A TIME SERIES APPROACH TO HYDROCHEMISTRY AND WATER QUALITY OF THE PERCHED AQUIFERS IN THE CUVELAI - ETOSHA BASIN

A THESIS SUBMITTED IN PARTIAL FULFILMENAT OF THE REQUIREMENTS OF THE UNIVERSITY OF NAMIBIA

BY PETRA P. HASLUND

(200437941)

UNAM

UNIVERSITY OF NAMIBIA

SUPERVISOR: Dr H.WANKE

Co-SUPERVISOR: Ms J. HAMUTOKO

DECLARATION

I, the undersigned Petra P. Haslund, hereby submit this thesis in the partial fulfilment for requirements for the Bachelor of Science (Honours) in Geology at the University of Namibia and it has not been previously submitted by me or any other person for a degree at this or any other institution. I, hereby state that the work presented in this thesis is mine, except where authors are cited.

……………………………..   ………………………..

Signature   Date

ACKNOWLEDGMENT

First and foremost, I would like to thank God for leading me throughout my undergraduate studies in geology. Secondly, I thank Rössing Uranium (Pty) Ltd for sponsoring my studies and not giving up on me when times were tough. Thirdly, my heartfelt gratitude goes to my supervisor: Dr H. Wanke and co-supervisor: Ms J. Hamutoko. Your guidance for the thesis is highly appreciated. I dare not forget Mr M. Harris for is help during the field trips and the entire geology department staff members, thank you all so much for shaping me into the geologist I am today. Special thanks goes to Mr B. Mabhiza for helping when QGIS, excel and laptop failed a couple of times and Mr H. Uushona for being my personal cheerleader throughout my studies and proof reading my paper. Lastly, I would like to thank my little person Joshua H. Haslund, my father Mrs S. Shimbike, Aunt E. Haslund and Grandmother E. Haslund- Hangula, the four of you have more faith in my abilities than I do. Not to forget my mother and siblings thank you all for being there.

I dedicate this thesis to my son

Joshua Heinrich Haslund

ABSTRACT

The Cuvelai Etosha Basin is one of the densest populated areas in Namibia, a semi-arid sub-Sahara African country. It is however also host to the least developed rural areas where people still rely on the traditional hand dug wells that tap perched aquifers of the basin. There is generally a lack of safe drinking water and sanitation in areas such as this and hence makes it prune to water borne diseases such as Cholera. This study focuses on a) determination of hydrochemical characteristics of the groundwater, b) determination of the water quality and the production of a time series analysis of the substances of concern and c) production of spatial and temporal variation maps of the substances of concern. The study aims to increase the knowledge on the nature of groundwater quality of perched aquifers in the CEB, especially those in the Ohangwena and Omusati regions. Groundwater samples from hand dug wells in the Ohangwena and Omusati regions were collected and analyzed for physio-chemical parameters. Sampling was carried out at four different times of the year i.e. in February and March 2015 (wet season) and June and August 2015 (dry season). In addition to the primary data collected for the project secondary data, 2014, available from the SASSCAL project was used Hand dug wells samples in the Omusati Region are predominantly of the Ca-SO_4-HCO_3 type in which strong acids (SO4 + Cl) exceed week acids (CO3 + HCO3) while those of the Ohangwena region are Ca-HCO_3 water type for deep wells and Na-HCO_3 water type for shallow wells. The physiochemical parameters exceeding the Namibia Water quality standards for the Omusati region have been identified as SO_4, Cl, F, Mg, EC and TDS while the TDS, EC, turbidity, nitrate and iron were identified for Ohangwena region. Shallow wells yield water of very poor quality than deeper wells. The Ohangwena region wells had more fresh water while the Omusati region wells have brackish water. There is a general increase of the substances of concern during the dry season. Hence the water quality is not the same throughout the perched aquifer of the CEB

Contents

CHAPTER 1: INTRODUCTION

1.1 Introduction

The Cuvelai- Etosha Basin (CEB) is in the north-central Namibia; the driest country in the sub-Saharan Africa. Surface water in the country is mainly restricted to four perennial rivers at the Northern and Southern borders and is only available for short periods during the raining season.

Water in Namibia is scares due to the fact that the only perennial rivers in the country are shared with neighbouring countries. According to the National Water Policy (2000), low annual average rainfall and a high evaporation rate which reduces surface runoff and groundwater recharge rate as well as regular seasons of draught and some social and political factors, results to the fact that the central parts of the country rely more on the ephemeral rivers and groundwater in both shallow and deeper aquifers. However, the groundwater in the highly populated northern part of the country is saline and most of the aquifers throughout the country are being over utilized.

The CEB is the most densely populated part of the country and the fastest growing area, with at least half of the country's population living there (Walzer, 2010 and Lohe, 2012).Although a pipeline system supplies the area with treated water from the Kunene River not the entire Region is reached and the rural population still relies on the traditional hand dug wells for domestic and livestock purposes (Wanke, Nakwalifa, Hamutoko, Lohe, Neumbo, Petrus, David, Beukes, Masule, Quinger, 2015). Hand dug wells were traditionally used to tap groundwater from shallow perched aquifers but are now replaced by boreholes. The groundwater quality varies greatly within the CEB.

According to Bittner (2006), the groundwater is saline towards the centre of the CEB and becomes better at the margins. Substantial amount of research has been carried out on the shallow and deep aquifers of the Cuvelai Etosha basin. This includes the hydrochemical and hydrological test on the shallow and deep aquifers, the production of GIS maps and the demarcation of the basin. However, very little work has been done on the perched aquifers of the area, let alone a time series analysis approach on the hydrochemistry and water quality of the basin. Therefore this project will focus on a time series approach to try and define the spatial and temporal variations in the water quality of the perched aquifers of Cuvelai Etosha Basin.

1.2 Statement of the Problem

Analysing and knowing the water quality is important for the monitoring and management of a water source. Since the perched aquifers of the Ohangwena and Omusati region in the Cuvelai Etosha Basin are understudied, a time serious approach to the water quality and hydrochemistry will aid in the water monitoring and management. This will also aid in ways to improve the sustainability and provision of the groundwater.

1.3 Objectives of the Study

- Determine the hydrochemistry and water quality of the study area
- Produce a time serious analysis of the substances of concern
- To produce spatial and temporal variation maps of the substances of concern.

1.4 Research Questions

a) What are the chemical characteristics of the groundwater of the CEB?

b) What are the contaminants in the groundwater of the CEB?

c) Is there any temporal and spatial variation in the water quality of the perched aquifers of the CEB?

1.5 Hypothesis of the Study

Little is known about the groundwater quality of the perched aquifer of the CEB. The study hypothesises that; firstly there is no significant variation in the water quality during the wet and dry seasons and secondly the water quality is the same throughout the whole perched aquifer of the CEB.

1.6 Significance of the Study

One of the objectives and or targets of the Government of the Republic of Namibia with regards to water and sanitation is to provide reliable and accessible safe water; safe and affordable sanitation on a sustainable basis to serve all (Namibia Water Supply and Sanitation Sector Policy 2008, Vision 2030). It is also the aim of the Government to preserve security and sustainability of the finite water resource by managing the resource base. In order to achieve these goals the government with the aid of foreign companies and parastatals have managed to drill boreholes and put up management programs in the study area, however there still seems to be a gap in the monitoring and maintenance of water quality.

A study of the characterisation and temporal variation of groundwater quality in the CEB will reveal the water quality parameters which can aid the water quality monitoring/ management and provide ways in which to treat the water. This will immensely help improve the health and water quality of the households and livestock (Vision 2030) in the CEB. Furthermore, it is desired that the outcome of these project will increase the knowledge on the nature of the groundwater in perched aquifers of the CEB.

CHAPTER 2: DESCRIPTION OF THE STUDY AREA

2.1 Location

The Etosha Cuvelai Basin is situated in north-central Namibia. It is part of the larger Ovambo basin and stretches from latitude: E 17^{0}10 to 18^{0} and Longitude: S17^{0}20 to20^{0}. The CEB is divided into four sub basins based on hydrological parameters, water supply and consumption, physiographic parameters, infrastructure, socio-economic and cultural units, population density and political regions (Bittner, 2006). The study uses two example areas one from the Olushandja sub-basin in Omusati region and anther from Niipele sub-basin in Ohangwena region.

The topography of the CEB declines from the surrounding mountains in the east, west and south east towards the lowest part of the basin, Etosha Pan. The surrounding mountains at the western rim, the Otavi Mountains and the eastern Kalahari rise to heights of 1200m a.m.s.l, 1500m a.m.s.l. and 1170m a.m.s.l respectively, while the CEB is a depression of about 1080m a.m.s.l (Bittner, 2006).

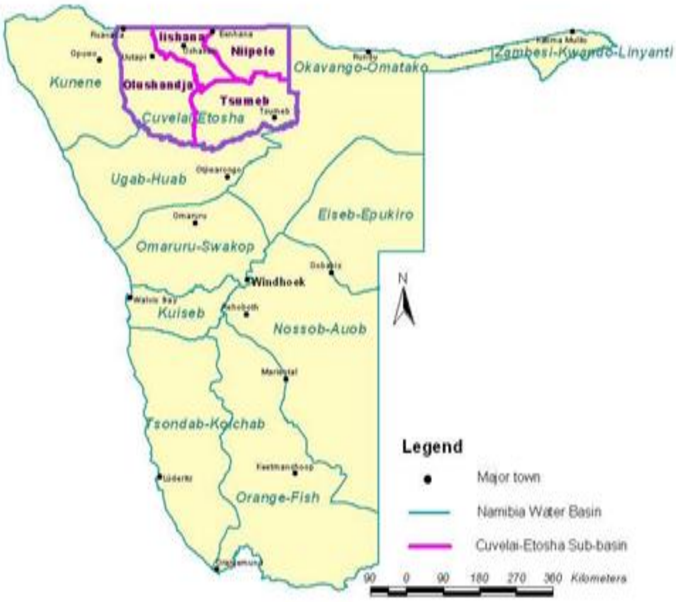

Figure 1 Location of the study area, after Bittner (2006)

2.2 Climate

The climate of the CEB is defined as semi-arid with a distinctive rainfall gradient running from highest in the east to lowest in the west. Rainfall in the area is restricted to the raining season, with the highest rainfall limited between November and April. The amount of rainfall received and its timing however show a grade degree of variation (Mendelsohn, Alice and Jarvis, 2013). In particular the southern parts of the basin receive lower average rainfall of 250mm per year compared to the northern part which gets an average rainfall of 600mm per year. The CEB exhibits higher levels of moisture (humidity) in comparison to the southern parts of the country (Mendelsohn et al., 2013). Humidity is lowest in September and highest during March.

There is very little variation of temperature throughout the basin therefore the average temperature in most parts is greater than 22^{o} C. The southern part of the basin is cooler than the northern part. The average daily temperature ranges from 17^0 C in winter to about 25^0 C during summer months (Mendelsohn, El Obeid and Roberts, 2000). Average minimum winter temperature drops to about 7^0 or 8^0 C, while the average maximum temperature during summer can raise to 30^0 to 35^0 C (Mendelsohn et el. 2000). The evaporation rate is similar throughout the basin except in the south eastern part where it is slightly lower (Mendelsohn et al., 2013). CEB has a high average evaporation rate of about 2500 millimetres of water per year.

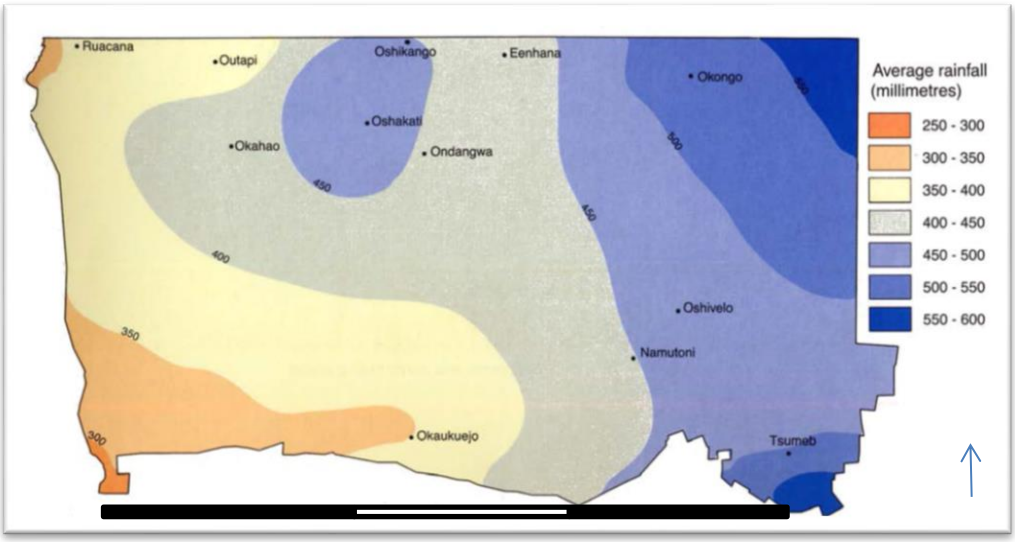

Figure 2: The average annual rainfall across north central Namibia (After Mendelsohn et al., 2000)

2.3 Geology and Structure

According to Bittner (2006), the geology of the area is affected by three distinct and different periods namely the Precambrian, Karoo and Kalahari. Sedimentary rocks of the Precambrian have undergone intense faulting and folding, metamorphism, and igneous intrusion. The occurrence of the Precambrian rocks, in the Owambo Basin, is restricted to the western and south eastern mountain ridges, Bittner (2006). These rocks are characterised by the limestone and dolomite of the Otavi Group, phyllite, quartzite, and schist of the Mulden Group and quartzite, conglomerate and schist of the Nosib Group. The younger Karoo Sequence rocks that overlay the Precambrian are not exposed in the CEB. The Karoo Sequence rocks in the area consist of rocks of the Dwyka and Ecca Formations and the Etjo Formation, Bittner (2006) and Miller (2008). Minor basalts of the Kalkrand Formation occur on the eastern and southern parts of the basin. Typical rocks of the Karoo Sequence are the tillite, sandstone and shale, the shale, sandstone and carbonate and the red sandstone or conglomerates of the Dwyka, Ecca and Etjo Formations respectively. The much younger Kalahari Sequence rocks lie with an unconformity over the Karoo Sequence rocks and have a thickness of up to 600 m near the Angolan boarder (Miller, 2008).

All water analysis used in this study are from wells that penetrate this sequence only. The onset of the Kalahari Sequence was during the end-Cretaceous or beginning of Tertiary by Aeolian to fluvial processes on a continental environment. Miller (2008) marked that towards the end of Cretaceous degradation and incision gave way to aggradations and deposition as the rocks of the Karoo Sequence were exposed to weathering and erosion before sedimentation resumed. Deposition was intermitted during this time followed by long periods of non-deposition which led to the calcrete cementation of the initially deposited Kalahari gravels. The early deposits, unconsolidated and calcrete cemented of the Kalahari were than eroded and new fluvial sands and gravels were deposited. According to Miller (2008 and 2010) this cycles of erosion and deposition, of adjacent highlands and underlying Karoo rocks led to the filling of the basin. Most of the silisiclastic sands of the Owambo basin are largely unconsolidated, only partially consolidated and cementing although limited is variable in the area. Deposition of these units is related to the sand dominated Cubango Megafan in the east and the smaller mud dominated Kunene megafan in the west (Miller, 2010). The silisiclastic sediments of the Kalahari are made up of the Ombalantu, Beiseb, Olukonda and Adonai Formations with the Ombalantu being the oldest. All of these formations are interfingered and coeval with the Etosha Calcrete Formation (Miller, 2010). Red beds (conglomerates, shale and sandstone) Ombalantu Formation is the basal units of the Kalahari Formation. Miller (2008) describes these units as semi-consolidated but friable with variable silicified mudstones consisting almost entirely of clay. He further evaluates its deposition to be mainly from accumulation of fine clastics in shallow, low energy deltaic environment. The BeisebFormation which overlies the Ombalantu red beds is gravel deposit that is widespread and can have a thickness of 47 m (Miller, 2008). Bittner (2006) however describes the unit as a brown and grey sandstone and/ or mudstone that reaches a maximum thickness of 30 m. The Formation represents a period of rapid and extensive input of material from the margins of the basin. The reddish brown sand and sandstone of the Olukonda Formation overlies the Beiseb Formation. Miller (2008), described the units of this formation as friable, poorly consolidated and poorly sorted with few gritty and pebbly layers. Adonai Formation blankets all the underlying units throughout the entire Owambo Basin. This unit consist of semi consolidated to consolidated medium gained sand, clayey sand and clay with colours ranging from white to light green and green. Calcrete of the Etosha Formation has formed in all the sediments of the Kalahari Sequence. It particularly forms a hard carbonate cover on top of the Adonai Formation. Younger aeolian sand of recent age covers parts of the study area.

The identification of structures in the CEB is made difficult by the deep sand cover and aeolian regime of the Kalahari Sequence. However, a few east-west faults and north-west faults or lineaments were interpreted from Aeromagnetic surveys, boreholes and seismic surveys. Miller (2010) presents Neoproterozoic fold structures, also from seismic surveys and exploration wells, at greater depth near the centre of the basin and uses this to interpret the origin of the basin's shape. According to him the shape is due to the uplift along its margins during the late Neoproterozoic continental collision in the Kaoko belt in the west and the Damara belt to the south. Its shape has not changed since then, but the centre was deepened due to the pre-Karoo and pre- Kalahari erosion.

