpredictable rainfall with perennial rivers which are found only on its borders. Rising temperatures and shorter rainfall events are predicted as a result of climate change, hence reducing water availability. Furthermore, monitoring of water resources is taking place but this is not integrated to provide a great picture of water resources and their management [1].

In the northern part of the country, the growing population in the Cuvelai Basin is expected to increase the pressure on soil and water resources due to a higher demand of water for agricultural, commercial and domestic uses [2]. By integrating social-ecological as well as technical aspects, Integrated Water Resource Management may be instrumental in mitigating these problems.

Due to the climatic situation in the Cuvelai region, the basin is dominated by strong seasonal and annual variations of either very dry conditions with drought, wetter situations during normal rainy season or heavy flooding in certain years [3].

Local heavy rains in the Namibian part of the Cuvelai usually cause localised flooding, while prevalent flooding is usually due to extensive heavy rain in higher altitude and higher rainfall areas upstream in Angola. Typically, the surface waters are short-lived, evaporating or seeping away after weeks or months, depending on the depth of the water and permeability of the soils [4].

Dams are essential infrastructure used for flow regulations in rivers and for harvesting floodwater in shallow streams. In Namibia, the idea of dams and water storage infrastructure started in late 1920’s during the famous “Famine of Dams”, when thousands of people, especially women and children were given food in return for their labour in excavating shallow dams [5]. These authors further state that more dams were built over the years and in 1971 the Department of Water Affairs had excavated 320 dams across the Cuvelai Basin with a storage capacity of 30,000 cubic meters each, designed to be filled with water flowing down the iishana [5].

During the period of 2008 to 2011, the Ministry of Agriculture, Water and Forestry constructed about 34 Earth dams in the Namibian Cuvelai-Etosha Basin, whereby 22 are in Iishana sub-basin, 7 in Olushandja sub-basin and 5 in Niipele sub-basin (2 under survey and design). All these earth dams were designed at 50m x 50m and 3.7m deep. The actual construction differed slightly from the design. Currently, the people of the Cuvelai-Iishana sub-basin face major challenges regarding sustainable water supply and its associated management [6].

1.2 Problem Statement

Recently, several new efforts have been made to rekindle the idea and use of dams, mainly for livestock [5]. This gave birth to the floodwater-harvesting scheme. The daily consumption of water for domestic stock on the Namibian side of the Cuvelai-Etosha Basin is about 35 million litres per day, excluding horses and donkeys [7]. In order for this amount of water to be available for livestock and agricultural practices in the region, earth-dams were constructed. Some activities such as road construction in the basin leave burrow pits, which have helped the communities to harvest more water than the excavated earth-dams or alternatively use hand-dug wells. Water crisis and agricultural activities are the biggest problem and challenges faced by the people in the Cuvelai-Etosha Basin due to the increase in population. Floodwater Harvesting Infrastructures are considered to be a more effective way to solve those problems. Hence the current status of the initiatives taken to harvest floodwater for use in the dry seasons needs to be determined. In addition, there is insufficient information on the efficiency and condition of existing water-harvesting infrastructures. A study was therefore done to assess the status of the existing floodwater harvesting infrastructures in the Cuvelai-Etosha Basin using remote sensing, secondary data and field validation.

1.3 Objectives

The main objective of the study was to assess the condition and performance of floodwater harvesting infrastructures in the Cuvelai-Etosha Basin.

To achieve the main objective, the following specific objectives were implemented:

1. To use an existing Remote Sensing-based method for mapping out existing water harvesting infrastructure in the Cuvelai-Etosha Basin from Sentinel Satellite Images.
2. To compare/evaluate the water harvesting infrastructure properties (surficial area) derived from satellite imagery with datasets derived from ground truthing.
3. To determine the communities' (human and agricultural) beneficial extent from these infrastructures.

1.4 Hypothesis

- The null hypothesis states that there is no significant difference in the sizes/areas of the floodwater harvesting infrastructures as obtained from Remote Sensing compared to those from field observations at a confidence interval of 95%.
- The alternative hypothesis states that there is a significant difference in the sizes/areas of the floodwater harvesting infrastructures as obtained from Remote Sensing compared to those from field observations.

1.5 Significance of the study

The study mapped out most of the existing floodwater-harvesting sites and assessed if they are serving the initial purpose for which they were constructed. The study also determined if the floodwater-harvesting infrastructures are still fully functional, and if there is a need to rehabilitate some of them to be fully functional for sustainable water use in the Cuvelai-Etosha Basin.

Considering the available literature, there is no study found that assesses the status of the floodwater-harvesting infrastructures in the Cuvelai Basin with reference to their location in order to capture substantial amount of flow for use over longer periods of time. This study therefore covered this aspect.

1.6 Limitations of the study

The study was limited in many respects and one of the limitations was time. As the research was carried out within the Cuvelai-Etosha Basin due to the spatial extent of the area it was impossible to visit all of the dams. In addition, during the times that the dams were visited there were few people near the study areas and due to time, I could not visit the households for interviews.

When the cloud cover is high, this affects the extraction of water bodies from Satellite images, making certain objects to be recognised as something it is not (shadows or dark areas). Another limitation was accessibility to these water bodies and how dangerous they were to take measurements.

1.7 Delimitations of the study

As delimitation, the study was limited to the Namibian side of the Cuvelai-Etosha Basin only.

2. Literature Review

2.1 Rain and Flood water harvesting

Technologies used for rainwater harvesting such as solar-coupled desalination and artificial groundwater enrichment, rational water use and new ways of handling wastewater (waste water reuse, ecological sanitation) have been reported extensively [2]. Traditional floodwater harvesting infrastructures such as shallow hand dug wells or the deeper wells where a bucket is lowered on a rope to draw water lying 20-30 meters below the surface are also relevant. During the past two decades, the ways Namibian pastoralists manage water have changed drastically [8], while exercising water and land rights to maintain boreholes. An increasing number of scientists from numerous parts of the world are involved in developing practices for rainwater harvesting (RWH), which is used throughout urban areas all over the world [9], yet only some countries face water scarcity problems. The positive aspects, which encourage its use, is the easy setup, low maintenance and energy costs. These characteristics promote the adoption of rainwater-harvesting systems in rural and urban areas, mainly in arid climates, due to water scarcity [10]. According to [11], an advantage of effective harvesting rainwater is reduced pressure on public water supply systems which in most cases are not functional, due to logistics and inadequate infrastructure.

2.2 Development in rainwater harvesting techniques

Rainfall is a major component in any RWH system, and it can only function if a catchment receives sufficient rainwater to store. The identification of suitable sites and their technical design determines the success of rain water harvesting (RWH) systems [12]. Slope also plays a major role in the amounts of runoff and sedimentation, the velocity of water flow, and the amount of material needed to construct a channel. The most frequently applied socio-economic criteria were: distance to settlements, distance to streams, distance to roads, and cost. For most RWH techniques, rainfall (distribution and rain intensity over the year), soil type (texture and saturated hydraulic conductivity), and slope are the basic criteria that determine the technical suitability of a location [13].

According to the Department of Water Affairs, intensive development of water supply started with dam excavation and pump storage techniques in 1954 [14], whereby the excavated dams were built at an elevated area to prevent rainfall runoff water to flow in freely hence reducing siltation. Therefore, these dams had no inlet or outlet for rain water to flow in. Since the water was used for domestic, livestock watering and industrial purposes, there was a small-scale purification site at the dam. Several instructions for the construction of storage dams were given by [15], namely: 1) The surface area should be limited to a minimum, 2) The basin of the dam should be as deep as possible, 3) The location of the storage dam should be well protected against weather influences and 4) A direct passage of the special river (a temporarily river in the Namibian climate) should be avoided. This design is completely different from the new earth dam design, which has a larger surface area and not protected against any weather influences.

2.3 Advantages of rain water harvesting infrastructures

Implementation of water harvesting ponds reduce the sediment yield to the downstream environments [16]. The sediment load leaving the watershed before water harvesting implementation was in the thousands of metric tons; but after the implementation of water harvesting it reduced to hundreds of metric tons (Fig.2.1) [16]. As shown in figure 2.1, without water harvesting there was a high flow of water, and hence there was no sediment during the dry periods. While with water harvesting, there was low water flow and it transported minor sediment yield.

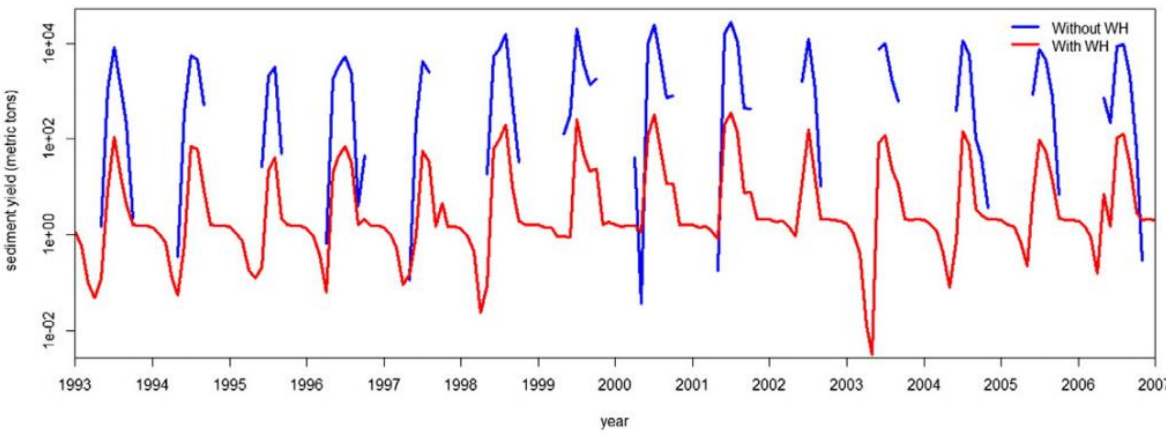

Figure 2.1 Sediment yield out of the watershed with and without water harvesting. [16] Lake Tana Basin, Ethiopia

The capacity of the water harvesting ponds reduces sediment yield to the downstream watersheds with advantages for both upstream and downstream. Water harvesting systems can prevent soil erosion and nutrient loss from upstream fields, thereby restoring soil fertility [16]. Water harvesting ponds can improve the water quality and avoid downstream ecological problems such as eutrophication of lakes and rivers. Moreover, they can reduce siltation of lakes and reservoirs downstream [16]. On the other hand, siltation of water harvesting ponds is discouraging [17] and there are challenges in removing sediments from these ponds to agricultural fields.

New water harvesting systems such as large storage containers common in the Cuvelai-Etosha Basin can be an open reservoir that is natural or hand dug to store water inflow from different drainage channels. The permeability of the pond can be improved by using a concrete or plastic lining and the sizes vary from 30 m^3 to 20,000 m^3 [18]. For simple infrastructures, water is extracted using a bucket, foot pump, or motor pump [19]. Cistern containers can be Man-made underground reservoirs of various shapes and geometry, storing water collected from a surface plot, capacity 5 m^3-100 m^3 [18, 20]. Some sand dam construction requires simple manual labour which can be done by the local communities, leading to a high community contribution in comparison to other systems [18]. Systems that use surface runoff as a water source are vulnerable to contamination, as animal droppings and other contaminants are flushed into the system. Sand dams are safe to a certain extent, because the water is stored in sand and extracted by a hand pump [22], which protects and purifies the water before use [21]. Open reservoirs are exposed to many factors such as the air/wind and sun, thus resulting in lower water quality. The entry point of water harvesting determines the quality of the water required either for humans and animals' consumption or irrigation water for crops [22]. Water harvesting is also a suitable strategy to adapt for water shortages caused by climate change [18].

2.4 Identification of water bodies by means of Remote Sensing

Waterbodies are one of the most common and important objects on earth surface. Remote sensing technology has been used in water resources assessment for more than two decades [23]. As remote sensing images are able to cover a large area with certain specific spatial, spectral and temporal resolutions, many waterbody extraction methods using remote sensing imagery have been proposed and widely used [24]. The methods can roughly be categorised as two types: classification methods and spectral feature analysis methods.

An important factor influencing reliability of Remote Sensing could be the type of environment within which water bodies are being identified [25]. There are at least two reasons for this. First, the spectral indicators of aquatic habitats are highly variable. This can be caused by variable chemistry of water, the shoreline vegetation, water blooms, and in shallow waters by the colouring of the bottom. Secondly, the reliability of methods could be negatively affected by the surroundings [26]. Vegetation, buildings and cloud cover could interfere with the right details being extracted from satellite images and at times fail to identify the right objects.

2.5 Processing images in Remote Sensing

Supervised classification of satellite images was carried out using ArcGIS and ENVI for multispectral satellite images from Landsat 7 with a resolution of 30 m [27] and simultaneously for multispectral satellite images from Sentinel 2 with a resolution of 10 m [28]. For the analysis of all images, a synthesis of the second, third, and fourth channels (i.e. the green, red and near-infrared zone) was used. The supervised maximum-likelihood classification method was followed [23]. Spectral profiles and experiments often show that small waterbodies and some land features water indices are misclassified [24]. In the study of [24], a new water index called weighted normalized difference water index (WNDWI) was proven to reduce those errors and improve the mapping accuracy of water bodies by using Landsat imagery. The same approach was adopted, although in this study Sentinel 2 images were used.

3. Methodology

3.1 Study Area

The Cuvelai-Etosha Basin lies in southern Angola and north-central Namibia and is composed of four sub-basins [2], namely: Niipele, Cuvelai-Iishana, Olushandja and Tsumeb on the Namibian side.

The amount of rainfall the Cuvelai-Etosha Basin receives decreases from 600 mm/a in the north-east to 300 mm/a in the west. In the same direction, potential evaporation increases from 2 700 to 3000 mm/a [29]. In Figure 3.1, spatial rainfall is interpolated using the IDW technique with stations that encompass at least 20 years with complete monthly data records in the period 1980–2009 (without any data gaps) [30]. During the study period (2019), the average rainfall was 109 mm recording the lowest rainfall in the basin in five years. 2019 was the worst drought in 90 years and was among the driest years of the Basin since 2014［31］.

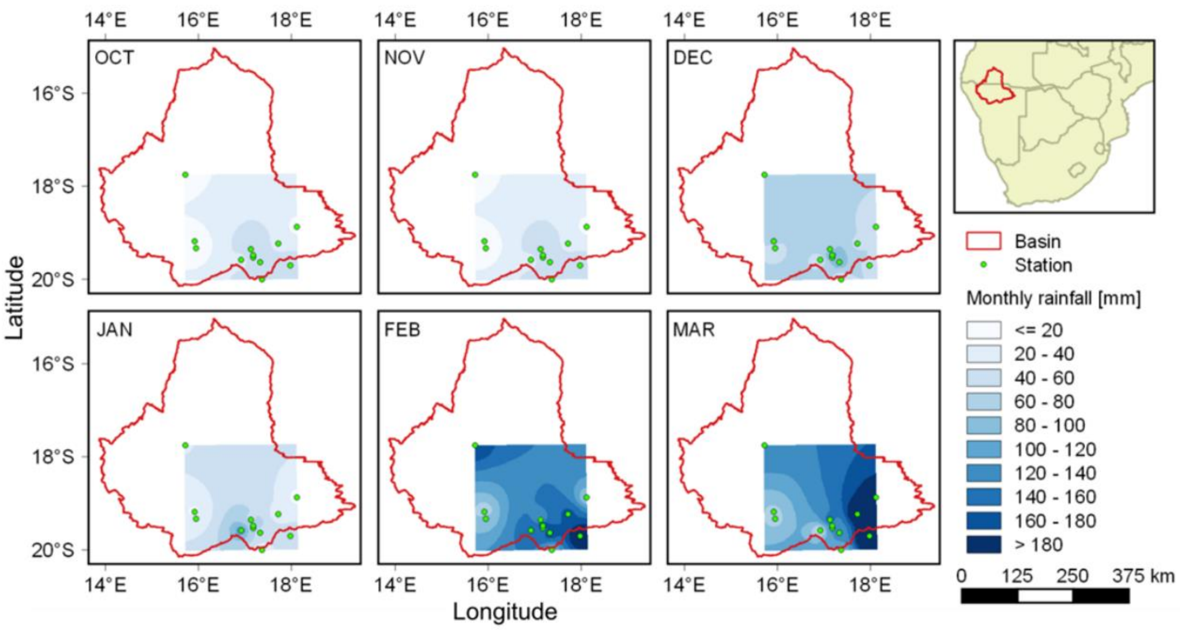

Figure 3.1 The average rainfall in the Cuvelai-Basin for the rainy season [30]

Three rainfall stations in Namibia (Ogongo, Okashana and Ondangwa), Mahenene at the border of Angola and Namibia and Ondjiva station in Angola, where the drainage system originates from were considered for rainfall distribution purposes as depicted in Figure 3.2.

Namibian Cuvelai-Etosha Basin (CEB) lithology is characterised by unconsolidated to semi-consolidated sand and gravel with calcrete [29].