Table 1: Stratigraphy and lithology of the CEB (After Bittner 2006)

SYSTEM	SEQUENCE (age)	GROUP	FORMATION	LITHOLOGY	THICKNESS Max [m]
Quaternary	Kalahari (<120 Ma)		Aluvium	Calcrete, sand	n/a
Tertiary			Etosha Limestone Member	Limestone, calcrete, sand	100
			Adonai	Sand, sandstone, silt	275
			Olukonda	Sand, sandstone, silt	175
			Beiseb	Sandstone, mudstone, gravel	50
Cretaceous			Ombalantu	mudstone	100
	Karoo (120-400 Ma)		DISCONFIRMITY		
			Kalkrand	Basalt	90
Jurassic			Etjo	Sandstone	140
Triassic			Prinz Albert	Shale, silt and sandstone, coal	285
Lower Permian			Dwyka	Tillite, shale	160
Caboniferous-Cambrian	EROSION/ DISCONFIRMITY (250 -450 Ma)				
Namibian	Damara (650- 900Ma)	Mulden			

2.5 Geohydrology

With the surface water being available only at certain periods of time in the Cuvelai Etosha Basin, people rely on the aquifers which have proven to be a stable source of water over time. The CEB exhibits a complex system of aquifers that stores fluctuating amounts of water at different depth. Bittner (2006) identified three main groundwater systems with flow direction towards the Etosha Pan:

a) Groundwater recharge in the fractured dolomites of the Damara Sequence in the south and west feeds the aquifer system of the Karoo and Kalahari Sequences. The shallow groundwater flow is in the north and eastward direction and discharge is through numerous springs.

b) Groundwater flow in the deep seated multi-layered Kalahari aquifer is in a southern direction towards the Etosha Pan and the Okavango River. The aquifer is believed to be recharged in Angola.

c) Both the above mentioned aquifers are overlain by the shallow Kalahari Aquifer. Recharge in to this mainly saline aquifer is the regular floods in the CEB drainage system.

The Damara sequence Aquifers in the rocks of the Mulden and Otavi Groups about are the deepest aquifers of the complex aquifer system of CEB. The Mulden group rocks aquifer is 670m below the surface and its water quality is saline to brackish (Mendelsohn et al., 2010). The Otavi dolomite aquifer yields fresh water and supplies the towns of Tsumeb area. These aquifers are overlain by the Main Shallow Aquifer which is about 20 to 40 km below ground level and extends throughout the whole CEB. Mendelsohn et al (2010), describes the water of the aquifer as saline and too brackish for human consumption and too salty in some areas such as the Omusati for livestock. However, the aquifer has been tapped with deeper wells known as the Oondungu and used extensively. Recharge to the aquifer is by percolation through fractures and the fresh water forms lenses on top of the saline layer. Both the above mentioned aquifers are overlain by the Discontinues Perched Aquifer which is the shallowest of the three. This aquifer depends on the seasonal rainfall and floods for its recharge. As a result the aquifer has fresh water after the raining season and becomes saline during the dry season. The aquifer is referred to as: discontinues perched, because it lies on top of a less permeable layer and the water is only found in certain places of the basin. Shallow wells known as the Omithima are used to draw water from the aquifer. Both the Discontinues Perched Aquifer and Main Shallow Aquifer are part of the Kalahari deposit.

Ohangwena Aquifer- KOH

The KOH is a multi-layered porous aquifer. The upper layers of the aquifer comprises of semi consolidated sandstones of the Adonai Formation which represents the main fresh source. The groundwater quality becomes brackish to saline towards the southwest of the aquifer, mainly due to the mixing with shallow saline groundwater of the Cuvelai drainage system. Recharge in the aquifer is from a proposed unconfined Kalahari aquifer in southern Angola.

Omusati Aquifer- KOM

The KOM is a multi-layered aquifer that comprises of unconsolidated to semi-consolidated sediments of the Kalahari Sequence. This includes sand, clay, calcrete/ dolocrete and large evaporitic deposits. Groundwater in this system is mainly brackish with shallow fresh water lenses in places. Recharge in the aquifer is from the KEL and Do in the west and not from the Cuvelai drainage system. This difference in the mode of recharge separates the KOM from the KOS (Oshana Aquifer). The high salinity of the sediments causes groundwater quality to decline towards the Etosha basin.

CHAPTER 3: LITERATURE REVIEW

3.1 Water Quality and Geochemistry

3.1.1 Water Quality

Groundwater from hand dug wells that tap shallow aquifers are still the main source of drinking water for the rural communities of Cuvelai Etosha Basin. Prichard et al, 2008, Sappa et el, 2014, and Liddle et al, 2015, found that it is a result of the abundance of shallow groundwater sources throughout sub Saharan Africa, the affordability of digging shallower wells than deep wells and the fact that groundwater is still believed to be less susceptible to pollution. However in many parts of the world and sub Saharan Africa people suffer from poor drinking water quality.

According to WHO (2004) standards; unsafe drinking water is related to a number of life threatening and infectious diseases. Prichard et al. 2008, supports this by stating that about 80% of all illnesses and or deaths in developing countries is due to water related diseases. Viruses and pathogens found in groundwater can cause diseases in humans. An example of such a pathogen is the cholera causing bacteria which is commonly derived from human faecal material and is the most common water quality problem in rural areas.

The quality of groundwater depends on the composition of recharging water and the mineralogy of the geological formations in the aquifers. According to Wanke, H., et al. 2015, the groundwater quality can also be influenced by groundwater pumping human activities, agricultural activities and contaminants from leaking fuel tanks. Unconfined aquifers and perched aquifers are more prone to contamination from overland flow, subsurface contamination, or atmospheric contaminants than confined aquifers. Also, shallower wells are more vulnerable to contamination than deeper wells and it is therefore crucial that hand dug wells be lined or covered. However this is not the case throughout the entire CEB.

3.1.2 The Geochemistry of Groundwater

The ability of water to dissolve ions from the solids it comes into contact with continuously changes the chemistry of water as it percolates through the subsurface. Inorganic and organic constituents, gases and solids found in the subsurface dissolve into groundwater. Hiscock (2005) notes that changes in geochemistry of groundwater can be related to the interaction of groundwater with geological materials i.e. soils and rocks, the varying composition of rainfall, modification of atmospheric input by evapotranspiration, biological processes in the soil zone as well as mixing of groundwater with seawater in coastal areas. Thus, interpretation of the distribution of hydrochemical parameters in the groundwater can help in the understanding of hydrogeological conditions, aid in classifying the water quality for drinking water and in ways to mitigate groundwater contaminants.

Changes in the chemistry of groundwater are not only due to the natural process as mentioned above but also due to anthropogenic input. Anthropogenic activities such as population growth, industrial growth and increase of agricultural activities can increase the concentration of certain constituent in the groundwater thus changing quality of the water and hence its use. For example, the excessive use of nitrogenous fertilizers can raise nitrate concentration in soil and groundwater above the desirable levels thus making this water unsuitable for human consumption.

Hiscock (2005) notes that organic compounds in groundwater are of a very low concentration of about 0.1 mg/l due to the oxidation of organic matter to carbon dioxide during infiltration through the soil zone. Inorganic constituents usually have a higher concentration and are divided into major constituents with concentrations greater than 10 mg/l; minor constituents with concentrations between 0.01 mg/l and 10 mg/l and trace elements with concentrations less than 0.01 mg/l, Hiscock (2005). Trace amounts of dissolved gasses, inert gasses and radiogenic products may also be present in ground water. The major constituents: major captions and major anions are the most common in ground water.

CHAPTER 4: RESEARCH METHODOLOGY

In this chapter the sampling and analytical methods employed to obtain the results on which the thesis is based are described. The chapter is divided into two parts: the first part describes the field work procedures and the second part the laboratory analysis of the samples collected during the field excursion. The research in general is quantitative, however qualitative observation and measurements of data are done is such a way that other researchers can duplicate the authors work.

4.1Field Work

The sampling took place during the raining season (February to March 2015) and during the dry season (August 2015). Samples were collected from perched aquifers; which are tapped by hand dug wells that use a rope and bucket method, of selected villages in the Omusati and Ohangwena region. Upon the arrival at a village, first contact was made with the village chief or owners of the wells for permission to sample the water. One or two wells were sampled at each village depending on whether they are used by the villagers. Water temperature, pH, redox, electrical conductivity (EC) and the depth to water table were measured on site for each well.

The above mentioned parameters change once exposed to the surface atmosphere and during storage and therefore are collected on site in order for them to be representative of the aquifer conditions (Hiscock, 2005) .

Water samples were collect in 1L and 250 ml plastic bottles for the analysis of anions and cations respectively. For the preservation of samples the 1L bottles were stored at a cool temperature in a cooler box with ice while samples in the 250 ml bottle were filtered and acidified with nitric acid. Cooling the samples limited the bacterial activity and the degradation of nutrient species while the acidification stabilized the dissolved metals in the solution. Thirty three hand dug wells were sampled during each sampling excursion (Tables 3 and 4 in Appendix 1). Two groundwater samples were collected at each well and hence a total of 66 samples were collected during each field trip. In addition to the data obtained from the analysis of these samples the researcher used some of the hydrochemical data, for 2013 and 2014, from the SASSCAL project available for the study area to better understand and interpret the special and temporal variations of the water quality.

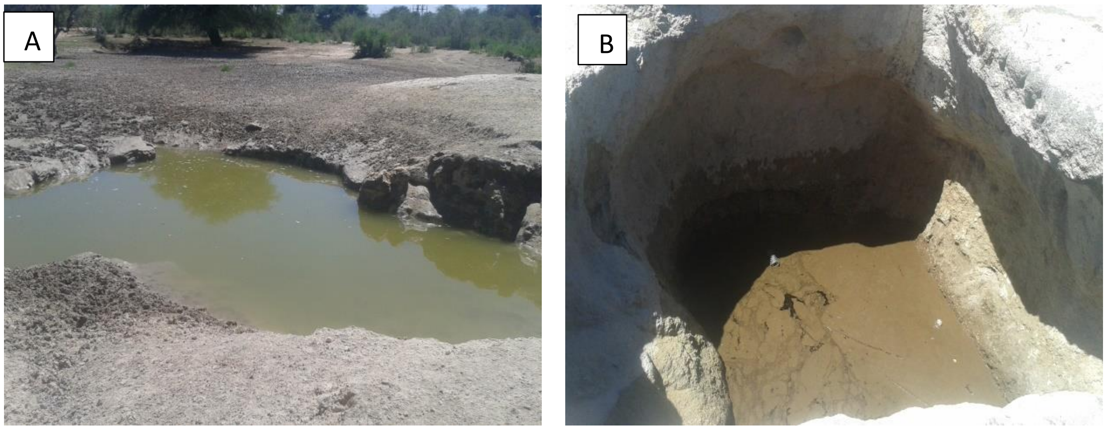

Figure 3: Pictures A and B is examples of wells sampled in the Omusati Region

4.2 Laboratory Analysis

This section gives a detailed description of the procedures employed for the analysis of the samples collected during the field excursion. The samples collected during the dry season where analysed by the researcher at the University of Namibia's hydrogeological laboratory while the samples collected during the raining season were analysed in Germany. Secondary data used were obtained from the analysis of the samples at the ACT laboratory. Analyses of samples at the UNAM laboratory were prepared with the Bach instruments. This was carried out by accurately following the instructions that came with each analytical instrument. The titration method was used for the analyses of chloride, fluoride, sulphide, nitride and alkalinity while filtration method was used for the TDS. Following subsections give a brief summary of the procedures.

4.2.1 Procedures for analysing Alkalinity

It was assumed that the sample had dissolved phosphates and carbonates, therefore a 100ml of the sample and the 1.600 H_2SO_4 was used. About 100ml of the sample was measured in an Erlenmeyer flask and one pack of Phenolphelein Indicator Powder added to it. Since the Sample did not change colour to light pink, a pack of Bromoresol Green-Methyl Red Indicator Powder was added upon which the colour changed to a greenish blue.

This solution was than titrated to a light pink colour (PH 4.5) with sulphuric acid. The total alkalinity was determined by the formular: Total Alkalinity= Digits Required x Digit Multiplier where the digit required is read off the Digital Titrator instrument and the digit multiplier is assumed as 1.0 based on the initial volume of the sample. Care was taken to clean the instruments after each analysis to minimize error.

4.2.2 Procedures for analysing Chloride (Cl^-), Fluoride (F^-) and Nitrate (NO_3)

The concentration of Chloride, Fluorite and Nitrated were determined using the Hach HQ40d multi analyser. For analysing the chloride content the HQ40d was calibrated with the

Chloride Standard Solutions. About 25 ml of the sample was measured into a beaker and one sack of chloride strength adjuster and a magnetic rod added to it. The sample was then placed on a stirrer plate and measured using the chloride reader tube. This tube was thoroughly washed with deionised water and the beaker rinsed after each sample. The chloride analyser tube was exchanged with the nitrate analyser and the HQ40d calibrated with the Nitrate standard Solutions. The procedure was repeated using the nitrate ionic strength adjuster instead of the chloride ionic strength adjuster. Fluoride concentration was determined using the same procedures however the HQ40d was calibrated with Fluorite Standard solutions and a fluoride ionic strength adjuster was used.

4.2.3 Procedures for determining TDS

A 100ml of the sample was measured in a measuring cylinder. The sample was than filtered using a filter paper and weight. All samples were than dried in an oven and the dry weight measured. The TDS was calculated by subtracting the dry weight of the sample from the weight of the wet sample (water). This was obtained in grams per millilitre and converted to the standard unit milligrams per litter.

CHAPTER 5: RESULTS

Table 2 Limits of Namibia Water Act (1956)

Parameter	Unit	Human consumption	Livestock watering
Temperature	°C	-	-
pH	pH-unit	< 4.0 ; > 11.0	-
Electrical Conductivity	µS/cm	4000	-
Turbidity	NTU	10	-
Sodium	mg/l	800	2000
Potassium	mg/l	800	
Calcium	mg/l	400	1000
Magnesium	mg/l	200	500
Iron	mg/l	2	10
Manganese	mg/l	2	10
Carbonate	mg/l	-	-
Bicarbonate	mg/l	-	-
Sulphate	mg/l	1200	1000
Chloride	mg/l	1200	3000
Fluoride	mg/l	3	6
Nitrate as N	mg/l	40	100
Nitrite as N	mg/l	-	10

5.1 Hydrochemistry

The physical- chemical parameters for analyzed groundwater samples showed a great variety during the wet and try seasons for each region. This subsection of the chapter gives a brief mathematical description of the physical-chemical parameters and a classification of the groundwater type for each region. The secondary data from the SASSCAL project is used for the classification of water type. This is because this sat of data has all the parameters analyzed. A tabulated summary of hydrochemical parameters for each region can be found in appendix 1 and 2.

5.1.1 Physical Parameters

Omusati Region

pH of the hand dug wells varied between 6.6 to 8.56 with an average of 7.49 and from 7.07 to 8.63 with an average of 7.53 during the wet and dry seasons of 2014 respectively, when resampled in 2015 it varied from 6.93 to 9.05 with an average of 7.47 and from 7.42 to 8.06 with an average of 7.70 during the wet and dry seasons respectively. The temperature of the hand dug wells ranged between 14.5- 22.6 ^{0}C with a mean of 17.8 ^{0}C and between 12.7- 31.9 ^{0}C with a mean of 19.2 ^{0}C during the wet and dry seasons of 2014 respectively. In 2015 the temperature varied between 19.8- 33.9 ^{0}C with a mean of 25.2 ^{0}C and between 12.5- 24 ^{0}C with a mean of 18.2^{0}C during the wet and dry seasons respectively. The range of EC for hand dug wells was 146- 7520 µS/cm and 630- 11450 µS/cm during the wet and dry seasons of 2014 respectively. When resampled in 2015 EC range was 203-10830 µS/cm during the wet season and 586- 9970 µS/cm during the dry season. The range of turbidity values was 6.02 to > 273 NTU during the wet season, 1.2 to > 297 NTU during 2014 and 1.98 to > 30 NTU during the 2015 wet season. The concentration of total dissolved solids ranged between 225.12- 5467.2 mg/l and 5.6- 7979.7 mg/l during the wet and dry seasons of 2014 respectively. When resampled during the wet and dry season 184.25- 3510.8 mg/l and

Ohangwena Region

The temperature of hand dug wells ranged between 23.8 ^{0}C and 33.7 ^{0}C with an average of 27.6 ^{0}C during the wet season of 2014, when resampled during dry1 season it ranged between 15 ^{0}C and 26 ^{0}C with an average of 22.5 ^{0}C and from 18.4^{0}C to 29.1 ^{0}C with an average of 23.9 ^{0}C during dry2 season. In 2015 it varied between 22.5- 36 ^{0}C with an average of 28.1 ^{0}C, 17.4- 28.6 ^{0}C with mean of 22.9^{0}C and 16.6- 27.2 ^{0}C with a mean of 24.1^{0}C during the wet, dry1 and dry2 seasons. The pH of the hand dug wells varied from 5.71- 10.39 with an average of 7.53, 5.81- 8.1 with an average of 7.25 and 5.68- 9.19 with an average of 7.37 during the 2014 wet, dry1 and dry2 seasons respectively. When resampled during the wet, dry1 and dry2 seasons of 2015 it varied between 4.45- 8.96 with mean of 6.62, 6.41- 8.87 with mean of 7.79 and 5-9.8 with mean of 7.50 respectively. EC values ranged between 45.1- 1904 µS/cm with an average of 520.14, 96.7- 2471 µS/cm with an average of 623.76 and 89.8- 909 µS/cm with an average of 389.54 µS/cm during the 2014 wet, dry1 and dry2 seasons respectively. During the 2015 sampling campaign the concentration of EC varied between 81.4- 867 µS/cm with an average of 415.41 µS/cm, from 52.1- 909 µS/cm with an average of 389.54 µS/cm and between 83.7- 898 µS/cm with an average of 370.94 µS/cm during the wet, dry1 and dry two seasons.