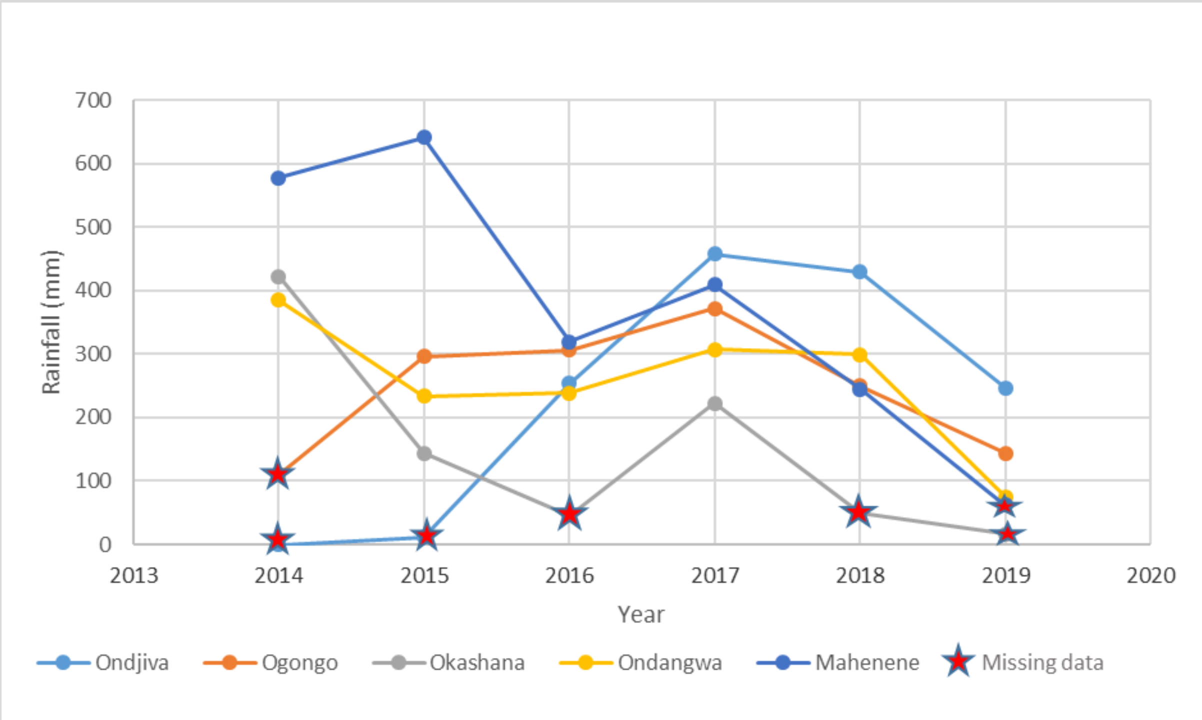

Figure 3.2. Total annual Rainfall of SASSCAL rainfall stations within and near the study area

The major reference soil group of the CEB is the Arenosols type (these soils are typical for the quartzous Kalahari Sands), then a variety of different soil groups such as the Cambisols, Calcisols, Gypsisols, Acrisols, Leptosols, Ferrasols and Vertisols [29]. The locations of sub-basins in the Cuvelai-Etosha Basin and the earth dams constructed by the Ministry of Agriculture, Water and Forestry from 2008 to 2011 can be seen in Figure 3.3.

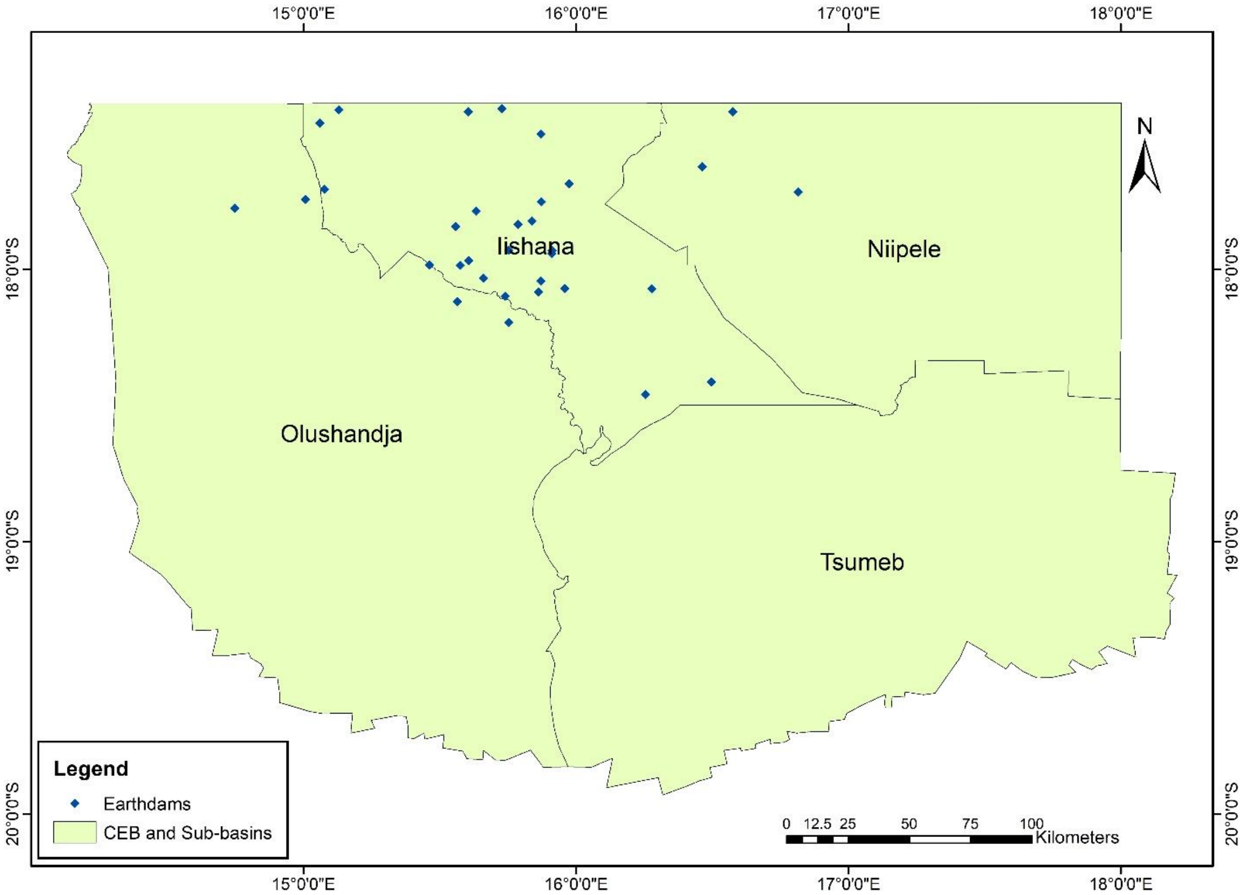

Figure 3.3 Location map of Constructed earth dams and sub-basins in the Cuvelai-Etosha Basin

The CEB has a total of 34 constructed earth dams of which 90% are located in the Iishana sub-basin. Olushandja sub-basin, Niipele sub-basin and Tsumeb sub-basins have 6%, 4% and 0% respectively. The majority of the dams were constructed in the Iishana sub-basin because this is the most flooded sub-basin in the CEB.

3.2 Research Design

The research design was based on using both Qualitative and Quantitative data on a completely randomised basis apart from the Remote Sensing data. Remote sensing was used to assess the status of floodwater harvesting infrastructures in the Cuvelai-Etosha Basin. To determine whether the constructed infrastructures are serving the purpose they were designed for the remote sensing data was compared with the observations from the ground.

3.3 Research Instruments

In order to know the state and whether the excavated earth dams in the Cuvelai-Etosha Basin are serving their purpose, a combination of primary and secondary data was used to locate the already existing excavated earth dams in the region. Raw data of the constructed infrastructures in the CEB was collected from the Ministry of Agriculture, Water and Forestry (Rural Water Offices in Oshakati). The state of these infrastructures as well as their coordinates were also provided. A measuring wheel was used for field measurements of some of the infrastructures as well as structured interviews were conducted. Finally, Sentinel data was used to see how well the satellites picked up these Floodwater-Harvesting Infrastructures on the Namibian side of the Cuvelai-Etosha Basin.

3.4 Procedure

Gathered data was studied (Appendix table 1) and areas to visit were randomly selected. Out of the 34 constructed earth dams, 18 dams were studied. Eight burrow pits and seven hand dug wells were also studied. GPS was used to find the exact locations (ground truthing) of possible floodwater harvesting infrastructure. Using ArcGIS, a map was created with the locations of the constructed earth dams and added as a base map layer on NAVILOCK NL-601US GPS to find location as well as using the Garmin GPS.

The 18 earth dams were randomly selected and located; field measurements were done in order to calculate surface area. In order to estimate the area of each floodwater-harvesting infrastructure, a wheel meter was used for the perimeter of the earth dams as well as the burrow pits. Information was gathered by means of structured interviews from the locals or people living in the area and acquainted with the sites; whereby a sample of five (1 Village chief, 1 herdsman and 1 person from 3 households) at each earth dam was selected, but the burrow pits and hand dug wells were ranging from 1-5 people because the focus was mainly on infrastructures constructed to harvest rain or flood water. Table 3.1 shows the number of people that were interviewed. Interviews were used to obtain the qualitative data.

Table 3.1. Number of people who took part in the questionnaire

Sub-basin	Type of water body	Village Chief (n)	Cattle herder/ Herdsman (n)	Households (n)	Total (n)
Iishana	Dam	12	12	32	56
	Burrow pits	1	4	1	6
	Hand dug wells	1	1	3	5
	Sub-total	**14**	**17**	**36**	**67**
Olushandja	Dam	4	4	12	20
	Burrow pits	0	1	0	1
	Hand dug wells	0	1	0	1
	Sub-total	**4**	**6**	**12**	**22**
Niipele	Dam	2	2	6	10
	Burrow pits	0	1	1	2
	Hand dug wells	0	0	0	0
	Sub-total	**2**	**3**	**7**	**12**
Total		**20**	**26**	**55**	**101**

Sentinel data was used to identify the water bodies in the Cuvelai basin by means of remote sensing. Targeted images were those taken after the rainy season. Satellite images were compared to what is on the ground. The parameters and areas of the water bodies was calculated in ArcMap. Sentinel 2 images were downloaded from the Sentinel data ESA website [28] and processed. A single image for an area was used starting from 2015 to 2019 in the Cuvelai-Etosha Basin. Table 3.2 shows details of the Sentinel images which were used for extraction of water bodies and their areas using the same sensor. The data was acquired over different times to ensure consistency within the data.

Table 3.2 Employed Sentinel image data

Spacecraft name	Image ID	Acquisition Date	Cloud Cover (%)
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KVA_20150918T091248	20150918	0.0%
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KWA_20150918T091248	20150918	0%
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KWV_20150918T091248	20150918	0%
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KXA_20150918T091248	20150918	0%
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KXV_20150918T091248	20150918	0%
Sentinel 2A	MSIL1C_20150918T084736_N0204_R107_ T33KYA_20150918T091248	20150918	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KVA_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KWA_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KWV_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KXA_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KXV_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20160922T085012_N024_R107_ T33KYA_20160922T091124	20160922	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KVA_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KWA_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KWV_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KXA_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KXV_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20170927T085011_N0205_R107_ T33KYA_20170927T090604	20170927	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KVV_20180902T125524	20180902	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KWV_20180902T125524	20180902	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KXV_20180902T123228	20180902	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KVA_20180902T141818	20180902	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KXA_20180902T141818	20180902	0%
Sentinel 2A	MSIL1C_20180902T084601_N0206_R107_ T33KYA_20180902T124211	20180902	0%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KVA_20190430T122717	20190430	0%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KVV_20190430T122717	20190430	0%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_	20190430	1%

	T33KWA_20190430T122717		
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KWV_20190430T122717	20190430	7%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KXA_20190430T122717	20190430	0.2%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KXV_20190430T122717	20190430	9.2%
Sentinel 2A	MSIL1C_20190430T084601_N0206_R107_ T33KYA_20190430T122717	20190430	0%

Six to seven tiles make up one image of the CEB and each tile has twelve bands. The method was adopted, [24] which extracted water from Landsat imagery using a weighted normalized difference water index. By using ArcMap software, the water bodies were extracted using the Normalized Difference Water Index (NDWI) equation:

$$\text{NDWI} = \frac{\rho\ Band\ 3 - \rho\ Band\ 8}{\rho\ Band\ 3 + \rho\ Band\ 8}$$

In order to map out the water bodies, the green band and Near Infra-Red (NIR) band were used. Each year had about five or six tiles altogether making up the Namibian part of the Cuvelai-Etosha Basin. Each image was reclassified into two classes, areas with water and those with no water (index threshold values differed from each tile, but water was in areas between 0.37 and 1). Given the small scale of the resultant maps and small sizes of the water bodies, not all water bodies extracted, were visible. Therefore, layers were changed from Raster to Polygon to make the water bodies visible.

After images were reclassified into areas with and without water, the areas with water were selected from the attribute table and extracted them to create a new layer showing the water bodies only (areas with water). A new water body layer for all tiles of each year was then created. In order to create one image for each year, tiles belonging to one year were merged. Areas of waterbodies in 2019 image was then calculated in ArcMap from the polygons. The centroid tool was used to create a point from the polygons. Water bodies were finally extracted as points.

3.5 Research ethics

Research activities in this study considered the ethical standards to respect human lives, the environment, the University of Namibia and laws of the Republic of Namibia. This was achieved by not practicing anything that contaminated the water sources visited or any sort of littering, not violating any human rights and not using any form of coercion to get the community members to participate in the interview. The researcher got permission to visit and do research in the area from the communities and the respective parties involved, the Ministry of Agriculture, Water and Forestry in Namibia, Regional and local authorities. Confidentiality is assured; personal details of interviewees was not shared with any other parties or public, no names were mentioned from the interviews.

Acknowledging the works of other authors by clearly stating, crediting and citing their works was the norm. No false findings or false data was used throughout this research.

4. Results

4.1 Field measurements

Eighteen randomly selected earth dams were studied from three sub-basins namely, Iishana, Olushandja and Niipele. Out of the studied earth dams the dam with the largest surface area is Sigopi (4316 m^2), the smallest area is Okakango (1617 m^2) and the average is 2809.8 m^2. Measurements of the 18 earth dams were taken and the surface areas calculated as shown in table 4.1.

Eight (8) burrow pits that were stumbled upon as well as 6 hand dug wells were studied in the Cuvelai-Etosha Basin as shown in table 4.2. The burrow pits were located and observed in Iishana, Olushandja and Niipele sub-basins while the hand dug wells were found only in Olushandja (two) and Iishana (four).

Table 4.1 Observed Earthdam areas and presence of water

Sub-Basin	Dam name	Surface Area (m^2)	Presence of water				
			2015	2016	2017	2018	2019
Iishana	Sigopi	4316	√	√	√	×	×
Olushandja	Ontaanda	3738	×	√	√	√	×
Olushandja	Enongo	3192	×	√	√	√	√
Iishana	Oshaaneko	3192	×	√	√	√	√
Iishana	Ondeka	3136	×	√	√	√	√
Iishana	Ontako	2888	√	√	√	×	×
Niipele	Ehoma	2835	√	√	√	×	×
Iishana	Iikuku	2805	√	√	√	√	√

Niipele	Ekangolangombe	2756	√	√	√	√	×
Iishana	Endombe	2704	√	√	√	√	√
Iishana	Okakango	2671	√	√	√	√	√
Iishana	Ontaanda	2506	√	√	√	√	×
Iishana	Iitiligane	2500	√	√	√	√	×
Olushandja	Elondo	2499	×	√	√	√	×
Iishana	Omevatahekele B	2470	√	√	√	×	×
Iishana	Omevatahekele	2376.5	√	√	√	√	×
Iishana	Oniindongo	2375	√	√	√	√	√
Olushandja	Engombe	1617	√	√	√	√	√
		Total	**13**	**18**	**18**	**14**	**8**

There is no consistency in terms of the relationship between dam size and presence of water, but two of the dams with the smallest area out of the 18 earth dams studied as well as three in the average size retained water throughout from 2015 to 2019.

Descriptive statistics were used to analyse the data (surface area) of earth dams, burrow pits as well as hand dug wells. The Iishana sub-basin had more dams with water over the study period. The years 2016 and 2017 all the dams had water over the study period and 2019 had the least (8).

Hand dug wells have the smallest surface area compared to earth dams and burrow pits as shown in table 4.2.

Table 4.2 Observed Burrow pits and hand dug wells areas

Sub-Basin	Type	Location	Surface Area (m^2)	Sub-Basin	Type	Location	Surface Area (m^2)
Iishana	Burrow pits	Oshandubala	3512.71	Iishana	Hand dug well	Omuthiya	1.8
Iishana	Burrow pits	Uuvudhiya	11980	Iishana	Hand dug well	Omuthiya	0.8
Iishana	Burrow pits	Onyaanya	10198.97	Iishana	Hand dug well	Omuthiya	1.9
Iishana	Burrow pits	Omuthiya	11980	Iishana	Hand dug well	Omuthiya	1.2
Iishana	Burrow pits	Iikuku	3543	Olushandja	Hand dug well	Ontaanda	2
Iishana	Burrow pits	Iikuku	3400	Olushandja	Hand dug well	Ontaanda	2
Olushandja	Burrow pits	Eendombe	7526.3				
Niipele	Burrow pits	Omevatahekele	6116.97				

Analyses was done for the surface areas of the burrow pits as well as the hand dug wells. The largest area of the burrow pits is 11980m^2, the smallest 3400m^2 and the average is 6374m^2. The largest area of the hand dug wells is 2m^2, the smallest 0.8m^2 and the average is 1.6m^2.

4.2 Mapping of water bodies

Figures 4.1 shows locations of water bodies detected from satellite images in the Cuvelai-Etosha Basin during the study period.