TDS concentration ranged between 48.24 -1226 mg/l with a mean of 325.97 mg/l during the wet season, from 64.79- 1645.1 mg/l with mean of 417.89 mg/l during dry1 season and from 55.61- 940.68 mg/l with a mean of 309.76 mg/l during dry2 season of 2014. In 2015 wet, dry1 and dry2 it ranged between 122.878- 580.89 mg/l with an average of 278.22, between 134.907- 609.03 mg/l with an average of 260.99 mg/l and from 56.079- 609.03 with an average of 269.46 mg/l respectively. The turbidity in hand dug wells ranged from 0- 169 NTU with mean of 48.8 NTU during the wet season and between 0.35- 761 NTU with an average of 87.51 NTU during the dry2 season of 2014. During 2015 wet season it ranged between 0.65- >185 NTU with an average of 46.48 NTU.

5.1.2 Chemical Parameters

5.1.2.1 Anions

Omusati Region

The chloride (Cl^-) concentration varied form 2.8 mg/l to 1006 mg/l and from 205 mg/l to 2143 mg/l during 2014 wet and dry seasons respectively. When resampled during the 2015 wet and dry seasons it ranged from 7.69 mg/l to 5673 mg/l and from 3.56mg/l to1653 mg/l respectively. Fluoride (F^-) concentration ranged between (0.1-1.5) mg/l and (0.1-1517) mg/l during the 2014 wet and dry seasons and between (0.19-1.95) mg/l and (0.39-3.92) mg/l when resampled during 2015 wet and dry season respectively. The sulphate concentration varied from <1mg/l to 2287 mg/l in 2014 wet season and from 2 mg/l to 3781 mg/l in 2014 dry season. When resampled during 2015 wet season it varied from 9 mg/l to 3200 mg/l and from 47 mg/l to 2356 mg/l during dry season of the same year. Nitrate varied from <0.5 mg/l to 103 mg/l during the wet season and from 0.9 mg/l to 27.5 mg/l in the dry season of 2014. In 2015 wet season nitrate concentration varied from 0.843 mg/l to 195 mg/l and from 0.55 mg/l to 614 mg/l in the dry season.

Ohangwena Region

The concentration of hand dug wells varied between 0.8- 0.17 mg/l, 0.666- 26.2 mg/l and 1.4-18 mg/l during the 2014 sampling campaign. In 2015 the concentration varied between 6.11-28.5 mg/l, 3.63- 20.9 and 3.67- 47.8 mg/l during the wet, dry1 and dry2 seasons respectively. Fluoride values varied between 0.1- 3.3 mg/l, 0.1- 4.36 mg/l and 0.1- 4.5 mg/l during 2014wet, dry1 and dry2 seasons respectively. When resampled during 2015 wet, dry1 and dry2 seasons it varied between 0.0456- 2.54 mg/l, 0.0- 2.94 mg/l and 0.039- 2.97 mg/l respectively. The sulphate concentration varied between <1- 29.1 mg/l, 0.99- 41.50 mg/l and 0- 53 mg/l in 2014 wet, dry1 and dry2 and between 1.99- 32 mg/l and 1.93- 29.1 during 2015 wet and dry2 seasons. Nitrate values ranged between <0.5- 64 mg/l, 0.56- 286 mg/l and 0.6-55 mg/l during the 2014 sampling campaign. In 2015 it ranged between 27.5- 2222 mg/l, 0.606- 220 mg/l and 1.16- 224 mg/l.

5.1.2.2 Cations

Omusati Region

The concentration of Sodium (Na^{+}) varied from 4.7 mg/l to 1633 mg/l and from 2 mg/l to 2414 mg/l during the wet and dry seasons of 2014 and from 2.9 mg/l to 2062 mg/l when resampled during 2015 dry season. Potassium (K^{+}) varied from 8.2 mg/l to 167 mg/l and 8.5 mg/l to232 mg/l during the 2015 wet and dry season respectively. When resampled during the 2014 dry season it ranged from 6.1 mg/l to 91.2 mg/l. The magnesium (Mg^{2+}) concentration varied from 5.4 mg/l to 194 mg/l during 2014 wet season and from 37 mg/l to 309 mg/l during dry season of the same year. When resampled during the dry season of 2014 it varied from 20 mg/l to 268mg/l. Calcium (Ca^{2+}) concentrate ion ranged between (24-1033) mg/l, (59-920) mg/l and (67.6-689) mg/l during 2014 wet, dry and 2015 dry season.

Ohangwena Region

The concentration of sodium in hand dug wells varied from 0.7- 462 mg/l, 1.0- 620 mg/l, and 0.8- 485 mg/l during 2014 wet, dry1 and dry2 seasons respectively. When resampled in 2015 it varied between 0.9- 62.5 mg/l and 0.7- 29.6 mg/l during 2015 dry1 and dry2 seasons. Potassium concentration varied between 3.6- 101 mg/l, 3.3- 132.5 mg/l and 2.7- 91 mg/l during the wet, dry1 and dry2 seasons of 2014. It varied between 2.5- 95.2 mg/l and 3.0- 82.6 mg/l during the 2015 dry1 and dry2 seasons. The concentration of magnesium in the hand dug wells ranged between 1.6- 31 mg/l, 1.53- 38.60 mg/l and 1.8- 41 mg/l during the 2014 wet, dry1 and dry2 seasons respectively. When resampled during the 2015 dry1 and dry2 season it varied between 0.833-29 mg/l and 2.34- 30 mg/l respectively. Calcium concentration varied between 2.5- 102 mg/l, 3.58- 117.0 mg/l and 3.6- 111 mg/l during 2014 wet, dry1 and dry2 seasons respectively. In 2015 it ranged between 2.85- 111 mg/l and 4.8- 102 mg/l during the 2015 dry1 and dry2 seasons.

5.1.3 Classification of groundwater type

The ionic concentrations of major cations (Na^+, K^+, Ca^{2+} and Mg^{2+}) and anions ($HCO3^-$, Cl^- and SO_4^{2-}) obtained from the analysis of the samples during wet and dry seasons were plotted on the Piper diagram to determine the groundwater type and its evolution. A piper plot was done for the wet and dry season for each region

5.1.3.1 Groundwater type for Omusati region

Analysis of the piper diagram for the samples collected during the wet and dry seasons suggest that the following water types exist in the Omusati Region

a) Ca-SO_4 type of water and

b) Na-HCO_3 type of water

Majority of the groundwater samples belonged to the Ca- SO_4 water type during both wet and dry seasons. Three out of the total samples belonged to the Na-Cl water type during both seasons. It is also observed from the plot that Ca^{2+} + Mg^{2+} cations dominate over the Na^+ + K cations which signify that alkaline earth (Ca+ Mg) exceeds alkalies (Na + k). SO_4 on the other hand dominates over the other anions. Piper diagrams for the Omusati region samples are shown in Figures 4 and 5.

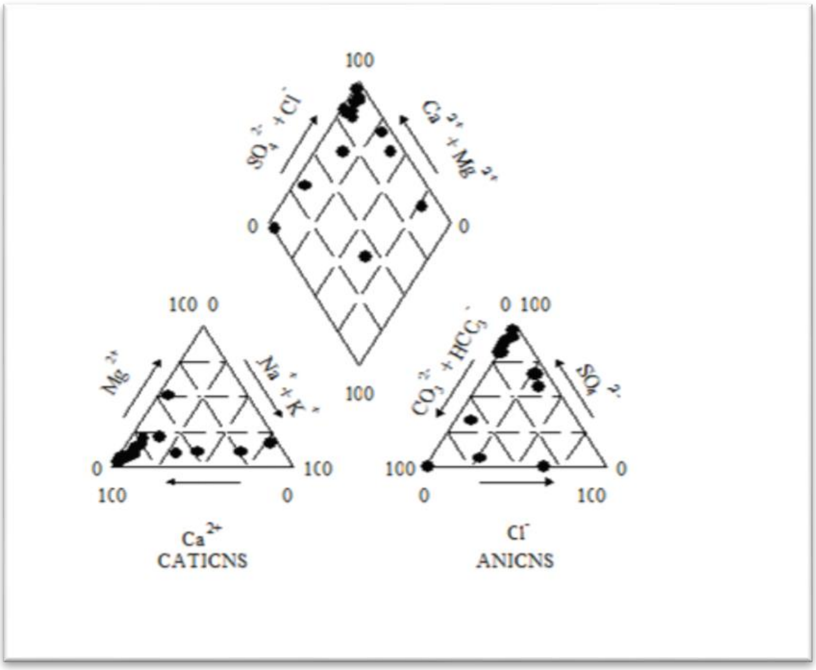

Figure 4: Piper diagram for hand dug wells in the Omusati region sampled during the 2014 wet season

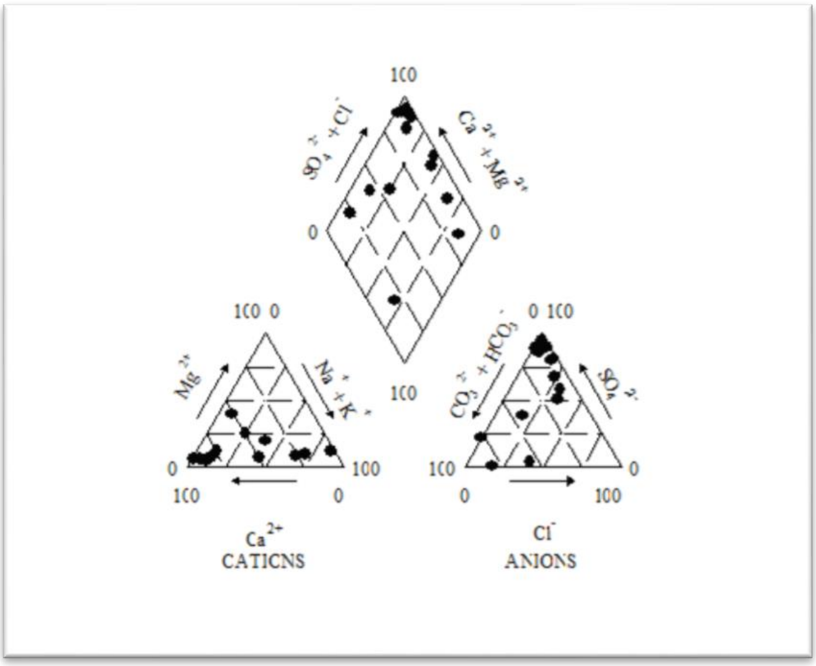

Figure 5: Piper diagram for hand dug wells in Omusati region sampled during 2014 dry season

5.1.3.1 Groundwater type for Ohangwena Region

Analysis of the piper diagram for the samples collected during the wet and dry seasons suggest that the following water types exist in the Ohangwena Region

a) $Ca\text{-}HCO_3$ water type for deep wells and

b) $Na\text{-}HCO_3$ water type for shallow wells

The majority of groundwater samples belonged to the $Ca\text{-}HCO_3$ water type during the wet and dry seasons for the deep wells while the majority of samples from the shallow wells belonged to the $Na\text{-}HCO_3$ water type. Week acids exceed strong acids in the deep wells as the HCO_3 anion dominates over the other anions. However, in the shallow wells alkalies (Na+ K) exceed alkaline earth (Ca+Mg). Piper diagrams for the Ohangwena region samples are shown in Figures 6 and 7.

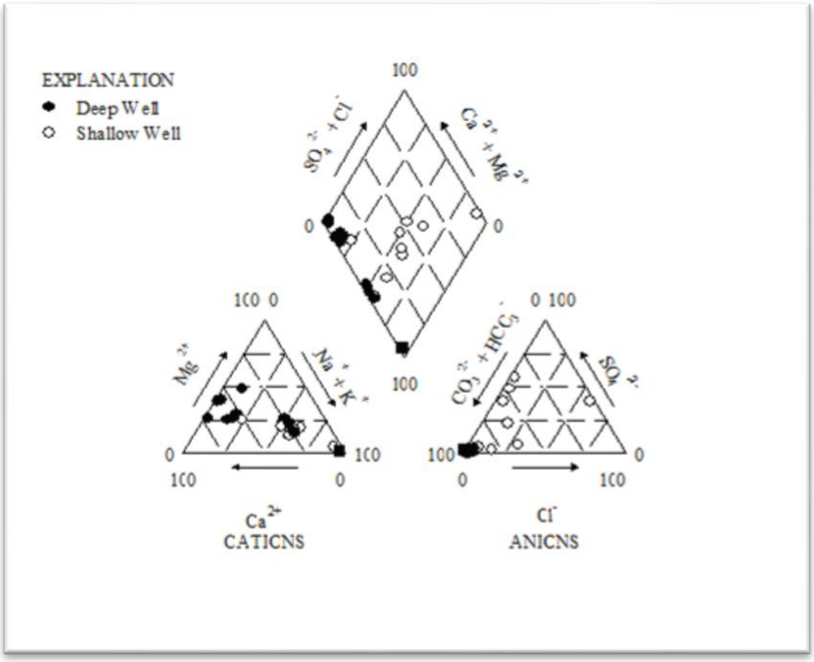

Figure 6: Piper diagram for hand dug wells in Ohangwena region sampled during the 2014 wet season

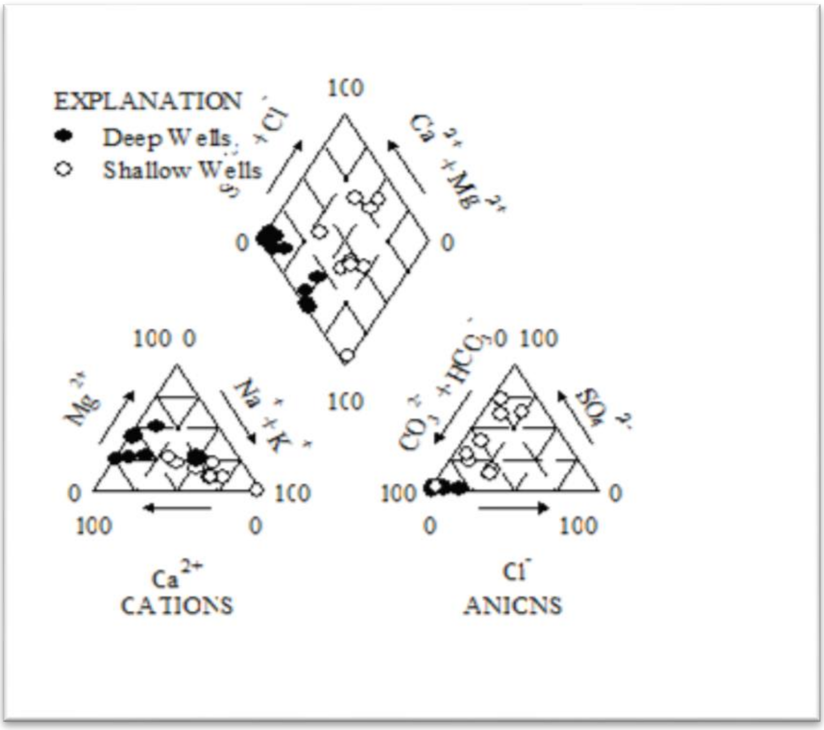

Figure 7: Piper diagram for hand dug wells in Ohangwena region sampled during 2014 dry season

5.2 Assessment of the groundwater quality

Assessment of groundwater quality was carried out in accordance with the Namibian Water Policy (Namibian Water Act, 1956) (Table 1). Substances of concern, which are parameters that are in classes C and D, were identified for each well and temporal and spatial variation maps and graphs produced for each substance. Only hand dug wells that were sampled and analysed for both dry and wet season of each year (2014 and 2015) were considered for the analysis of the water quality. Even though there are a number of parameters that have aesthetic effects in drinking water, only those that are of concern in the study area are described in depth. Tables 6 and 7 in appendix 3 give a summary of the substances of concern for Omusati and Ohangwena Region respectively.

5.2.1 Groundwater quality for Omusati Region

Total dissolved solids, electric conductivity, turbidity, sulphate, chlorite, fluoride and manganese were identified as the main substances of concern in the hand dug wells of Omusati region.

Total dissolved solids (TDS)

After Hiscock (2005) ground water can be classified based on TDS into:

- Fresh water 0-1000 mg/
- Brackish water 1000- 10,000 mg/l
- Saline water (sea water) 10,000- 100, 000 mg/l
- Brine water >100,000 mg/l

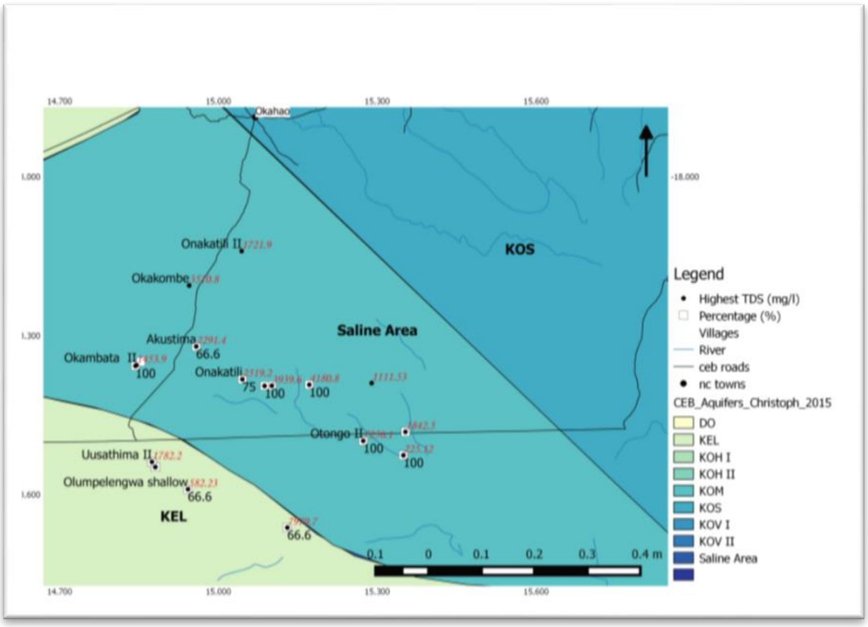

Figure 8: A map of TDS distribution in the hand dug wells of the Omusati region

77 % of the samples showed TDS values greater than 1000 mg/l. Only one out of ten wells had fresh water well the rest had brackish water. Hand dug wells in the north eastern part of the aquifer show a higher TDS concentration then the wells in the south west (Figure 8). The concentration of TDS shows a great variation between the wet and try seasons of each year. TDS concentration is generally higher during the dry season compared to the wet season (Figure 9).