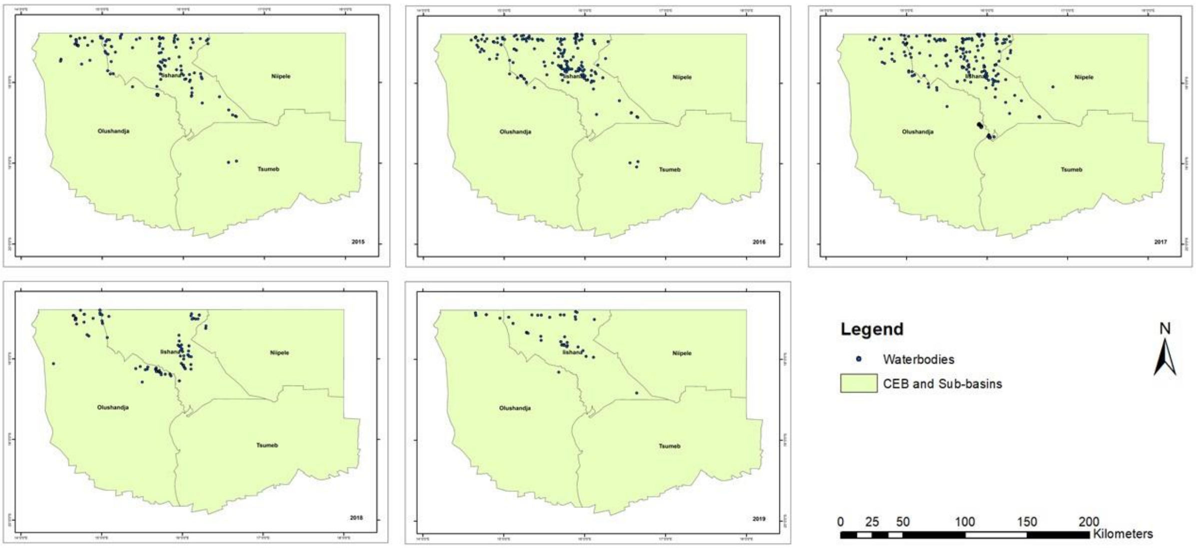

Figure 4.1 Waterbodies from Sentinel images of 2015, 2016, 2017, 2018 and 2019

In 2015 all four sub-basins (Iishana, Olushandja, Tsumeb and Niipele) had waterbodies, 80% of them are in the Iishana and less than 5% in Niipele sub-basin. In 2016 only Iishana and Olushandja sub-basins had waterbodies, 85% of them still in Iishana. In 2017 all four sub-basins (Iishana, Olushandja, Tsumeb and Niipele) had waterbodies, with 76%located in Iishana and 8% in Niipele. In 2018, three sub-basins had waterbodies namely: Olushandja (45%), Iishana (52%), and Niipele (3%) sub-basin. In 2019 only Iishana (96%) and Olushandja (4%) had waterbodies, most of them are located in Iishana sub-basin.

The number of water bodies extracted from the Sentinel 2 images in the CEB is shown in figure 4.2. Out of the 223 water bodies in 2015, 215 were visible in 2016 but 223 were all observed in 2017. From the year 2015 to 2019, only 42% water bodies retained water. The average number of water bodies (388) with persistent water becomes 25% and this is a quarter of the average.

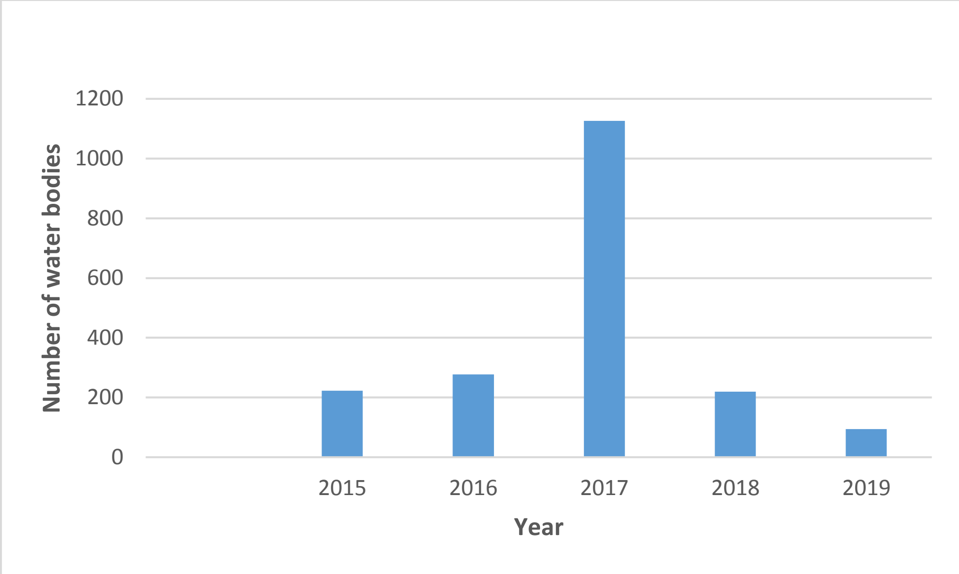

Figure. 4.2 Number of water bodies extracted from Sentinel 2 images in the CEB

The figure 4.2 shows 2019 had the lowest waterbodies picked up by the satellite followed by 2018, 2015 and then 2016 while 2017 had the most water bodies, which correspond to 95, 219, 223, 277 and 1126 respectively. These water bodies are picked up at Olushandja dam and its surrounding, but more than 80% are in the Iishana sub basin.

The average area of the 94 waterbodies was 31432.39 m^2, the smallest was 100 m^2 and the largest was 3457900 m^2, which is the Olushandja dam. 71% of the water bodies are in the Iishana sub basin, 28.8% in Olushandja.

4.3 Interviews

Just over 100 table 4.7participants took part in the interview from all three sub-basins: Iishana (67), Olushandja (22), and Niipele (12).

Figure 4.3 shows the earth dam uses; with the highest usage being for livestock, followed by livestock and domestic combined. The earth dams were least used for Agricultural purposes.

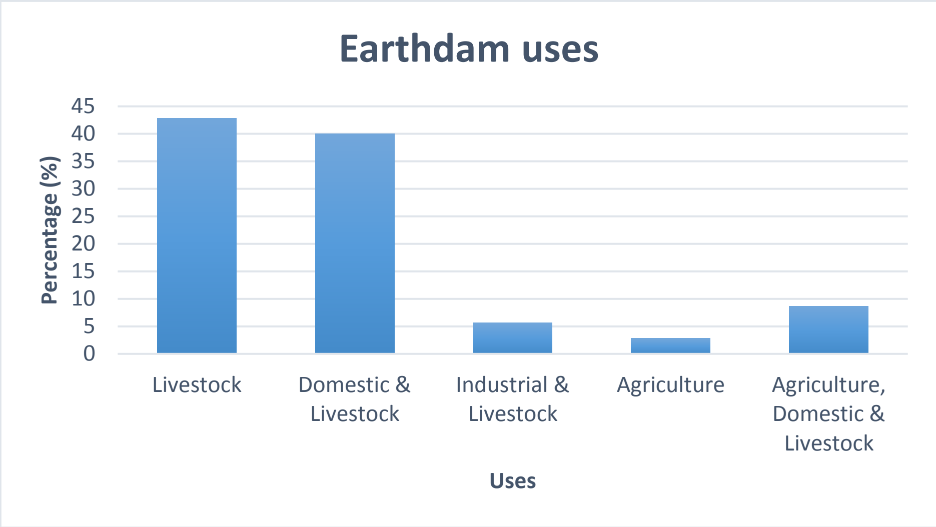

Figure 4.3 Earth dam uses

It is difficult to quantify the number of households using water from the burrow pits. Each dam is used by approximately 45 households. Figure 4.4 shows the estimated number of households that use the earth dams showing the majority being more than 100 households. This is on average, the number of households served per dam. In other words, average number of households within a dam's catchment area.

The earth dams are very helpful to the people, except for the Ontako dam where the community members claimed it is not helpful to them. This is due to high salinity that both animals and people cannot consume it, as well as the fact that the dam does not retain water for long (less than 6 months).

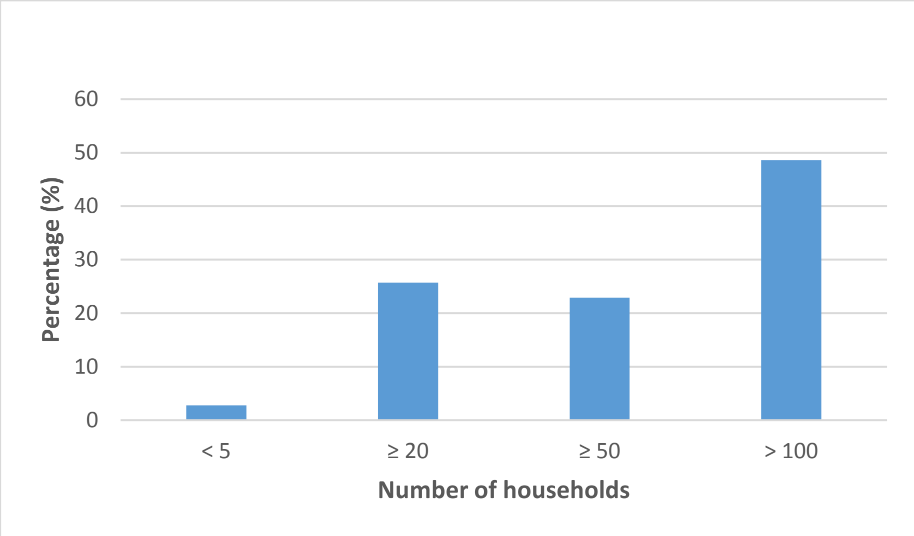

Figure 4.4. Estimated number of households using earth dam

Based on the structured interviews conducted, 82.9% of the constructed earth dams fill up yearly to the maximum capacity if there are good rains in the area and this water can be retained till the next rainy season. Only 17.1% of the dams retain water for only six months or less. 42.8% of the earth dams are used for livestock watering only, 40% is used for both domestic and livestock, 5.7% for industrial and livestock, 2.8% for agriculture and 8.7% of the earth dams are used for agriculture, livestock and domestic purposes.