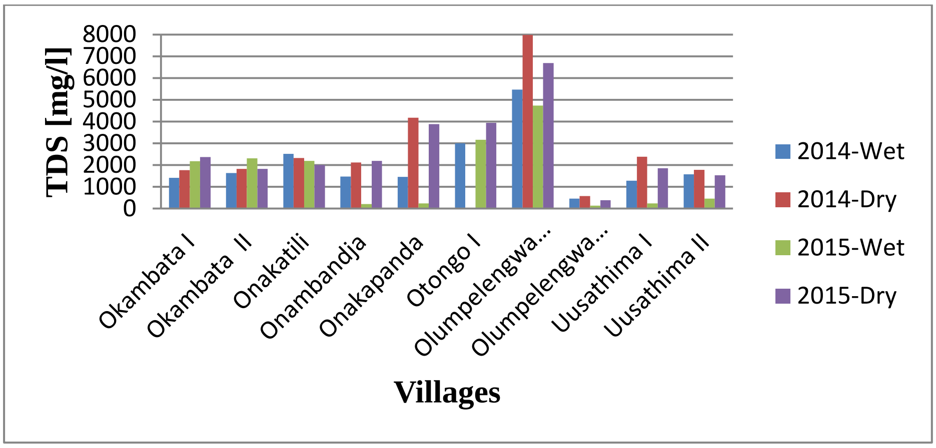

Figure 9: TDS time series for hand dug wells in the Omusati region

Electric Conductivity (EC)

Groundwater can be classified based on EC into (Adopted from Schaller):

- Rainwater 5 - 30 µS/cm
- Fresh groundwater 30 - 2000 µS/cm
- Mineral water 10000 - 20000 µS/cm
- Saline water 450000 -550000 µS/cm

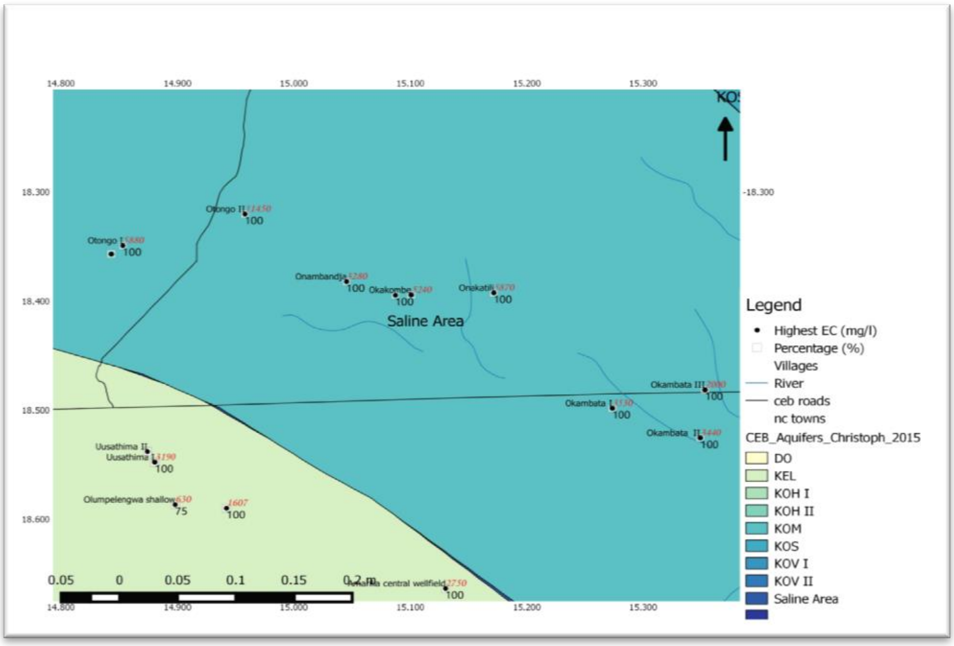

Figure 10: A map of EC distribution in hand dug wells of the Omusati region

95 % of the samples exceeded the Namibian drinking water limit of 400 µS/cm (Namibia Water Act, 1956). Electric conductivity shows a similar distribution to TDS concentration (Figure 10). The dry months recorded higher EC values then the wet months in both 2014 and 2015 (Figure 11).

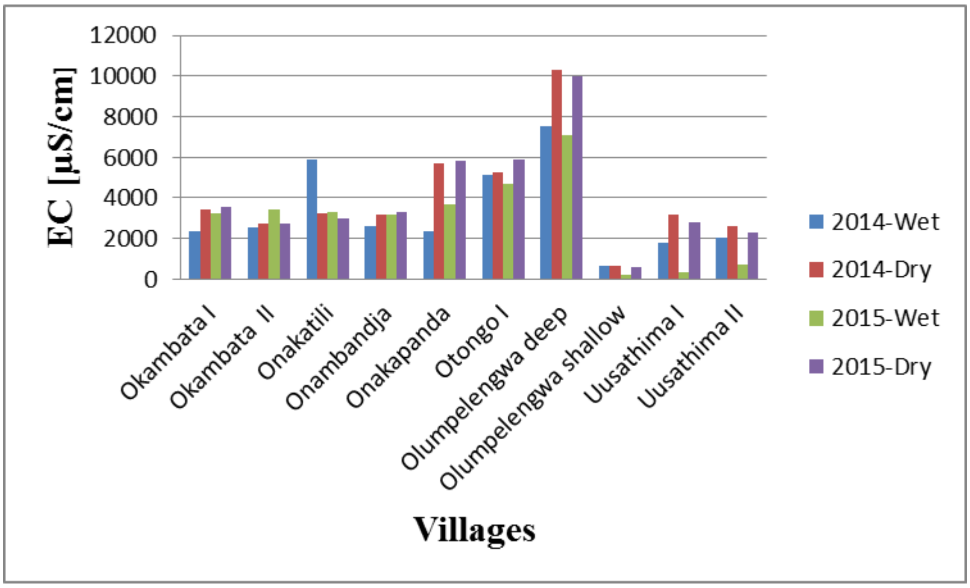

Figure 11: EC time series for hand dug wells in Omusati region

Turbidity (NTU)

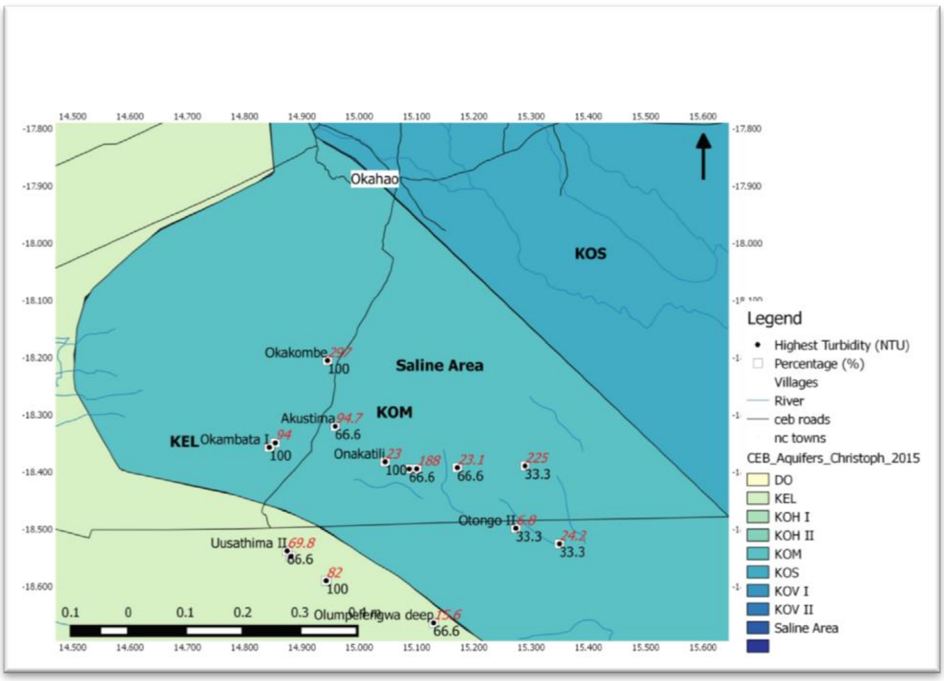

Figure 12: A map of the turbidity distribution in the hand dug wells of the Omusati region

75% of the samples exceeded the Namibian drinking water limit of 10 NTU (Namibian Water

Act, 1956). However 100% of the wells fell in the C and D classes, implying that turbidity is high throughout the whole aquifer (Figure 12). Even though a great variation of turbidity is observed in the hand dug wells (Figure 13), no specific trend is observed between the wet and dry seasons.

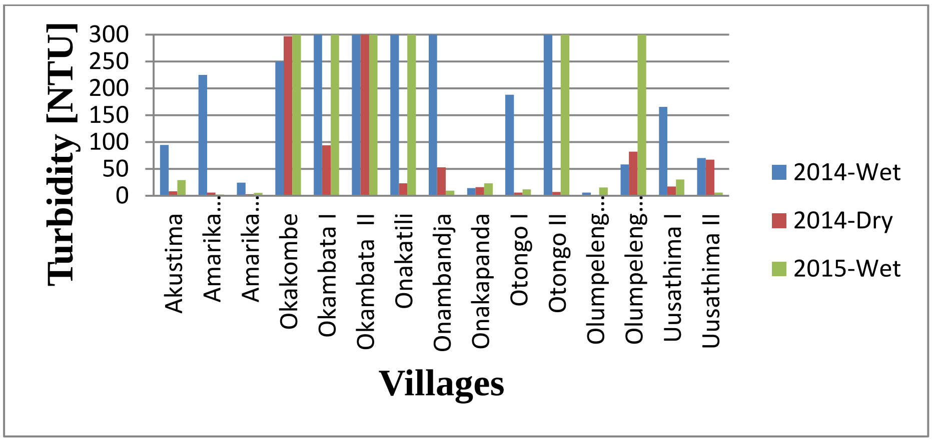

Figure 13: Turbidity time series for hand dug wells in the Omusati region

Sulphate (mg/l)

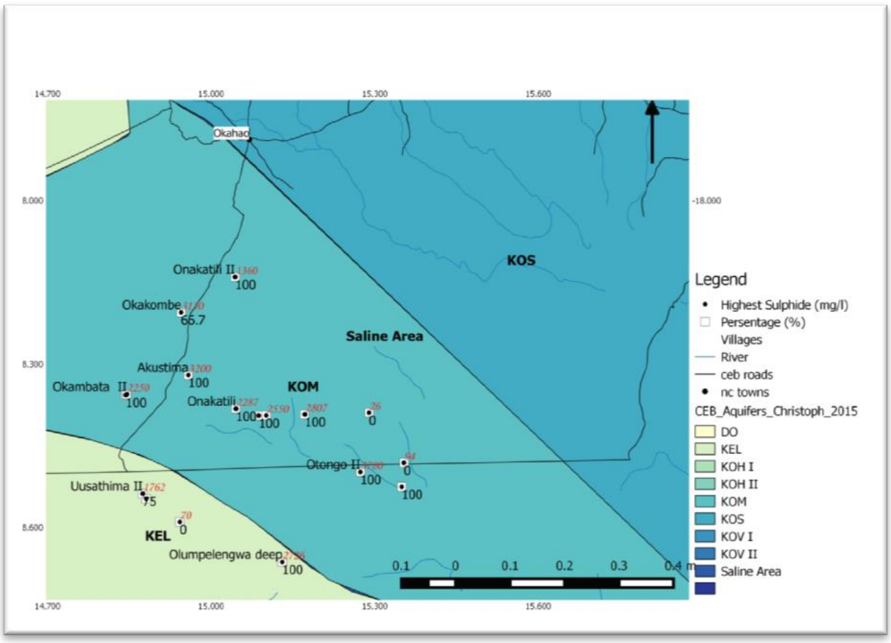

Figure 14: A map of sulphate distribution in the hand dug wells of Omusati region

The sulphate concentration is generally higher during the dry season as opposed to wet season (Figure 15). 70% of the samples exceeded the Namibian drinking water limit of 1200 mg/l (Namibian Water Act, 1956). Only one out of five hand dug wells had sulphate concentration in the A class. No specific trend was observed for the distribution of sulphate throughout the aquifer (Figure 14).

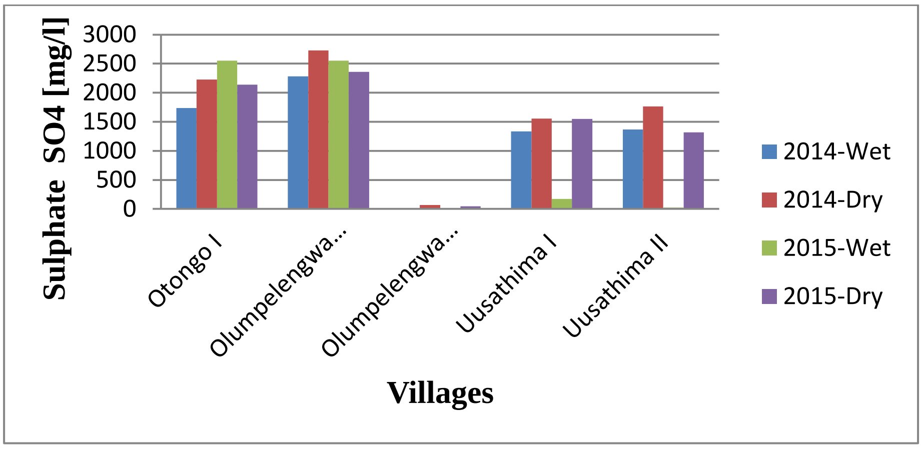

Figure 15: Sulphate time series in the hand dug wells of Omusati region

Chloride (mg/l)

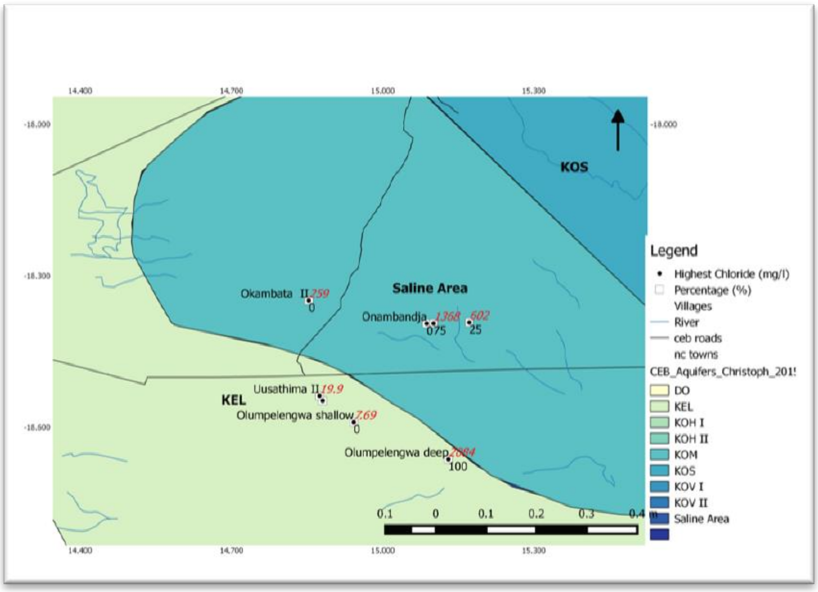

Figure 16: A map of the distribution of chloride in the hand dug wells of Omusati region

12.5 % of the samples exceeded the Namibian drinking water limit of 1200 mg/l (Namibian Water Act, 1956) and two out of eight wells had chloride concentration falling in the C and D classes. The chloride concentration was highest during the 2015 wet season but no specific trend is observed over the seasons (Figure 17). The two wells with high chloride values are on the eastern side of the aquifer (Figure 16).