The earth dams are very helpful to the communities, but also unsafe due to the sedimentation in them. At some parts it looks dry, but when the animals step close, they get stuck in the mud and cannot manage to get out. About 94.3% stated the importance of the earth dams and how helpful they are to the communities. There are no challenges faced by 65.8% of the participants, 2.8% of them reported diseases such as malaria and flooding or overtopping of the dams, 28.6% reported other accidents including drowning of animals in the dams.

Some earth dams are constructed without community's input and are not placed at ideal locations. 85.7% of the dams are located in ideal areas to capture maximum amount of flow. The majority have not come across any conflict among users, but 14.3% of the participants stated conflicts among users. 5.7% participants stated the presence of human-animal conflicts, whereby the wild animals come to the water sources used by the locals and at times cause havoc.

In all studied sub-basins 37.1% used hand dug wells, 25.7% of the interviewees had no other water sources apart from the earth dams, 22.9% of them had other sources and 14.3% have earth dams and burrow pits as their water sources. In order to harvest more water for use in the dry season, 68.6% prefer more earth dams, 5.7% hand dug wells, while the remaining 25.7% want the existing dams to be rehabilitated or renovated due to siltation mainly caused by placing of removed soil very close to the dam and later washed into the dam by rainfall runoff.

In Iishana and Olushandja sub-basins, burrow pits were found along the roads and they have a larger surface area compared to both earth dams and hand dug wells. All burrow pits had water in them apart from the ones in southern side of Iishana and Olushandja sub-basin that were dry.

The figures below show a situation analysis of some of the earth dams in the CEB that were studied.

Figure 4.5 Siltation in Ontako

Figure 4.6 Sigopi earth dam silting up

Figure 4.7 Animal stuck in Oshaaneko earth dam **Figure 4.8 Enongo earth dam**

(a) **(b)**

Figure 4.9 (a) Earth dam fenced off in Ontaanda and its water quality (b)

Figure 4.10 (a) Ekangolangobe earth dam **Figure 4.10 (b) Ekangolangobe close up**

Google Satelite images of the corresponding earth dams, 22 September 2019

Figure 4.12 Satelite image of Ontako

Figure 4.13 Satelite image of Oshaaneko

Figure 4.14 Satelite image of Sigopi

Figure 4.15 Satelite image of Enongo

5. Discussion

The earth dams used in the study had an average area of 2809.8 m^2. Small amount of water was observed in these dams except for Enonogo and elondo which were completely dry during fieldwork. Their areas are relatively large and this suggests that the large surface areas of the earth dams contribute to higher evapotranspiration rates, which is made worse by the low rainfall for 2019 as indicated in Fig.3.2, the study area only received an average rainfall of 108.58 mm. In India they have multiple small dams [30], length is 10m, width is 1m and the depth of 5m. This depth and surface area encourage low evapotranspiration. The sides of the dams are reinforced with bamboo posts and mats to reduce siltation and maintain water quality and quantity. In Ethiopia [20], most of the water harvesting ponds had a volume of less than 1,500 m^3 to reduce the rate of evapotranspiration and could have water for longer periods.

The most appropriate method of controlling evaporation of water is through the use of pump-storage dams were also introduced in the Cuvelai. The risk of waterborne diseases such as malaria or contamination by animals is greatly reduced by installing hand pumps also to provide clean water in the Cuvelai-Etosha Basin. Farmers and cattle owners in semi-arid parts of Tanzania build small earth dams. These dams are built in a way, which tries to reduce evaporation losses by deepening the water reservoirs and minimising their surface area.

Rehabilitation particularly desilting is to restore the dam to the original status at the lowest cost without hindrance of the operation of the water supply system [31]. This is done by first pumping water out if the dam still has water in it and then remove the silt. The best way would be to wait until the dam is almost dry and then remove the silt in order to improve the quality of the water in the future.

It is important to have an outlet pipe to take water from the dam by gravity instead of pumping it out to reduce cost. In order to use it for irrigation or watering stock. Selecting a suitable dam site: Check watershed area for soil erosion. Excessive erosion will silt up your reservoir in a relatively short time and would perhaps make the whole project economically unsound [32,33].

Hand dug wells are not only fed by surface water, but underground water as well. They are dug mostly targeting the aquifer, so this adds to reasons why they retain water over long periods compared to earth dams and burrow pits.

The year 2019 had the lowest rainfall recorded on the SASCAL weather site followed by 2015 and the number of water bodies picked up are also in correspondence to that. The highest number of water bodies were observed in 2017, with the highest amount of rainfall recorded and thus leading to more water bodies retaining water. The second highest number of water bodies were observed in 2016, but the second highest amount of rainfall was recorded in 2018, which has the third lowest number of water bodies picked up. This implies that having high amount of rainfall does not necessarily equate to more water bodies. Possibly the rainfall was not spread over time to such an extent that the water could accumulate over time. The probable explanation for this might also be that the satellite images of 2018 were taken when the dams were dry already. The years 2016 and 2017 presented that all the dams could retain for about a whole year. This brings the number of depressions with persistent water till 2019 to 25% - a quarter of the total. Planning of water resources would need consider this scale of water harvesting that can be expected in such a cyclic environment.

Ogongo station rainfall date in Figure 5.1 was selected because it had almost no gaps in rainfall data and had more rainfall amount received in 2016 compared to 2018. Secondly, rainfall was not so spread over time in 2018 to such an extent that water that was received by December may have evaporated by January, so, the accumulation of water was disrupted.

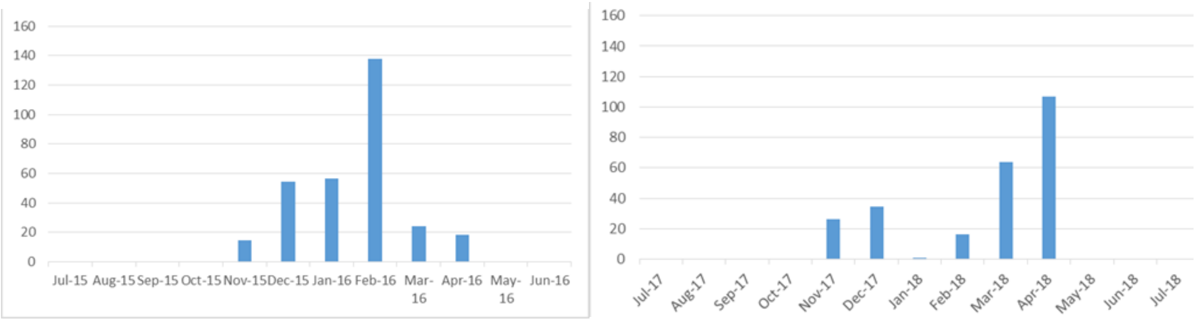

Figure 5.1 Ogongo rainfall 2016 vs 2018

Iishana sub-basin

The dams fill up to maximum capacity every year after good rains. Most of the dams retain water for one year or till the next rainy season. The water is mostly used for livestock watering, but very few people in the sub-basin use it for domestic purposes after purification with chlorine tablets

The major challenge in the sub basin is drowning of animals. Other challenges faced in the sub basin especially around or in Oshikango shOmbome is the overtopping of the dam, resulting in this water flooding the nearby school and homesteads and this might be that the dam is not situated at an ideal area. Another important aspect that was omitted in the construction of these earth dams is a spillway. In Kenya and many other parts of the world a spillway is excavated even for the earth dams to avoid overtopping and damage of infrastructure [34], but the dams here are constructed different that as soon as they are filled, they overflow. There are no human-animal conflicts in the sub-basin. Most of the community members found earth dams to be the best way to harvest rain or flood water in the region, apart from the people in Ontako area due to high salinity, unless a system is put up that pumps water from the dam as it fills up into a tank for storage. There are no other sources of water close to the homesteads in the sub-basin apart from the earth dams and the piped water from the taps. The major conflict among users is between those who want to catch fish with their fishing nets and those who want to use the water for domestic purposes or for livestock watering. Using fishing nets changes the quality of the water and will not be able to be used again.

Taking care of the water sources is a challenge in the community, because people are ignorant when it comes to preserving the quality of water in the dams and not contaminate it, but most keep it at least fit for animal consumption. Apart from the earth dams, there are burrow pits and hand dug wells to harvest rain-water. Making some Oshanas deep might also help in water harvesting. Not many people are educated on the techniques of rain water harvesting at home or on small scale and there is a need to educate people on sustainable water use measures. There are set measures especially for those who fish when the water level in the dam is still high. The community is not allowed to fish when the water level is still high, they should wait till the levels is very low, then the whole community is informed to set a date for fishing. Yet some would still be catching fish at night when no one sees them, resulting in water becoming muddy and unfit for use. In some areas such as Sigopi in Onathinge, they put in old metals in the dam and thick sticks at the corners to prevent people from pulling their fishing nets through the dam.

As part of the regulations set up by the community, people are not allowed to pump water into big tanks and 25 litres bottles for industrial purposes such as making bricks. Fencing off the dams in this area, is not ideal, because the water level rises and damages the fence as it is under water for more than three months.