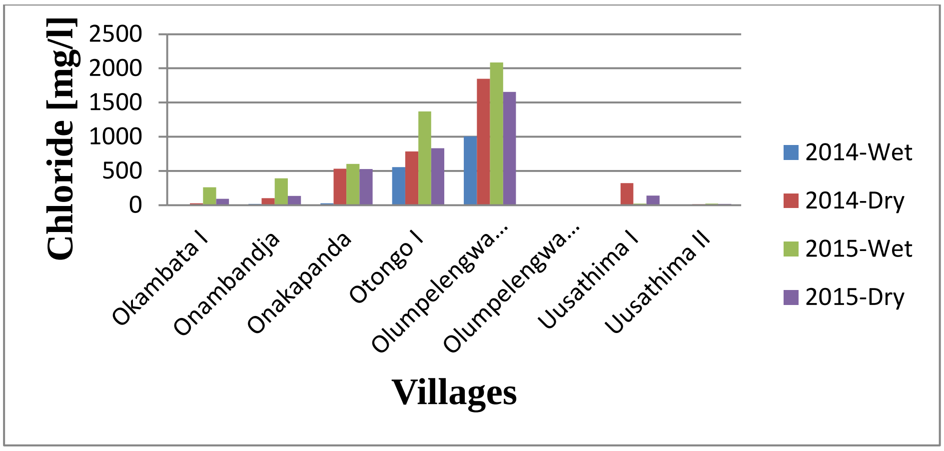

Figure 17: Chloride time series for hand dug wells in Omusati region

Fluoride (mg/l)

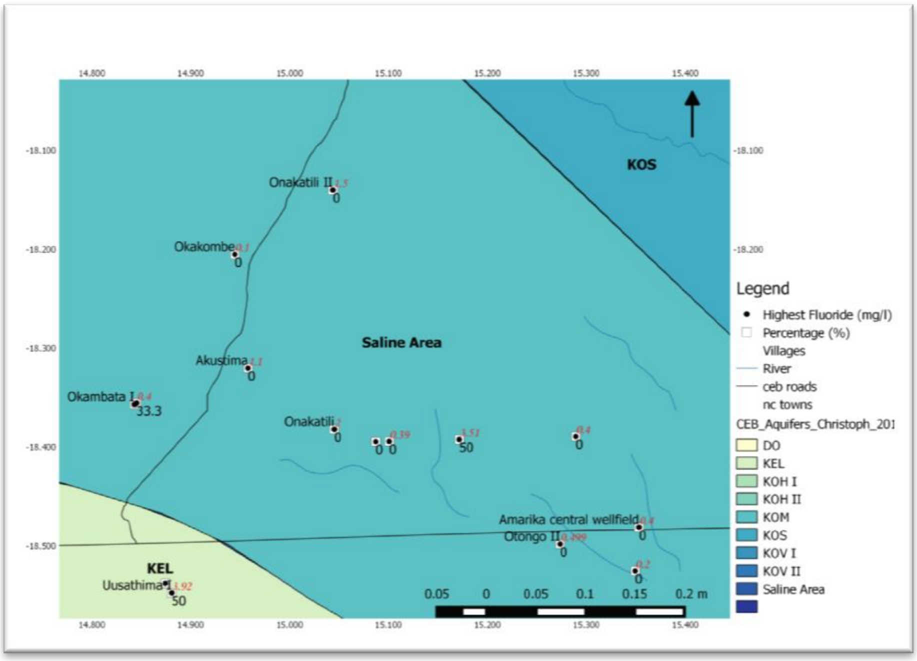

Figure 18: A map of the Fluoride distribution in hand dug wells of Omusati Region

There is no specific distribution pattern for fluoride in the aquifer (Figure 18). 18.8 % of samples exceeded the Namibian drinking water limit of 3 (mg/l) and three out of thirty hand dug wells had fluoride concentration > 3 mg/l. Fluoride concentration is higher during the dry season (Figure 19).

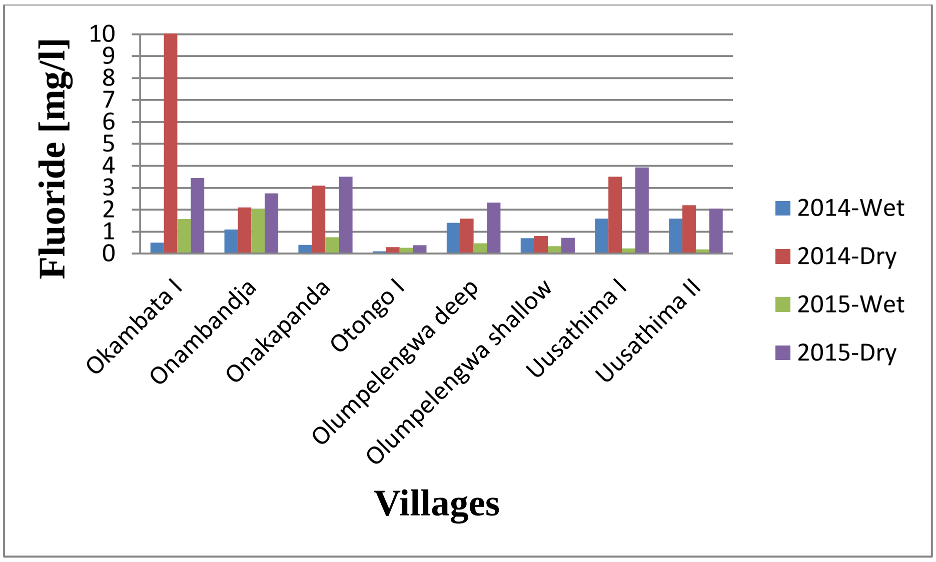

Figure 19: Fluoride time series for hand dug wells in Omusati region

Manganese (mg/l)

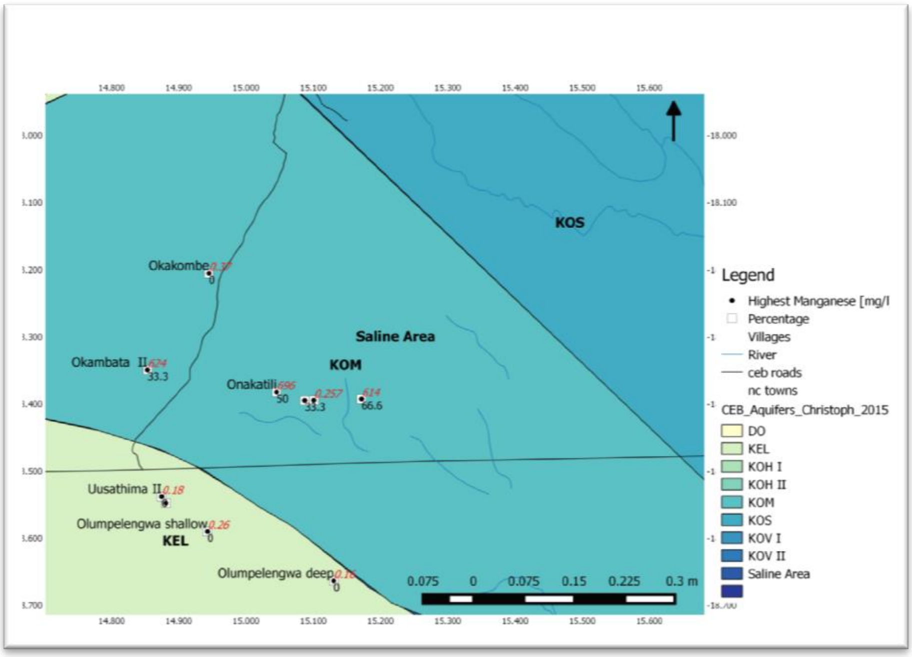

Figure 20: A map of manganese distribution in the hand dug wells of Omusati region

12.5 % of the samples exceeded the Namibian drinking water limit of 2 mg/l and five out of forty hand dug wells had Mn > 2 mg/l. Manganese concentration is highest during the dry seasons (Figure 21). Hand dug wells with high Mn are in north of the aquifer (Figure 20).

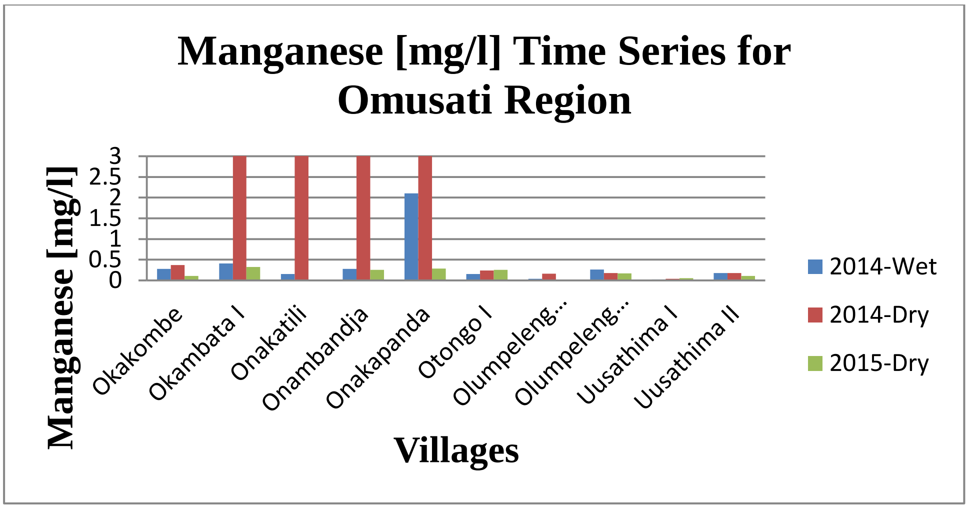

Figure 21: Manganese time series for hand dug wells in Omusati region

Figure 22: Manganese time series for hand dug wells in the Omusati region

5.3 Groundwater quality for Ohangwena Region

Total dissolved solids, EC, turbidity, nitrate and iron were identified as the major substances of concern in the Ohangwena region

Electric conductivity EC (µS/cm)

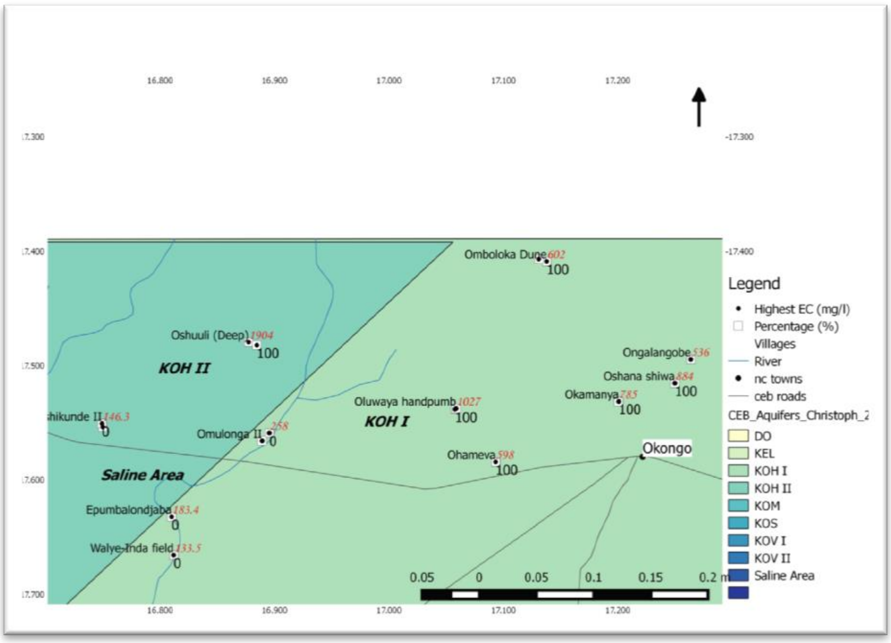

Figure 23: A map of the EC distribution in hand dug wells of the Ohangwena region

41 of 84 samples (48.8%) exceeded the Namibian drinking water limit of 400 µS/m (Namibian Water Act, 1956). Six out of fourteen wells can be classified as fresh groundwater

(EC< 200 µS/m). The EC does not really exhibit a great temporal variation over the two years it was sampled except in the Oshuuli shallow well which has a much higher EC during the dry season as compared to the wet season (Figure 24). Spatially the deeper wells on the north eastern side closer to Okongo have a higher EC than shallow wells (Figure 23).

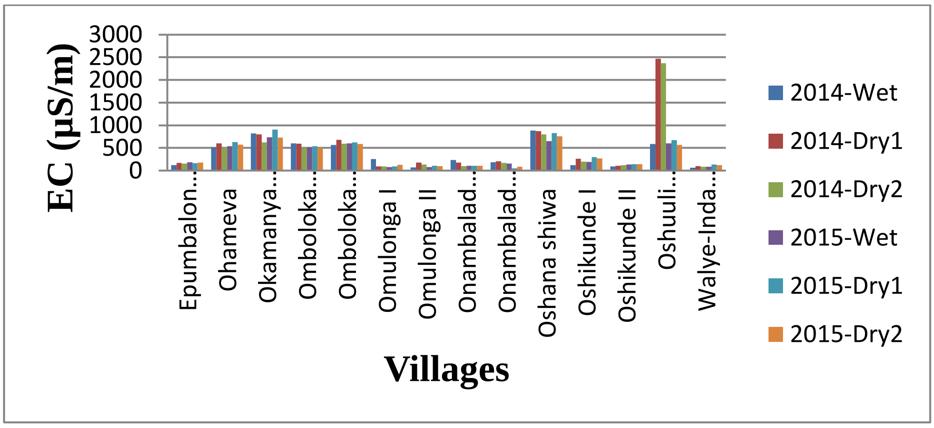

Figure 24: EC time series in hand dug wells of Ohangwena region

Total dissolved solids TDS (mg/l)

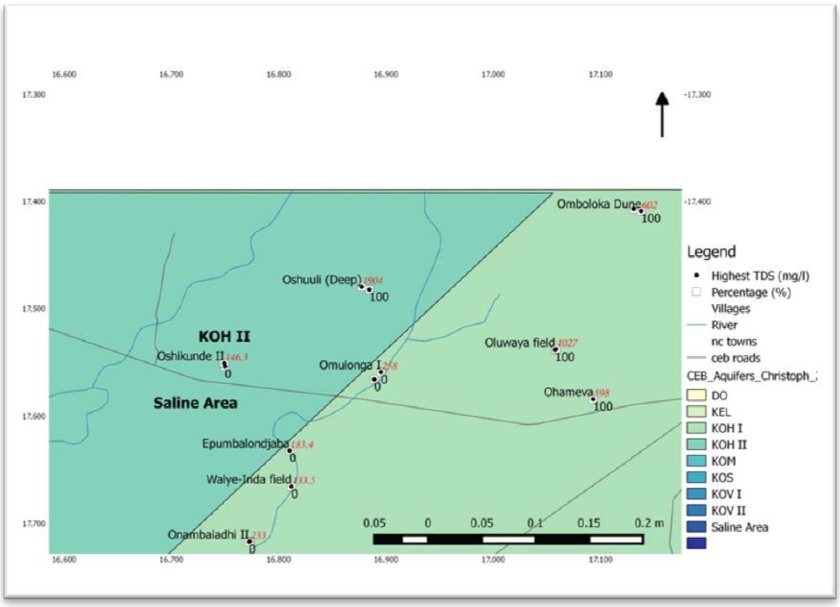

Figure 25: A map of TDS distribution in hand dug wells of the Ohangwena region

TDS shows a similar distribution to EC, but in lower concentrations. The deeper wells show a higher TDS than shallow wells (Figure 25). Where high concentrations occur in the north and eastern parts of the aquifer, low concentrations occur towards the west and south. 1of 84 samples (Oshuuli shallow well) can be classified as brackish water (TDS: 1000-10000), whereas the rest is fresh water, TDS< 1000 mg/l. Even though there is a variation during the wet and dry seasons of both 2014 and 2015 no specific trend of temporal variation is observed (Figure 26). Only Oshuuli shallow well had brackish water (TDS>1000) while the rest of the wells had fresh water (TDS< 1000)

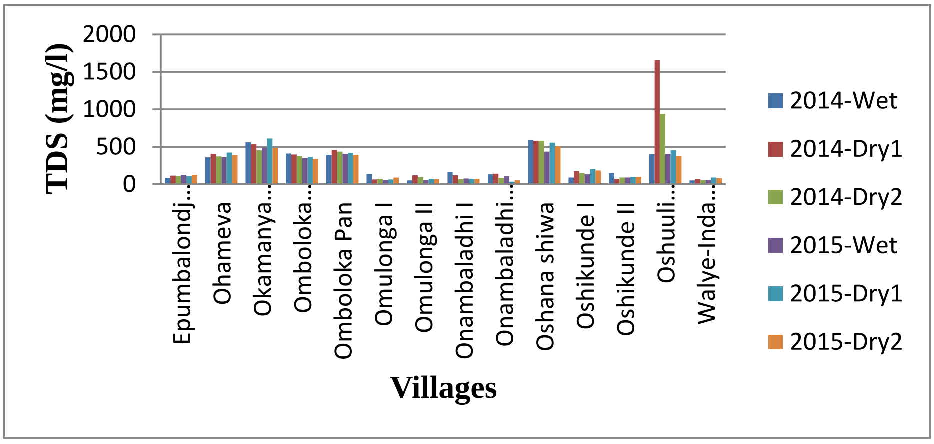

Figure 26: TDS time series of hand dug wells in Ohangwena region

Turbidity (NTU)

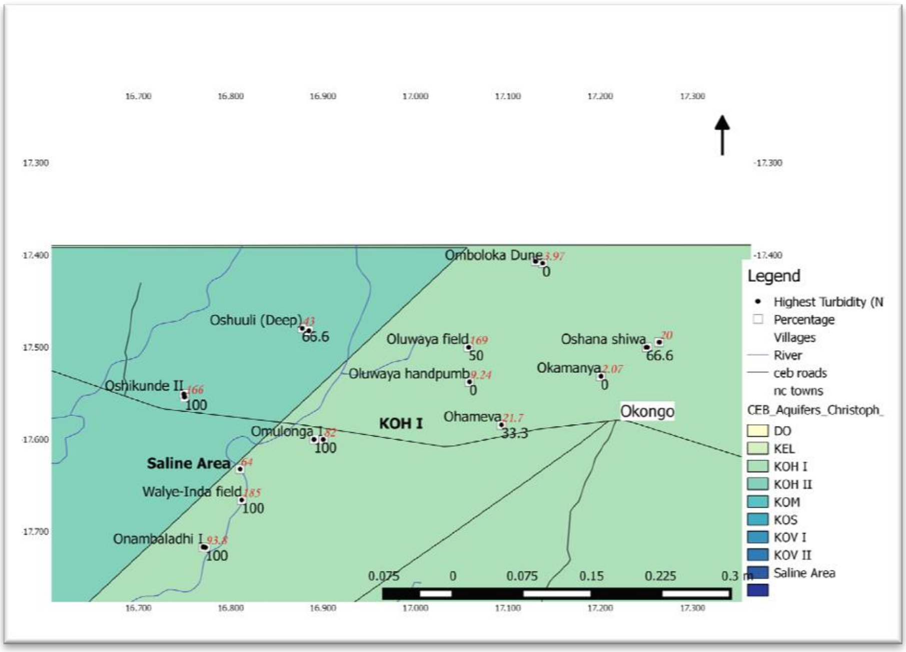

Figure 27: A map of turbidity distribution in hand dug wells of Ohangwena region

30 of 45 samples (66.7 %) exceeded the Namibian drinking water limit of 10 NTU (Namibian Water Act, 1956) and twelve out of seventeen wells had a high turbidity concentration .The groundwater turbidity for the hand dug wells on average was higher during 2014 dry2 season

compared to the wet seasons (Figure 28). The shallower wells have a higher turbidity than the deeper wells this is mostly on the western side of the region (Figure 27).

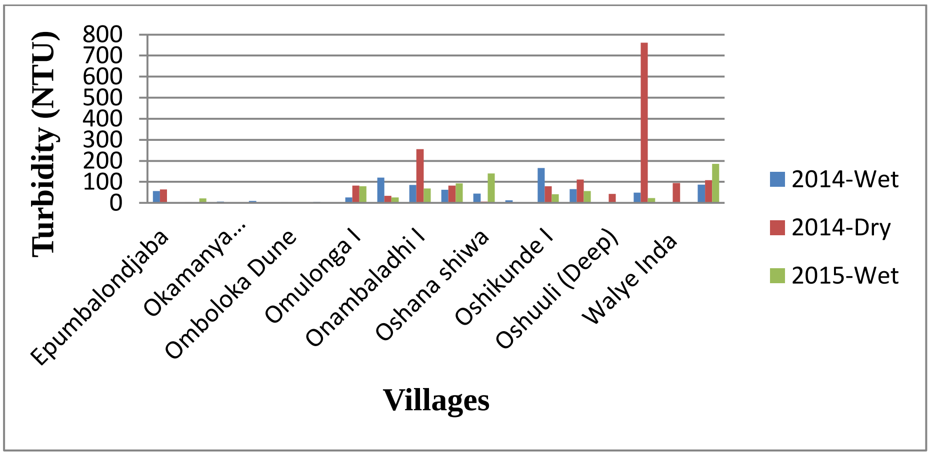

Figure 28: Turbidity time series for hand dug wells in Ohangwena region

Nitrate N (mg/l)

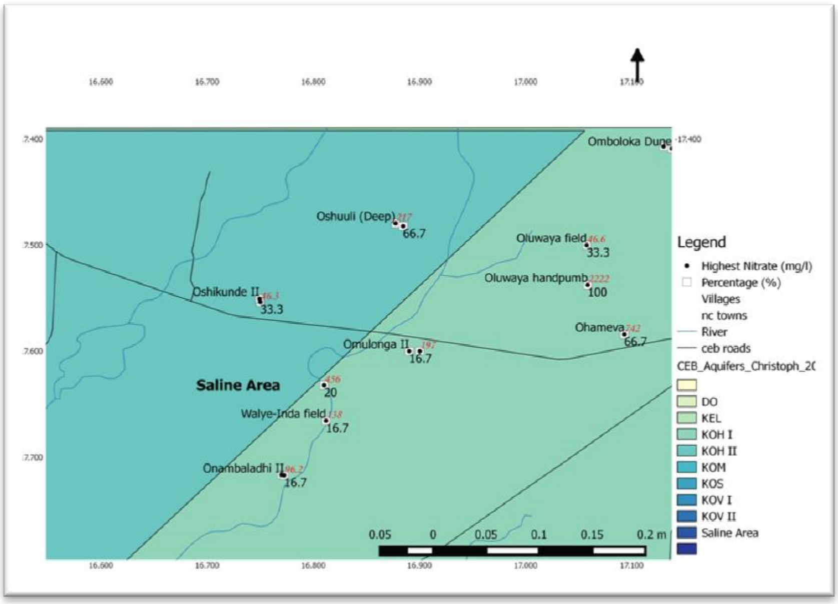

Figure 29: A map of Nitrate distribution in hand dug wells of the Ohangwena region

Nitrate concentrations in the hand dug wells show a great variation between the seasons. 32 of 78 samples exceeded the Namibian limit of 40 mg/l (Namibian Water Act, 1956) while 10 out of fourteen wells had a high N concentration. High concentration of nitrate was measured in the north of the aquifer (Figure 29). Highest values were measured during the 2015 wet season (Figure 30).

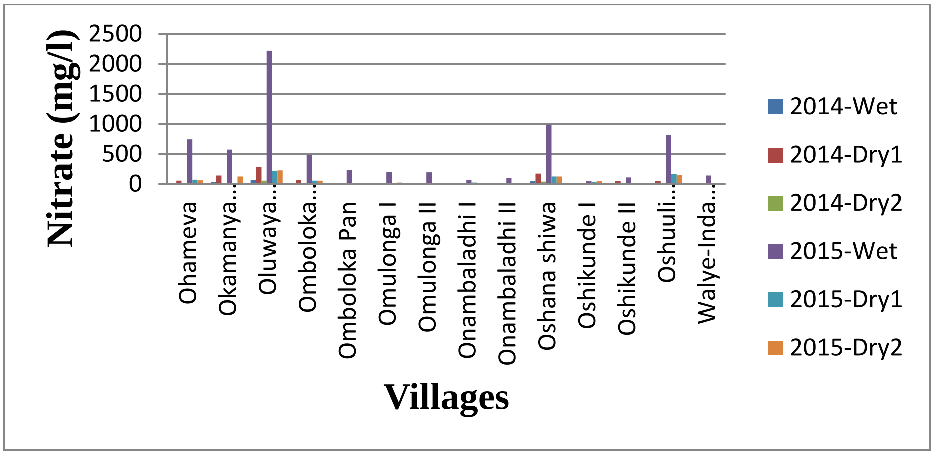

Figure 30: Nitrate time series for hand dug wells in Ohangwena region

Iron Fe (mg/l)

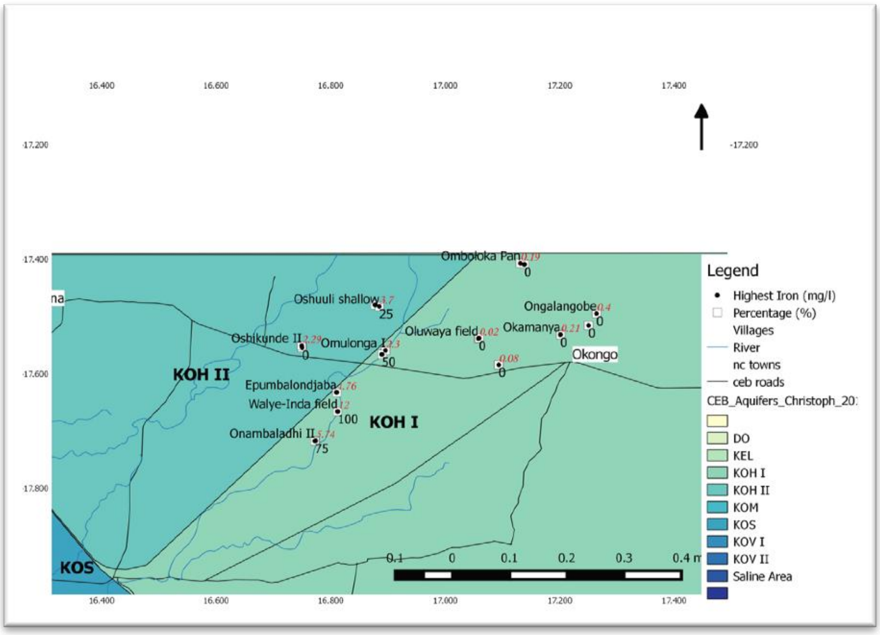

Figure 31: A map of Iron distribution in hand dug wells of Ohangwena region

Six out of thirteen wells show a high Fe concentration. 42.9% (24 of 56) of samples exceeded the Namibian limit of 2mg/l (Namibian Water Act, 1956). Highest values of iron were recorded during the dry seasons as compared to wet seasons of both 2014 and 2015 (Figure 31). These high iron concentrations were recorded in shallow wells in the west and east of the aquifer (Figure 32).

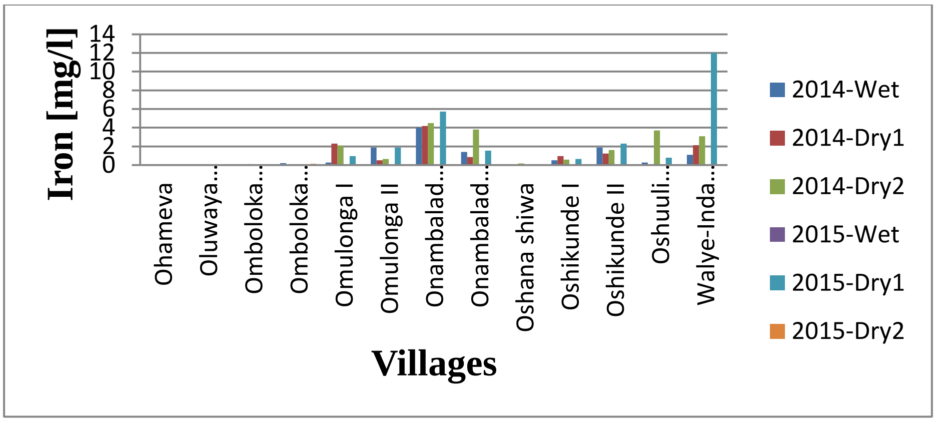

Figure 32: Iron time series for hand dug wells in Ohangwena region

CHAPTER 6: DISCUSSION AND INTERPRETATION

This chapter presents the discussion and interpretation of the results. This discussion and interpretation of the results follow the order of the study objectives.

6.1 Hydrochemistry of groundwater in the perched aquifers of Omusati and Ohangwena Region

The study revealed that groundwater in the Omusati region is dominated by low pH and high TDS, EC and turbidity as tabulated (Table 11). Further analysis of the major ions showed an abundance of the ions in ratio of $Ca^{2+} > Mg^{2+} > Na^{+} > k^{+}$ and $SO_4^{-} > HCO_3^{-} > Cl^{-} > NO_3^{-}$ (Figure 4 and 5). Groundwater samples of the Ohangwena region is dominated by low pH, TDS and EC and high turbidity for the shallow wells (Table 12). Referring back to (table) it is clear that the deep hand dug wells are dominated by low pH and turbidity and TDS and EC values than the shallow wells but less than the wells of the Omusati region (Table 6). The ionic abundance pattern of the water samples from cations to anions for the shallow hand dug wells is $Ca^{2+} > Na^{+} > Mg^{2+} > K^{+}$ and $HCO_3^{-} > NO_3^{-} > SO_4^{-} >$ Cl (Figure 6) and that of the deep wells is $Na^{+} > K^{+} > Ca^{2+}$ and Mg^{2+}(Figure 7). The abundance of

the ratio shows that the geology of the aquifer is composed of calcium rich minerals at shallow depth and sodium rich minerals at deeper levels. This is in line with the findings of Bittner (2006) and Miller (2008) that described the geology of the CEB as resent aeolian deposits covering calcrete which overlie the Adonai formation of the Kalahari Sequence. The hydrochemistry of the area is therefore influenced by the weathering of geological units of the aquifer. The enrichment of iron in the Ohangwena region and manganese in the Omusati region could be due to the weathering of the iron rich red clay minerals and carbonates in the aquifer. It could however also be a result of surface water seepage, direct seepage or direct surface runoff.

6.2 Substances of concern in the hand dug wells of the study area

Findings presented in (Table 12) show those total dissolved solids, conductivity, turbidity, nitrate and iron are the main substances of concern for the Ohangwena study area. Schaller (2012) also identified the same parameters as substances of concern for the Ohangwena aquifers. While total dissolved solids, conductivity, turbidity, sulphate, fluoride, chloride and manganese are the main substances of concern for the Omusati region (Table 11). Wanke, H., et al. (2015) also identified TDS and sulphate as major substances of concern in the Omusati region. Iron and nitrate exceeded the Namibian drinking water limits in one or two wells in the Omusati region while fluoride and chloride were identified as minor substances of concern for the Ohangwena region.

The reading of figures (showing the distribution of substances of concern) clearly show that TDS, EC, turbidity, sulphate, chloride, fluoride, iron and manganese concentrations generally increase during the dry season and decrease during the wet season. These could be due to the high evaporation rates during summer and the dilution of the groundwater due to rise in water level during raining season. The nitrate concentration on the other hand increased during raining season as shown in figure 16.

6.3 Spatial variation of substances of concern

No specific spatial distribution of TDS, EC turbidity, sulphate and chloride where observed in the Omusati region, except for fluoride as shown in figure 18 which showed high concentrations on the east of the aquifer. Generally, the substances of concern are wide spread throughout the aquifer.

Comparing (figure 23) to (figure 25) it is clear that TDS and EC are higher in the deep wells of the Ohangwena region than to the shallow wells. This could be due to the interaction of groundwater with the mineralogy of the aquifer. Turbidity and Nitrate on the other hand are higher in the shallow wells than in the deeper wells as presented in figures 27 and 29. This could be due to the high evaporation rates, surface runoff and or surface water seepage into the perched aquifer.

Chapter 7: Conclusion and recommendations

The results of my findings presented in my tables and figures show that shallow wells yield water of very poor quality hydrochemical. Chemical constituents such as TDS, EC, turbidity, sulphate, chloride, fluoride and manganese influence the water quality of the Omusati region while the water quality of the Ohangwena region is influenced by TDS, EC, turbidity, nitrate and iron. The salinity of the CEB is observed to be decreasing from the north to south as observed in the regions. Hence the water quality is not the same throughout the perched aquifer of the CEB. It can also be concluded from the temporal variations that the water quality in the perched aquifer is not the same during the wet and dry seasons.

The groundwater of the Omusati region was classified as $Ca\text{-}SO_4$ water type and that of Ohangwena region as $Ca\text{-}HCO_3$ water type for deep wells and $Na\text{-}HCO_3$ water type for shallow wells.

Even though the objectives of the study were reached further improvements can be made to ensure maximum accuracy is obtained from the data. It is therefore recommended that all parameters be analyzed for each well that is sampled, only wells that are in constant use are sampled and that samples are labeled the same during each sampling excursion to avoid mixing of samples. It is also recommended that water be treated by defluoridation and desalination before consumption.

References

Fetter C. W, 2001, Applied Hydrogeology

Hiscock K. M, 2005, Hydrogeology: principles and practice

MENDELSOHN, J., EL OBEID, S. & ROBERTS, C. (2000): A profile of north-central Namibia. – *Environmental profiles project; Directorate of Environmental Affairs, Ministry of Environment and Tourism; 79 p.; Gamsberg Macmillan Publisher, Windhoek.*

Mendelsohn J., Jarvis A., Robertson T., 2013, A profile and atlas of the Cuvelai Etosha Basin

Miller R. McG., Pickford M., and Senut B., 2010, *Geology, palaeontology and evolution of the Etosha Pan, Namibia: Implication for the terminal Kalahari deposition. South African journal of geology, 2010, volume 113.3 page 307-334*

Ministry of Agriculture, Water and Forestry, 2008, Water supply and sanitation policy, File number 7/3/78P

Namibia's Fourth National Development Plan (NDP_4), ISBN 978-99945-0-055-0

Office of the President National Planning Commission, 2012/13 to 2016/17, Republic of Namibia

Roscoe Moss Company, Handbook of groundwater development

Word Meteorological Organisation, 2013, Planning of Water Quality Monitory Systems, Technical Report Series No. 3

Appendix 1

Table 3: Location and description of hand dug wells in Omusati region

Village	Latitude (S)	longitute	Type of hand dug well
Okakombe	-18.20500	14.94444	SHW
Akutsima	-18.32000	14.95778	SHW
Okambata I	-18.35667	14.84306	SHW
Okambata II	-18.34889	14.85306	SHW
Okambata III	-18.35528	14.845	SHW
Onakatili I	-18.38194	15.045	SHW
Onakatili II	-18.14000	15.04361	SHW
Onambandja	-18.39444	15.08694	SHW
Onakapanda	-18.39222	15.17139	SHW
Olumpelengwa deep	-18.66333	15.13	SHW
Olumpelengwa shallow	-18.58972	14.94222	SHW
Uusathima I	-18.54750	14.88056	SHW
Uusathima II	-18.53778	14.87417	SHW
Otongo I	-18.39417	15.10056	SHW
Otongo II	-18.49806	15.27333	SHW
Amarika Southwellfield	-18.52528	15.34917	SHW
Amarika central wellfield	-18.48111	15.35306	SHW
Amarika north wellfield	-18.38917	15.28917	SHW
Okakewa I	-18.64639	15.45083	SHW
Okakewa II	-18.64833	15.45472	SHW