According to some community members, these dams were not constructed in suitable places for maximum amount of flow into the dams. Most of the community members are more acquainted with the drainage system in the area and might have more

A private earth dam constructed in Iikuku village for the Pendukeni Fruit and Vegetable project was also studied. It is situated at the bank of the River. This idea of building dams along the river channel was adopted from Egypt (dams built along the Nile River) [28]. This dam fills up every year and retains water for the whole year till the next rainy season. It is very helpful for the project. The major challenge faced is that animals drink directly from the dam and therefore it needs to be fenced off. The dam needs to be rehabilitated to reduce siltation, because drip irrigation is used for the project and the system cannot function properly if the water consistency changes, because this can block the water outlets.

The burrow pits have never dried up before, apart from this year. The burrow pits in the sub basin retain water much longer than the earth dams and fill up every year. The water is mainly used for agricultural, industrial purposes such as brick making and domestic. More than thirty households make use of the water. It is very helpful for the communities, but also very dangerous, because it is very steep and deep. The challenges are diseases such as malaria and drowning of both people and animals. There are no conflicts among users and also no human-animal conflicts. A drainage channel was created from the river flowing into one of the burrow pits in Iikuku. In order to harvest more water, the burrow pits need to be rehabilitated (fenced off and have troughs) to prevent animals from entering and drowning in it. As part of the agreements made or Environmental Impact Assessment, companies need to seal the bottom of these pits with concrete or any other material to prevent infiltration. There is no way at the moment to make these pits safe. As the water level is dropping, people who pump water for industrial purposes such as making bricks are not allowed to get water from these sources.

The hand dug wells were constructed in the late 1950's. They fill up yearly and can retain water for a whole year. The wells are used by more than five villages. The water is used for livestock watering and are very helpful to the community. No challenges reported so far. The conflicts faced among users is that some community members would not help dig the wells, but would take their animals to drink from there. Rehabilitating the wells and deepening some depressions are ways to harvest more water in the sub-basin. One well is used until it reaches a certain level, then the next well is used in the same way. To prevent siltation and contamination of water in the wells, they need to be built well.

Niipele sub-basin

All other dams in the basin retain water for the whole year apart from Ekangolangobe. They all fill up every year and the water is used for livestock watering, with the few that use it for domestic purposes. The number of households that use the dams ranges from three to nine villages. The dams are very helpful, apart from Ekangolangobe which has a lot of water still yet very dark and muddy. Other water sources in the region are burrow pits, the hand dug wells are not used much. There are no human-animal conflicts.

People take care of the water sources by not swimming in there, fencing it off to prevent accidents such as animals entering from the elevated side or people passing by from the cuca shops at night. Some areas are ideal for the dam construction such as Ehoma and the others are not. This is due to lack of community participation in selecting suitable place for the dam with the indigenous knowledge they have. While the water levels of the dams are low, rehabilitation needs to be done.

Hand dug wells are privatised, because they are in people's farms or land and are not utilised much. Burrow pits hold water, but are very deep and steep making it both difficult and dangerous for animals to drink from there. Work needs to be done on the burrow pits to make them safer. According to the interviews conducted in Okakango, there have been many reported death cases in Okakango village caused by the burrow pit there.

Olushandja sub-basin

All the dams hold water till the next rainy season and get filled up yearly. The water is used for livestock watering, with few that use it for domestic purposes. According to the village headman of Ontaanda in Olushandja the number of households that benefit from these earth dams range from fifty to five hundred, with Ontaanda having more than five hundred households. These dams are very helpful to the communities, especially with helping the animals. Most of these dams have accumulated mud, so the challenge is that animals get stuck in the mud. There are no conflicts among users and also no human-animal conflict. Other water sources in the region include hand dug wells and burrow pits, although one burrow pit is on someone’s farm and they do not allow people to bring their animals to drink there. The community members are educated on water use and taking care of the water sources. Some practice rain water harvesting at home from their roofs. Children are not allowed to play in the water sources or close by, people do laundry away from the water sources and no fishing with nets. Strict regulations are set up by the community members especially to those with brick making projects to not get water from these dams.

There are great drainage channels in the sub-basin, but there is a need for earth dams to harvest more water for the villages to meet the livestock water demand. Some dams such as the Ontaanda and Eendombe community members state that these dams are not located at ideal places due to the type of soil that is there which instantly changes the consistency of the water. Rehabilitation of the dams is crucial to have more water and less silt. In Ontaanda village there are two traditional wells that were upgraded by United Nations International Children's Emergency Fund (UNICEF) in the 1990’s with very clean water that is used mainly for livestock watering, but also sometimes for domestic purposes.

Some measures are put in place by some of the community members to ensure safe and prolonged use of water in the dam, with some still being ignorant and would practice activities to contaminate the water, making it unfit for both human and animal consumption.

Other water harvesting infrastructures such as burrow pits and hand dug wells are helpful too, but difficult to access and need to either be upgraded or made easily accessible. Earth dams are good and the best infrastructures to harvest rain or flood water.

Out of the 18 earth dams that were studied, 6 of the earth dams are in the same location with the water bodies picked up by the satellite images and these earth dams are all in Iishana sub-basin. 12 of the earth dams studied on the ground were 1 meter away from the waterbodies observed by the satellite. 13 of the earth dams observed on the ground were 3 meters away from the waterbodies observed by the satellite. 17 earth dams were 50m away from the waterbodies picked up by the satellite. Out of the 8 burrow pits, only 2 were 20m away from the satellite water bodies and none of the hand dug wells could be seen. The areas of the earth dams observed in field were slightly bigger than what was calculated from the water bodies picked up by the satellite. This is because the calculation from the water bodies picked up by the satellite focused on the area that had a pixel picked up by water only and not the surface area covered by the entire earth dam or water infrastructure.

During the usage of the pump storage dams no satisfactory method of reducing the amount of evaporation was discovered. According to [15] pump storage dams were built as deep as possible to prevent evaporation. While with the new earth dam design, evaporation and siltation is increased.

6. Conclusion and Recommendations

All objectives were achieved. The maps created were used throughout the thesis. Iishana sub basin had the most water bodies both in the satellite images and the constructed infrastructures compared to the other sub-basins.

Conditions of dams' operation changed:

- Old system had no inlet or outlet (Sedimentation & Contamination is reduced)
- Pumping system
- Fencing, to prevent animals to enter
- Lifespan of dams are reduced with the new systems

From field observations the average areas of the burrow pits were the largest compared to earth dams and hand dug wells, with a mean value of 7020, 2810 and 2 m^2 respectively.

94.3% of the interviewed participants stated the importance of the earth dams and how helpful they are to the communities.

The conditions and performance of floodwater harvesting infrastructures in the Cuvelai-Etosha Basin were assessed and it is found that the structures have changed physically compared to when they were constructed. Storage capacity is reduced, because the depth is reduced by siltation. There has been no maintenance of the waterbodies and would need to be rehabilitated to capture sufficient amount of water and function as initially. The surface area has broadened and evaporation rate is increased, hence reducing water quality as well.

Some of the shortcomings was depth, it could not be measured accurately, due to siltation and danger to get in these areas. Inaccuracies with the GPS could not get all the observed water bodies to be mapped from the Satellite images, only 59.4% was overlaying with the satellite. Thus, a more accurate GPS can be considered.

Much was learnt from Remote sensing; a lot could be obtained from the satellite images apart from the perimeter and areas of waterbodies water quality can also be obtained from there. Therefore, tests for water quality of these sites would be one of the recommendations of this study as well as to carry out field observation on dates not far apart with the dates the sentinel images were taken. Trees and shrubs can be grown on the windy site of these dams to function as windbreakers and reduce evaporation. Lastly, the usage of unmanned vehicles can be used to check the depth in order to accurately calculate the depths of the earth dams and generate contour maps of the water body floor.

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8. Appendix

Appendix I: Raw data on earth dams from the Ministry

Region	**Constituency**	**Dam**	**Coordinates**		**Year financed**	**Remarks**
Ohangwena	Epembe	Ekangolangobe	S 17°42.923'	E 16°48.917'	2008/2009	Completed
Ohangwena	Eenhana	Omevatahekele	S 17°37.404'	E 16°27.837'	2008/2009	Completed
	Ongenga	Oshali-Ondobe yOmunghudi	S 17°25.27'	E 15°36.26'	2009/1010	N/A
	Omulonga	Ehoma	S 17°23.98'	E 16°34.55'	2009/2010	N/A
	Ohangwena	Okakango	S 17°30.19'	E 15°52.22'	2010/2011	N/A
	Ongenga	Ombulu – Omatangela	S 17°24.58'	E 15°43.67'	2010/2011	N/A
Oshikoto	Onyaanya	Iitiligane	S 18°04.285'	E 16°16.687'	2008/2009	Completed
	Omuthiya	Oshikangoshombome	S 18°24.759'	E 16°29.798'	2008/2009	Completed
	Omuntele	Oshithashonke	S 18°27.514'	E 16°15.292'	2009/2010	N/A
Omusati	Okalongo	Ondeka	S 17°24.882'	E 15°07.730'	2009/2010	Completed
	Tsandi	Elondo	S 17°44.576'	E 15°00.377'	2009/2010	Completed
	Tsandi	Ontanda	S 17°46.530'	E 14°44.844'	2008/2009	Completed
	Ogongo	Eendombe	S 17°42.353'	E 15°04.601'	2008/2009	Completed
	Anamulenge	Oshipaya	S 17°27.763'	E 15°03.564'	2009/2010	N/A
Oshana	Uuvudhiya	Engombe	S 18°07.059'	E 15°33.865'	2008/2009	Completed
	Ompundja	Ontako	S 18°01.941'	E 15°39.571'	2008/2009	Completed
	Uuvudhiya	Omapopo	S 17°59.048'	E 15°27.739'	2009/2010	N/A
	Ompundja	Sogopi	S 18°05.900'	E 15°44.367'	2009/2010	N/A
	Ompundja	Oshaaneko	S 17°58.088'	E 15°36.367'	2008/2009	Completed
	Okaku	Oniindongo	S 17°41.102'	E 15°58.488'	2009/2010	N/A
	Okaku	Oshoongela	S 17°45.115'	E 15°52.341'	2009/2010	Completed