SHW- Shallow well

Table 4: Location and distribution of hand dug wells in Ohangwena region

Village	Latitude (S)	longitute	Type of hand dug well
Oshana-shiwa handpump	-17.51438	17.25073	DW
Oshana-shiwa	-17.51525	17.24986	DW
Ongalangobe	-17.49447	17.26375	DW
Okamanya handpump	-17.53152	17.20070	DW
Omboloka Pan	-17.40678	17.13072	DW
Omboloka Dune	-17.40878	17.13767	DW
Oluwaya handpumb	-17.53747	17.05842	DW
Oluwaya field	-17.53808	17.05747	DW
Ohameva	-17.58411	17.09300	DW
Epumbalondjaba	-17.63208	16.80992	SHW
Walye-Inda field	-17.66561	16.81169	SHW
Onambaladhi I	-17.71669	16.77308	SHW
Onambaladhi II	-17.71711	16.77228	SHW
Oshikunde I	-17.55364	16.74981	SHW
Oshikunde II	-17.55058	16.74911	SHW
Oshuuli shallow	-17.48203	16.88436	SHW
Oshuuli (Deep)	-17.47936	16.87719	DW
Omulonga I	-17.55889	16.89528	SHW
Omulonga II	-17.56572	16.88900	SHW

SHW- Shallow well

DW- Deep well

Appendix 2

Table 5: Summary of chemical parameters (anions) in hand dug wells of Omusati region

Parameter	Chloride Cl (mg/l)				Fluoride F (mg/l)				Sulphate SO_4 (mg/l)				Nitrate N (mg/l)			
Season	2014		2015		2014		2015		2014		2015		2014		2015	
Month	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August
Villages																
Akustima	4	26	43	-	0.6	1.1	0.954	-	1198	1712	3200	-	0.6	2.3	14.7	-
Amarika Southwellfield	9	-	-	-	0.2	-	-	-	1274	-	-	-	0.8	-	-	-
Amarika central wellfield	21	218	1393	-	0.3	0.4	0.338	-	94	2	54	-	0.9	2.9	47.2	-
Amarika north wellfield	186	297	411	-	0.2	0.4	0.233	-	<1	26	9	-	6.4	2.2	3.45	-
Okakombe	46	134	4771	-	0.1	0.1	-	-	15	1669	3150	-	1	0.9	195	-
Okambata I	3.8	28	259	92.1	0.5	1517	1.58	3.44	1245	1517	2250	-	0.6	3.7	4.36	0.55
Okambata II	11	-	1.16	37.8	0.5		1.01	3.66	1355	-	2250	-	0.8	-	12.2	7.85
Okambata III	5.9	-	-	-	0.4	-	-	-	1274	-	-	-	4.1	-		-
Onakatili	17	52	6081	-	0.5	2	1.95	-	2287	2009	2150	-	interference	1.9	2.97	-
Onakatili II	25	-	-	-	1.5	-	-	-	1360	-	-	-	1.1			-
Onambandja	17	101	392	136	1.1	2.1	2.03	2.75	1245	1680	1800	-	0.5	4.2	2.44	-
Onakapanda	28	534	602	526	0.4	3.1	0.752	3.51	1279	2807	2200	-	0.7	14	4.34	-
Otongo I	557	783	1368	831	0.1	0.3	0.265	0.39	1737	2226	2550	2139	1.5	4	5.73	3.41
Otongo II	641	2143	5673	-	0.2	0.4	0.499	-	2084	3780	2900	-	1.1	1.5	18.9	-
Olumpelengwa deep	1006	1847	2084	1653	1.4	1.6	0.465	2.33	2281	2726	2550	2356	103	316	11.6	614
Olumpelengwa shallow	2.8	2.5	7.69	3.56	0.7	0.8	0.343	0.72	<1	70	13	47	4.5	17	0.843	8.12
Uusathima I	4.5	322	21.7	140	1.6	3.5	0.236	3.92	1337	1555	175	1552	<0.5	11	1.71	27.8
Uusathima II	9	10	19.9	15.9	1.6	2.2	0.19	2.05	1366	1762	25	1317	<0.5	2.7	1.29	1.27

(-) Not sampled

(*) Not analyzed

Table 6: Summary of physical parameters in hand dug wells of Omusati region

Parameter	Ph				Temperature				EC				Turbidity				TDS			
Year	2014		2015		2014		2015		2014		2015		2014		2015		2014		2015	
Month	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August
Villages																				
Akustima	7.19	7.35	7.63	-	18.5	20.2	21.6	-	2030	2530	3420	-	94.7	8.4	29	*	1407	1862.6	2291.4	-
Amarika Southwellfield	6.6	-	-	-	18.9	-	-	-	146	-	-	-	212	-	-	*	225.12	-	-	-
Amarika central wellfield	7.75	8.18	7.01	-	15.6	12.7	24.4	-	526	2148	2750	-	225	5.7	1.98	*	315.57	1518.22	1842.5	-
Amarika north wellfield	7.44	7.51	7.16	-	17.2	14.1	22.9	-	1338	1607	1274	-	24.2	2.6	5.23	*	692.78	1111.53	853.58	-
Okakombe	7.2	7.22	7.02	-	16.8	19.3	28.1	-	2220	3970	5240	-	250	297	too high	*	1574.5	2056.9	3510.8	-
Okambata I	7.67	7.33	7.01	7.42	17.8	21.6	20.4	21.7	2360	3430	3250	3530	too high	94	too high	*	1413.7	1775.5	2177.5	2365.1
Okambata II	7.36	7.07	6.93	7.59	18.1	16.9	19.8	21.8	2540	2730	3440	2730	too high	too high	too high	*	1634.8	-	2304.8	1829.1
Okambata III	7.48	-	-	-	16.8	-	-	-	2000	-	-	-	too high	-	-	*	1453.9	-	-	-
Onakatili	7.51	7.27	7.06	7.52	18	23.6	22.2	24	5870	3240	3270	2980	too high	23	too high	*	2519.2	2324.9	2190.9	1996.6
Onakatili II	7.13	-	-		20	-	-	-	2910	-	-	-	273	-	-	*	1721.9	-	-	-
Onambandja	7.27	7.13	7.04	7.5	22.6	27.6	21.8	22.8	2630	3180	3200	3280	too high	53	9.6	*	1480.7	2123.9	2144	2197.6
Onakapanda	7.78	7.52	7.29	7.62	17.1	19.3	21.5	16.5	2370	5710	3650	5800	14.4	16	23.1	*	1467.3	4180.8	2445.5	3886
Otongo I	8.56	7.55	7.61	7.61	16.2	14.1	31.1	16.8	5130	5250	4710	5880	188	5.6	11.7	*	3008.3	3899.4	3155.7	3939.6
Otongo II	7.62	7.45	7.43	-	17.9	19.4	33.8	-	5740	11450	10830	-	too high	6.8	too high	*	3685	8482.2	7256.1	-
Olumpelengwa deep	8.01	8.63	9.05	8.06	18.2	15.4	23.5	15	7520	10320	7070	9970	6.02	1.2	15.6	*	5467.2	7979.7	4736.9	6679.9
Olumpelengwa shallow	7.43	7.9	7.71	8.05	20.2	31.9	33.9	15.7	626	630	203.6	586	58	82	too high	*	457.61	582.23	136.412	392.62
Uusathima I	7.83	7.61	8.5	8.03	15.5	16.1	26.7	15.5	1757	3190	355	2770	165	17	30	*	1289.75	2391.9	237.85	1855.9

Table 7: Summary of chemical parameters in hand dug wells of Omusati region

Parameter	Sodium Na (mg/l)				Potassium K (mg/l)				Magnesium Mg (mg/l)				Calcium Ca (mg/l)				Manganese Mn (mg/l)				Iron Fe (mg/l)			
Year	2014		2015		2014		2015		2014		2015		2014		2015		2014		2015		2014		2015	
Month	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August	May	Sep	Feb	August
Villages																								
Akustima	36	22	*	-	52	22	*	-	77	40	*	-	768	700	*	-	0.36	0.23	*	-	0.55	0.16	*	-
Amarika Southwellfield	8.5	-	*	-	8.2	-	*	-	5.4	-	*	-	54	-	*	-	0.24	-	*	-	0.7	-	*	-
Amarika central wellfield	76	373	*	-	13	24	*	-	6.8	47	*	-	26	113	*	-	0.13	0.19	*	-	0.49	0.04	*	-
Amarika north wellfield	31	41	*	-	8.6	8.5	*	-	25	37	*	-	126	256	*	-	1.2	0.66	*	-	0.07	0.04	*	-
Okakombe	50	79	*	101	43	22	*	48.7	50	57	*	97.1	778	651	*	666	0.28	0.37	*	0.109	0.04	0.07	*	0.019
Okambata I	36	26	*	112	52	18	*	27.4	77	42	*	196	768	624	*	618	0.41	624	*	0.323	0.013	0.24	*	0.033
Okambata II	16	-	*	44.5	60	-	*	16.4	32	-	*	83.6	893	-	*	618	0.30	-	*	0.109	0.009	-	*	0.019
Okambata III	21	-	*	-	43	-	*	-	43	-	*	-	767	-	*	-	0.43	-	*	-	0.086	-	*	-
Onakatili	41	45	*	-	133	85	*	-	173	104	*	-	1033	696	*	-	0.15	696	*	*	0.3	0.18	*	*
Onakatili II	48	-	*	-	74	-	*	-	94	-	*	-	732	-	*	-	0.21	-	*	*	0.03	-	*	*
Onambandja	33	74	*	101	70	51	*	48.7	43	84	*	97.1	710	708	*	666	0.28	708	*	0.257	0.11	0.31	*	0.036
Onakapanda	45	591	*	616	12	44	*	40.9	31	291	*	268	776	614	*	613	2.10	614	*	0.287	0.13	0.3	*	0.013
Otongo I	449	625	*	686	167	57	*	64.4	85	113	*	135	946	797	*	689	0.15	0	*	0.257	0.05	0.02	*	0.031
Otongo II	704	2169	*	-	151	232	*	-	107	286	*	-	759	920	*	-	0.31	0.56	*	-	0.42	2.2	*	-
Olumpelengwa deep	1623	2414	*	2062	120	100	*	91.2	194	309	*	276	79	59	*	102	0.04	0	*	0.015	<0.01	1.2	*	0.006
Olumpelengwa shallow	4.7	4.4	*	2.9	11	9.9	*	6.1	47	57	*	42.4	66	73	*	67.6	0.26	0	*	0.173	0.26	1.5	*	0.043
Uusathima I	13	19	*	19.2	11	77	*	68.4	12	42	*	43.7	624	803	*	654	0.02	0	*	0.052	0.01	0.18	*	0.004
Uusathima II	8.4	9.6	*	6.3	13	12	*	9.9	32	43	*	24	702	712	*	618	0.18	0	*	0.105	0.13	0.09	*	0.010

APPENDIX 3

Table 8 Summary of chemical parameters in hand dug wells of Ohangwena region

Parameter	Chloride Cl (mg/l)						Fluoride F (mg/l)						Sulphate SO_4 (mg/l)						Nitrate N (mg/l)					
Year	2014			2015			2014			2015			2014			2015			2014			2015		
Month	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug
Villages																								
Epumbalondjaba	1.0	7.24	7.5	15.1	11.4	-	0.1	0.07	0.1	0.0778	0.1	-	10	13.80	26	15	14.8	-	6	33.00	0.6	27.5	26.5	-
Ohameva	2.3	3.06	2.0	7.32	5.67	4.78	2.4	2.92	2.9	2.54	2.55	2.5	2.8	2.26	3	1	1.99	4.70	0.9	0.56	1.2	44.8	0.606	1.16
Okamanya	5.5	17.9	-	21	15.5	-	1.6	2.04	-	1.59	0.827	-	5.9	2.03	-	0	2.17	-	1	1.067	2.2	67.6	1.35	2.11
Okamanya handpump	8.6	17.30	14	21.9	-	15.7	0.7	0.947	0.8	0.769	-	0.887	3.3	2.30	3	0	-	3.12	1	3.09	2.5	68.1	6.2	4.99
Oluwaya	-	12.90	-	-	-	-	-	2.04	-	-	-	-	-	4.86	-	-	-	-	1.6	3.98	2.8	96.2	10.8	6.37
Oluwaya field	2.5	3.34	1.4	-	-	-	3.3	4.36	4.5	-	-	-	1	4.92	6	-	-	-	2	4.25	2.9	109	12.4	6.8
Oluwaya handpumb	7.7	25.1	10	23	16.8	17.9	1.4	1.75	1.7	1.51	1.73	1.74	5.9	4.49	6	2	4.47	6.72	2.1	4.58	3.2	138	12.8	14.30
Omboloka Dune	2.6	8.71	6.7	12.5	5.7	5.05	0.5	2.1	2.0	1.81	2.1	2.09	4.2	4.6	5	0	3.4	4.25	2.5	7.12	3.5	192	17.7	19.80
Omboloka Pan	3.0	3.68	3.3	8.68	3.63	3.67	1.8	0.66	0.6	0.471	0.485	0.553	6.4	2.18	2	0	2.72	4.03	2.5	7.67	3.8	197	24.6	25.5
Omulonga I	1.2	3.63	3.3	8.49	4.1	5.9	0.1	0.03	0.1	0.0486	0.0	0.062	<1	5.20	24	5	4.9	7.16	3.7	13.10	4.5	217	32.9	46.3
Omulonga II	1.1	4.9	2.2	9.14	4.15	5.8	0.1	0.01	0.1	0.05	0.04	0.039	<1	5.69	11	1	5.22	4.71	3.8	19.4	4.6	232	57.1	56.5
Onambaladhi I	17	12	2.3	16.9	7.6	9.81	0.2	0.20	0.2	0.235	0.2	0.245	5.0	8.2	34	7	10.6	10.8	5	34.4	5.4	265	71.2	62.10
Onambaladhi II	1.7	16.90	4.9	15.3	4.330	5.16	0.1	0.113	0.2	0.202	0.142	0.243	30	16.70	22	2	3.370	1.93	6	43.40	5.7	456	124	122
Ongalangobe	5.2	7.61	1.4	-	-	-	0.3	0.363	0.4	-	-	-	<1	2.24	<1	-	-	-	9.1	43.40	8.3	489	125	125
Ongalangobe II	-	2.48	-	-	-	-	-	0.802	-	-	-	-	-	2.65	-	-	-	-	12	46.60	10	573	164	150.0
Oshana shiwa	2.4	8.47	6.3	9.49	6.38	7.07	2.4	2.94	2.8	1.97	2.94	2.97	4	3.14	5	0	2.6	4.2	35	53.8	13	742	220	224
Oshana-shiwa hand pump	2.4	0.666	2	6.11	-	-	2.4	2.82	2.7	2.38	-	-	1.1	1.09	2	0	-	-	46	65	15	811	-	-
Oshikunde I	4.4	7.00	18	28.5	14.9	13.1	0.1	0.066	0.1	0.109	0.1	0.098	<1	0.99	13	1	14.2	23.8	64	76.80	37	987	-	-
Oshikunde II	11	4.65	11	19.6	9.9	10.2	0.1	1.5	0.1	0.081	0.1	0.143	20	11.80	6	0	5.9	11.8	-	139.00	38	2222	-	-
Oshuuli (Deep)	1.9	26.20	14	21.8	-	-	1	0.189	0.2	0.329	-	-	20	41.50	<1	0	-	-	-	170.00	55	-	-	-
Oshuuli shallow	6.0	4.65	9	26.8	20.9	17.5	0.1	1.5	1.2	0.164	0.245	0.213	<1	11.80	18	53	32	29.1	-	231.00	-	-	-	-
Walye Inda	-	-	2.5	23.9	14.1	16.6	-	-	0.2	0.236	0.246	0.257	-	-	24	0	9.83	15.1	<0.5	286	-	-	-	-
Walye-Inda field	0.8	6.01	2.8	10.9	9.70	6.76	0.1	0.212	0.3	0.304	0.61	0.551	17	5.41	7	13	9.46	7.66	<0.5	-	-	-	-	-

Table 9: Summary of physical parameters in hand dug wells of Ohangwena region

Parameter	Temperature (°C)						Ph						EC (µS/m)						Turbidity (NTU)						TDS (mg/l)					
Year	2014			2015			2014			2015			2014			2015			2014			2015			2014			2015		
Month	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug
Villages																														
Epumbalondjaba	32.4	24.4	18.4	34.9	20.5	26.2	7.97	5.81	5.68	5	4.76	6.41	125.1	170	155.5	183.4	163	181.1	56.1	*	64	Too high	*	*	86	113.9	109	122.878	109.21	121.337
Ohameva	26	24.8	25.5	26.5	24.8	23.5	7.96	7.69	7.8	7.68	4.45	7.96	518	605	508	542	628	577	3.74	*	0.65	21.7	*	*	356	405.35	372.52	363.14	420.76	386.59
Okamanya	25.3	24.4	-	26.2	25.3	-	7.73	7.65	-	7.79	7.42	-	722	754	-	664	785	-	2.07	*	-	1.78	*	*	496.47	505.18	-	444.88	525.95	-
Okamanya handpump	26.1	26	24.7	27.4	24.3	25.8	7.26	7.24	7.38	7.24	7.35	7.76	820	801	621	734	909	728	6.08	*	1.4	1.98	*	*	557	536.67	450	491.78	609.03	487.76
Oluwaya	-	24.4	-	-	-	-	-	7.63	-	-	-	-	-	888	-	-	-	-	-	*	-	-	*	*	-	594.96	-	-	-	-
Oluwaya field	25.1	22.2	22.5	-	-	-	7.91	7.98	7.84	-	-	-	526	603	548	-	-	-	169	*	1.7	-	*	*	358.45	404.01	398	-	-	-
Oluwaya handpumb	25.4	23.9	24.9	26	-	24.8	7.51	7.52	7.64	7.51	-	7.93	986	1027	857	867	-	898	9.24	*	0.9	0.7	*	*	651.24	688.09	617.07	580.89	-	601.66
Omboloka Dune	25.3	24	24.1	25.5	25	23.8	7.12	7.55	7.41	7.49	7.53	7.95	602	593	513	519	542	500	3.97	*	2.7	1.51	*	*	408.7	397.31	381	347.73	363.14	335
Omboloka Pan	26.6	25	24.4	26.3	25.2	24.5	7.4	7.16	7.2	7.16	7.14	7.73	567	682	593	603	623	587	4.48	*	0.35	1.11	*	*	391	456.94	434.83	404.01	417.41	393.29
Omulonga I	33.7	20.6	27	31	22	27.2	10.39	6.31	7.21	8.13	6.6	7.47	258	96.7	92.2	83	96.2	129.5	26.6	*	82	78.9	*	*	135.34	64.789	72.36	55.61	64.454	86.765
Omulonga II	32.8	15	23.3	29.1	24.3	24.2	7.11	6.67	7.76	7.8	8.96	7.34	71	180	135	81.4	107.7	97.5	120	*	34	26.3	*	*	48.91	120.6	93.13	54.538	72.159	65.325
Onambaladhi I	25.1	17	18.9	30.6	17.9	17.9	6.8	6.66	6.64	8.3	5.42	8.39	233	178	102.3	109.9	106.4	107.5	85.6	*	255	69.5	*	*	164.82	119.26	65.66	73.633	71.288	72.025
Onambaladhi II	26.2	20	21.7	29.3	17.4	16.6	6.7	6.78	6.8	9.8	5.62	8.87	185	207	173.5	157.1	52.1	83.7	62.2	*	82	93.8	*	*	129.98	138.69	85.76	105.257	34.907	56.079
Ongalangobe	26.3	22.9	26.4	-	-	-	7.61	7.68	7.64	-	-	-	536	499	530	-	-	-	1.65	*	20	-	*	*	369	334.33	381	-	-	-
Ongalangobe II	-	25.6	-	-	-	-	-	8.05	-	-	-	-	-	1199	-	-	-	-	-	*	-	-	*	*	-	803.33	-	-	-	-
Oshana shiwa	26.1	23.5	24.6	25.6	22.5	24.3	7.61	7.72	7.69	7.71	7.74	8.04	884	868	799	651	830	760	44.1	*	6	140	*	*	592.28	581.56	578	436.17	556.1	509.2
Oshana-shiwa hand pump	27.4	24.7	26.1	27.6	-	-	7.62	8	7.9	7.85	-	-	596	598	558	568	-	-	13	*	1.5	0.65	*	*	401.33	400.66	406.69	380.56	-	-
Oshikunde I	32.3	21.4	26.1	24.3	17.4	25.3	8.67	8.7	9.19	7.32	7.61	8.58	125	262	196.9	195.5	296	271	166	*	80	41.5	*	*	90.45	175.54	146.73	130.985	198.32	181.57
Oshikunde II	28.2	24.4	26.2	22.5	23.9	25.9	5.71	6.35	6.4	6.43	6.76	7.55	94.6	109	122.9	133	142	146.3	66	*	111	56.1	*	*	148.07	73.03	89.11	89.11	95.14	98.021
Oshuuli (Deep)	25.8	19.1	29.1	26.2	-	-	8.38	7.14	7.06	7.82	-	-	1904	833	589	863	-	-	0	*	43	Too high	*	*	1226	558.11	432	578.21	-	-
Oshuuli shallow	23.8	22.4	22.5	24.6	28.6	25.9	7.03	6.31	8.48	6.89	7.1	7.54	585	2470	2370	601	675	564	48.9	*	761	23.1	*	*	399.99	1654.1	940.68	402.67	452.25	377.88
Walye Inda	-	-	22.1	36	23.6	23.8	-	-	6.41	6.8	5.47	7.35	-	-	126.3	250	143.7	183.6	-	*	95	Too high	*	*	-	-	86	167.5	96.279	123.012

Table 10: Summary of chemical parameters in hand dug wells of Ohangwena region

Parameter	Sodium Na (mg/l)						Potassium K (mg/l)					
Year	2014			2015			2014			2015		
Month	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug
Villages												
Epumbalondjaba	4.1	6.6	8.2	*	11.6	-	13	14.2	15	*	11.6	-
Ohameva	0.7	1.5	1.2	*	3.4	4.3	6.8	7	6.6	*	11.8	12.8
Okamanya	9.4	8.6	-	*	11.0	-	38	34.7	-	*	26.1	-
Okamanya handpump	9.3	9.8	3.4	*	-	11.1	28	26.8	14	*	-	26.3
Oluwaya	-	15	-	*	-	-	-	10.3	-	*	-	-
Oluwaya field	3.8	3.4	4.3	*	-	-	20	11.7	24	*	-	-
Oluwaya handpumb	25	21.2	25	*	26.4	29.5	24	20.2	23	*	23.8	27.2
Omboloka Dune	1	1.2	0.9	*	0.9	0.7	3.7	3.3	2.7	*	2.8	3.0
Omboloka Pan	1.1	1.0	0.8	*	0.9	0.8	3.6	3.4	2.9	*	3.9	26.3
Omulonga I	6.7	1.9	3.4	*	2.4	3.4	30	8.6	10	*	8.8	13.4
Omulonga II	0.8	2.1	2.2	*	2.3	3.3	5.4	13.1	14	*	9.7	11.8
Onambaladhi I	17	13.7	11	*	12.9	14.9	18	11.2	8.6	*	6.1	9.8
Onambaladhi II	9.6	16.3	18	*	7.1	11.7	19	18.3	14	*	2.5	5.5
Ongalangobe	29	44.9	30	*	-	-	76	8.7	73	*	-	-
Ongalangobe II	-	247	-	*	-	-	-	76.4	-	*	-	-
Oshana shiwa	75	69.3	74	*	62.5	-	40	36	36	*	34.3	-
Oshana-shiwa hand pump	58	58.7	62	*	-	-	32	31.1	30	*	-	-
Oshikunde I	9.8	29.5	25	*	30.7	29.6	8.0	11.5	14	*	29.7	24.7
Oshikunde II	15	14.5	18	*	20.6	23.6	27	5.6	6.2	*	5.7	7.9
Oshuuli (Deep)	462	17	13	*	-	-	40	132.5	91	*	-	-
Oshuuli shallow	8.2	620	485	*	16.8	14.2	101	47.6	38	*	95.2	82.6
Walye Inda	-	-	12	*	17	25.2	-	-	11	*	11	15.4
Walye-Inda field	6.9	13	10	*	27.7	24.8	5.4	5.3	6.4	*	5.4	5.4

Parameter	Magnesium Mg (mg/l)						Calcium Ca (mg/l)					
Year	2014			2015			2014			2015		
Month	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug
Villages												
Epumbalondjaba	2.4	3	3.2	*	2.64	-	5.8	7.07	7.1	*	6.480	-
Ohameva	26	29.2	32	*	28.8	29.3	59	64.2	64	*	75.5	73.2
Okamanya	27	29.5	-	*	23.6	-	79	86	-	*	95.1	-
Okamanya handpump	24	24.90	22	*	-	23.9	96	96.3	90	*	-	97.4
Oluwaya	-	26.8	-	*	-	-	-	117.00	-	*	-	-
Oluwaya field	31	38.60	41	*	-	-	42	49.7	48	*	-	-
Oluwaya handpumb	29	32.70	32	*	28.1	30.0	102	117.0	101	*	96.8	102
Omboloka Dune	16	28.4	31	*	28.3	29.1	73	107.0	68	*	67.0	68.8
Omboloka Pan	28	19.7	21	*	16.6	23.9	71	67.9	107	*	111	97.4
Omulonga I	3.8	2.0	2.7	*	2.32	3.74	8.3	7.1	8.3	*	7.72	11.9
Omulonga II	2.2	3.4	4.6	*	3.30	2.65	7.3	10.7	12	*	11.1	8.85
Onambaladhi I	3.9	2.3	2.8	*	1.22	3.13	9.0	6.1	7.6	*	4.17	7.79
Onambaladhi II	4.5	3.56	1.9	*	0.833	2.55	10	9.5	5.5	*	2.85	9.67
Ongalangobe	10	9.99	13	*	-	-	26	43.9	31	*	-	-
Ongalangobe II	-	1.6	-	*	-	-	-	6.21	-	*	-	-
Oshana shiwa	28	30.2	30	*	29	-	41	47.8	43	*	45.8	-
Oshana-shiwa hand pump	17	18.4	20	*	-	-	29	32.7	29	*	-	-
Oshikunde I	1.6	2.7	3.0	*	2.81	3.19	6.1	11.9	12	*	13.8	16.8
Oshikunde II	3.9	1.53	1.8	*	1.61	2.62	13	6.4	7.6	*	7.65	11.9
Oshuuli (Deep)	3.1	20.50	16	*	-	-	15	46.80	33	*	-	-
Oshuuli shallow	3.8	2.86	1.8	*	15.7	13.6	8.3	10.2	8.4	*	35.7	31.5
Walye Inda	-	-	1.8	*	1.19	2.34	-	-	6.2	*	2.85	8.04
Walye-Inda field	1.6	2.07	2.7	*	3.12	2.78	2.5	3.58	3.6	*	7.00	4.8

Parameter	Manganese Mn (mg/l)						Iron Fe (mg/l)					
Year	2014			2015			2014			2015		
Month	March	June	Sep	March	June	Aug	March	June	Sep	March	June	Aug
Villages												
Epumbalondjaba	0.1	0.177	0.16	*	0.144	-	0.74	1.76	1.5	*	1.23	-
Ohameva	<0.01	0.001	<0.01	*	0.040	0.003	0.01	0.003	0.02	*	0.042	0.012
Okamanya	0.08	0.011	-	*	0.011	-	0.0	0.096	-	*	0.21	-
Okamanya handpump	0.01	0.02	0.07	*	-	0.010	0.5	0.021	0.09	*	-	0.137
Oluwaya	-	0.003	-	*	-	-	-	0.063	-	*	-	-
Oluwaya field	0.02	0.002	0.01	*	-	-	0.05	0.003	0.08	*	-	-
Oluwaya handpumb	<0.01	0.002	0.01	*	0.003	0.003	<0.01	0.00	0.02	*	0.007	0.004
Omboloka Dune	0.01	0.003	0.02	*	0.028	0.015	0	0.00	0.09	*	0.013	0.007
Omboloka Pan	0.09	0.019	<0.01	*	0.007	0.01	0.2	0.009	0.010	*	0.004	0.137
Omulonga I	0.12	0.201	0.11	*	0.052	*	0.26	2.3	2.1	*	0.952	*
Omulonga II	0.18	0.125	0.14	*	0.154	*	1.9	0.50	0.640	*	1.89	*
Onambaladhi I	0.26	0.247	0.18	*	0.230	*	4.00	4.17	4.500	*	5.74	*
Onambaladhi II	0.08	0.073	0.22	*	0.064	*	1.40	0.873	3.800	*	1.56	*
Ongalangobe	0.06	0.006	0.09	*	-	-	0.08	0.01	0.400	*	-	-
Ongalangobe II	-	0	-	*	-	-	-	0.055	-	*	-	-
Oshana shiwa	0.01	0.008	0.05	*	0.035	-	0.08	0.012	0.18	*	0.004	
Oshana-shiwa hand pump	0.02	0.05	0.02	*	-		0.02	0.08	0.04	*	-	
Oshikunde I	0.08	0.148	0.11	*	0.091	*	0.5	0.97	0.58	*	0.643	*
Oshikunde II	1.1	0.098	0.11	*	0.138	*	1.9	1.24	1.600	*	2.29	*
Oshuuli (Deep)	0.03	0.207	0.12	*	-	-	0.0	0.1	0.820	*	-	-
Oshuuli shallow	0.12	0.013	0.33	*	0.113	*	0.26	0.03	3.700	*	0.794	*
Walye Inda	-	-	0.14	*	0.2	*	-	-	21	*	8.91	*
Walye-Inda field	0.03	0.054	0.08	*	0.145	*	1.10	2.12	3.1	*	12	*

Appendix 4

Table 11: Summary of substances of concern for Omusati region

Village Name	May-June-14	Sep-14	February-March-15	Jun-15	Aug-15
Akustima	SO_4^{2-}, Ca, Turbidity	Not sampled	SO_4^{2-}, EC, Turbidity		
Amarika Southwellfield	Turbidity	Not sampled			
Amarika central wellfield	Turbidity	Turbidity	NO_3^-, Cl^-, EC		
Amarika north wellfield	Mn, Turbidity	Ca	Turbidity		
Okakombe	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, Ca, EC,TDS, Turbidity	SO_4^{2-},Cl^-, EC, Turbidity		
Okambata II	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, Ca, Turbidity			
Okambata I	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, EC, Turbidity		SO_4^{2-}, F^-, Ca, EC
Okambata III	SO_4^{2-}, Ca, Turbidity	Not sampled	SO_4^{2-}, EC, Turbidity		SO_4^{2-}, F^-, Ca, EC
Onakatili	SO_4^{2-}, Ca, Mg, EC,TDS, Turbidity	SO_4^{2-}, Ca, Mg, EC,TDS, Turbidity	SO_4^{2-}, Cl^-, EC,Turbidity		
Onakatili II	SO_4^{2-}, Ca, Turbidity	Not sampled			
Onambandja	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, F^-, Ca, EC,TDS, Turbidity	SO_4^{2-}, EC, Turbidity		SO_4^{2-}, Ca,Mg, EC
Onakapanda	SO_4^{2-}, Ca, Mn, Turbidity	SO_4^{2-}, F^-,Na, Ca,Mg EC,TDS, Turbidity	SO_4^{2-}, EC, Turbidity		SO_4^{2-}, F^-,Na, Ca,Mg, EC
Otongo I	SO_4^{2-}, Ca, Na, EC,TDS, Turbidity	SO_4^{2-}, Cl^-, Ca, Na, Mg, EC, TDS, Turbidity	SO_4^{2-}, Cl^-, EC,Turbidity		SO_4^{2-}, Ca, EC
Otongo II	SO_4^{2-}, Cl^-, Ca, Na, Mg, EC, TDS, Turbidity	SO_4^{2-}, Cl^-, Ca, Na, Mg, Fe, EC, TDS, Turbidity	SO_4^{2-},Cl^-, EC, Turbidity		
Olumpelengwa deep	SO_4^{2-}, Cl^-, Na, Mg, EC, TDS	SO_4^{2-}, Cl^-, NO_3^- , Na, Mg,Fe, EC, TDS	SO_4^{2-},Cl^-, EC, Turbidity	SO_4^{2-}, Cl^-, Na, Mg, EC	
Olumpelengwa shallow	Turbidity	Fe, Turbidity	Turbidity	None	
Uusathima I	SO_4^{2-}, Ca, Turbidity	SO_4^{2-}, F^-, Ca, EC,TDS, Turbidity	None		SO_4^{2-}, F^-, Ca, EC
Uusathima II	SO_4^{2-}, Ca, Turbidity	F^-, Ca, Turbidity	None		SO_4^{2-}, Ca, EC

Table 12: A summary of substances of concern in hand dug wells of Ohangwena region

Sample	Mar-14	May-June-14	Sep-14	February-March-15	Jun-15	Aug-15
Epumbalondjaba	Turbidity	Not sampled	Fe, Turbidity	NO_3^-, Turbidity	None	
Ohameva	EC	Not sampled	EC	NO_3^-, Turbidity, EC	NO_3^-,EC	NO_3^-,EC
Okamanya	NO_3^-, EC	Not sampled	EC	NO_3^-,EC	NO_3^-,EC	NO_3^-,EC
Okamanya handpump	EC	Not sampled	EC	NO_3^-,EC	NO_3^-,EC	NO_3^-,EC
Oluwaya field	F^-,EC	Not sampled	F^-, EC	NO_3^-,EC	Not sampled	Not sampled
Oluwaya handpumb	NO_3^-, EC	Not sampled	NO_3^-, EC	NO_3^-,EC	NO_3^-,EC	NO_3^-,EC
Omboloka Dune	EC	Not sampled	EC	NO_3^-,EC	NO_3^-,EC	NO_3^-,EC
Omboloka Pan	EC	Not sampled	EC	NO_3^-,EC	EC	EC
Omulonga I	Fe, Turbidity	Not sampled	Fe, Turbidity	NO_3^-, Turbidity	None	None
Omulonga II	Turbidity	Not sampled	Turbidity	NO_3^-, Turbidity	None	None
Onambaladhi I	Fe, Turbidity	Not sampled	Fe, Turbidity	NO_3^-, Turbidity	None	None
Onambaladhi II	Fe, Turbidity	Not sampled	Fe, Turbidity	NO_3^-, Turbidity	None	None
Ongalangobe	EC	Not sampled	Turbidity	None	None	None
Oshana shiwa	NO_3^-, EC	Not sampled	NO_3^-, Turbidity, EC	NO_3^-, EC	NO_3^-	NO_3^-
Oshana-shiwa hand pump	EC	Not sampled	EC	EC	EC	EC
Oshikunde I	Turbidity	Not sampled	Turbidity	NO_3^-, Turbidity	None	NO_3^-
Oshikunde II	Fe, Mn, Turbidity	Not sampled	Turbidity	NO_3^-, Turbidity	None	None
Oshuuli (Deep)	EC	Not sampled	NO_3^-, Turbidity, EC	NO_3^-, Turbidity, EC	NO_3^-, Turbidity, EC	NO_3^-, Turbidity,EC
Oshuuli shallow	None	Not sampled	Fe, Na, Turbidity	NO_3^-, Turbidity	NO_3^-	NO_3^-
Walye-Inda field	Fe, Turbidity	Not sampled	Fe, Turbidity	NO_3^-, Turbidity	None	None