	Ongwediva	Panguleni	S 17°49.375’	E 15°50.313’	2009/2010	Completed
	Okatjali	Oshihe	S 18°04.205’	E 15°57.560’	2009/2010	Completed
	Oshakati West	Oshuulo	S 17°50.546’	E 15°33.478’	2008/2009	Completed
	Oshakati East	Oshinyadhila	S 17°50.114’	E 15°47.222’	2008/2009	Completed
	Uukwiyu-ushona	Onekaku	S 17°56.504’	E 15°546.50’	2010/2011	N/A
	Uukwiyu-ushona	Omukandu	S 18°02.558’	E 15°52.279’	2010/2011	N/A
	Uuvudhiya	Inakulu Yomadhiya	S 18°11.684’	E 15°45.168’	2010/2011	N/A
	Okatjali	Okasheshete	S 18°04.958’	E 15°51.731’	2010/2011	N/A
	Okatana	Uukwedhidhi	S 17°47.147’	E 15°37.997’	2010/2011	N/A
	Oshakati West	Oshitowa	S 17°59.124’	E 15°34.457’	2010/2011	N/A
	Oshakati East	Onyalo	S 17°55.782’	E 15°45.174’	2010/2011	N/A
	Ondangwa	Amusa	S 17°55.852’	E 15°54.727’	2010/2011	N/A

Appendix II: Earth dam locations in Longitudes and latitudes

Region	Constituency	Dam	Lat	Long
Ohangwena	Epembe	Ekangolangobe	-17.71528	16.81528
Ohangwena	Eenhana	Omevatahekele	-17.62333	16.46389
	Ongenga	Oshali-Ondobe yOmunghudi	-17.42111	15.60417
	Omulonga	Ehoma	-17.42111	16.57583
	Ohangwena	Okakango	-17.50306	15.87028
	Ongenga	Ombulu – Omatangela	-17.40944	15.72778
Oshikoto	Onyaanya	Iitiligane	-18.07139	16.27806
	Omuthiya	Oshikangoshombome	-18.41250	16.49639
	Omuntele	Oshithashonke	-18.45833	16.25472
Omusati	Okalongo	Ondeka	-17.41444	15.12861
	Tsandi	Elondo	-17.74278	15.00611
	Tsandi	Ontanda	-17.77528	14.74722
	Ogongo	Eendombe	-17.70583	15.07667
	Anamulenge	Oshipaya	-17.46250	15.05917
Oshana	Uuvudhiya	Engombe	-18.11750	15.56417
	Ompundja	Ontako	-18.03222	15.65944
	Uuvudhiya	Omapopo	-17.98389	15.46222
	Ompundja	Sogopi	-18.09833	15.73944
	Ompundja	Oshaaneko	-17.96813	15.60611

	Okaku	Oniindongo	-17.68500	15.97472
	Okaku	Oshoongela	-17.75167	15.87222
	Ongwediva	Panguleni	-17.82278	15.83833
	Okatjali	Oshihe	-18.07000	15.95917
	Oshakati West	Oshuulo	-17.84222	15.55778
	Oshakati East	Oshinyadhila	-17.83500	15.78694
	Uukwiyu-ushona	Onekaku	-17.94167	15.91083
	Uukwiyu-ushona	Omukandu	-18.04250	15.87111
	Uuvudhiya	Inakulu Yomadhiya	-18.19472	15.75278
	Okatjali	Okasheshete	-18.08250	15.86194
	Okatana	Uukwedhidhi	-17.78556	15.63306
	Oshakati West	Oshitowa	-17.98528	15.57417
	Oshakati East	Onyalo	-17.92944	15.75278
	Ondangwa	Amusa	-17.93083	15.91194

Appendix III: Number of people who took part in the questionnaire

Sub-basin	**Dam**	**Number**	**Village Chief**	**Cattle herder/ Herdsman**	**Households**
Iishana	Ontako	3	1	1	1
Iishana	Ontaanda	5	1	1	3
Iishana	Endombe	5	1	1	3
Iishana	Iitiligane	5	1	1	3
Iishana	Iikuku	3	1	1	1
Iishana	Oshipaya	5	1	1	3
Iishana	Oniindongo	5	1	1	3
Iishana	Omevatahekele	5	1	1	3
Iishana	Omevatahekele B	5	1	1	3
Iishana	Ondeka	5	1	1	3
Iishana	Okakango	5	1	1	3
Iishana	Oshaaneko	5	1	1	3
Olushandja	Enongo	5	1	1	3
Olushandja	Elondo	5	1	1	3
Olushandja	Ontaanda	5	1	1	3
Olushandja	Engombe	5	1	1	3
Niipele	Ehoma	5	1	1	3
Niipele	Ekangolangombe	5	1	1	3
Burrow Pits					
Iishana	Oshandubala	1	0	1	0
Iishana	Iikuku	2	0	1	1
Iishana	Onyaanya	3	1	2	0
Olushandja	Eendombe	1	0	1	0
Niipele	Omevatahekele	2	0	1	1
Hand dug well					
Iishana	Omuthiya	5	1	1	3
Olushandja	Ontaanda	1	0	1	0
Total number of participants		**101**			

Appendix IV: 2019 satellite image waterbodies' area

Water body Id	Area (m^2)
362	68
365	3172
374	68
375	135
376	68
377	4850
378	68
384	68
385	1860
387	329
388	307
389	137
390	68
394	137
395	68
407	68
408	68
411	68
412	135
413	558
414	2760
415	68
422	3457970
423	27511
424	137
425	301
426	381
427	135
428	1538
429	68
433	135
434	9166
435	376
436	68
437	382
26	68
27	68
28	68
29	2099
30	2939
31	5865
32	68
33	15496
34	68
35	302

36	68
37	200
38	200
39	1171
41	64
42	140
44	68
45	1447
46	1901
47	135
48	4530
52	135
53	9166
54	1316
55	722
56	68
57	10528
58	137
59	68
60	68
62	22178
63	68
64	4425
65	68
66	383
67	7131
68	235
69	68
70	200
72	324
73	2181
74	6550
75	135
76	21026
77	135
78	68
79	11560
80	455
81	1786
82	68
83	883
84	137
85	68
86	68
87	690
88	68
89	422
91	836

92	1661
93	68
95	11865
96	6989
97	68
98	475
99	9229
100	68
101	440
102	137
103	68
104	68
105	5204
106	2191
107	68
108	68
109	6101
110	68
1	68
1	68
2	6101
3	68
4	1408
1	68
2	1720

Mean	31432.38983
Median	170
Mode	68
Minimum	64
Maximum	3457970
Sum	3709022
Count	118

Appendix V: Questionnaire

Assessment of the floodwater harvesting infrastructures in the Namibian Cuvelai-Etosha Basin

Interview Questions

Date: ____________________

Region: ________________________

Dam Name: ________________________

1. When was the dam constructed?

____

2. How often does it fill up?

< 6 months ☐ ≥ 6 months ☐ 1 year ☐ ≤ 5 years ☐ > 5 years ☐

3. Does the water last till the next rainy season?

Yes ☐ No ☐

4. For how long after the rainy season does the dam retain water?

< 6 months ☐ ≥ 6 months ☐ 1 year ☐

5. What is the water used for?

Domestic ☐ Agricultural ☐ Livestock ☐ Irrigation ☐ Industrial ☐

6. How many households benefit from the dam?

< 5 ☐ ≥ 5 ☐ 10 ☐ ≥ 20 ☐ ≥ 50 ☐ ≥ 100 ☐

7. Is it helpful for the community?

Yes ☐ No ☐

8. What are the challenges?

Diseases ☐ Flooding/Overtopping ☐ Drowning ☐ Other accidents ☐ None ☐

9. Is the dam location ideal?

Yes ☐ No ☐

10. Are there any conflicts among users?

10.1 Yes ☐ No ☐

10.2 If Yes, Explain

____

____

11. Has there been any Human- Animal conflict?

11.1 Yes ☐ No ☐

11.2 If Yes, Explain

____

____

12. What do you think can be done to harvest more water for the community to use in the dry season?

____

13. What other water sources are in the area where people get water apart from the earth dams?

None ☐ Hand dug wells ☐ Burrow pits ☐ Underground tanks ☐ Other ☐

14. How do people take care of the water sources in the area?

____

____

15. Any other comments you feel like to air in this interview?

____