ESTIMATION OF EVAPORATION LOSSES BASED ON STABLE ISOTOPE COMPOSITION OF WATER IN THE CALUEQUE-OSHAKATI CANAL, NAMIBIA.

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ABSTRACT

The open concrete-lined Calueque-Oshakati canal has been operational since the 1970s, carrying raw water from the Calueque Dam on the Kunene River in the Southern region of Angola to the Central Northern region of Namibia. This raw water is conveyed to the purification plants along the canal, where it is purified before distribution to towns and villages through pipelines. This thesis presents the findings on the estimation of evaporation losses using the stable isotopic composition of water in the canal. The study aimed at estimating the amounts of water lost from the Calueque-Oshakati canal due to evaporation against the amounts supplied to the lower Cuvelai-Etosha Basin (CEB) in Namibia. The water samples were collected along the canal and sent to the laboratory for stable isotope composition analysis. The isotopic data was inserted in a hydro-calculator with climatic variables to compute the evaporation factors. The findings of the research showed that higher amounts of water are lost due to evaporation during the dry season than the wet season. This paper finally recommends the change of the method of transferring water from Angola to Namibia and the establishment of the local evaporation line (LEL) in the Central Northern Namibia.

Keywords: *raw water, stable isotopic composition, hydro-calculator, evaporation factor, LEL*

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LIST OF ABBREVIATIONS AND/OR ACRONYMS

CEB	Cuvelai Etosha Basin
GMWL	Global Meteoric Water Line
JEDS	Jose Eduardo dos Santos
LEL	Local Evaporation Line
NAMWATER	Namibian Water Corporation
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Management
SMOW	Standard Mean Ocean Water
SPSS	Statistical Package for Social Scientists
UNAM	University of Namibia

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DEDICATION

I dedicate this thesis to my family, that keeps showering me with endless support, kindness and devotion. You people have been there for me and believed in me even when I did not believe in myself that much. Dad (in memoriam), you have left fingerprints of grace on our lives and you shall not be forgotten. Beloved mom, brothers and sisters, you have been amazing. And to anybody else that believes in the richness of learning, this is for you.

DECLARATIONS

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Date: 07/07/2020

Isak Elago Natangwe Nahenda

CHAPTER 1: INTRODUCTION

1.1 Introduction

This chapter gives a general overview of the study, stating the research concerns, unanswered questions and gaps in knowledge that give rise to the research problem. It indicates the purpose of the study, the research issues that were investigated in the study and testable hypotheses based on theory and on the statement of the problem. Information on the anticipated contribution of the study to knowledge and the field of study, boundaries and limitations of the study is also constituted in this chapter.

1.2 Orientation of the study

Namibia is considered as one of the sunniest countries worldwide, with hot and dry climate. Its climate is generally arid to semi-arid which results from excessively higher potential evapotranspiration than the precipitation [1]. Namibia has a precipitation increasing trend from southwestern regions to the northeastern regions. The annual precipitation ranges from 0 mm to a maximum of about 600 mm [1]. The Namibian high degree of aridity is known to be related to the influence of the strong subtropical high pressure and the influence of the cold Benguela current that moves northward in the Atlantic Ocean along the coast of Namibia [2]. The study focused on the Central Northern part of Namibia, the densely populated region which is home to about 40 % of the Namibian population. The majority of the Central Northern Namibians heavily depend on the Kunene River water carried along the 150 km long open concrete canal known as the Calueque-Oshakati Canal, in the Cuvelai-Etosha Basin (CEB). This canal carries surface water from the Calueque Dam in Southern part of Angola to four water treatment or purification plants in Namibia (Olushandja, Ombalantu, Ogongo and Oshakati), which is then supplied to people and livestock in the nearest villages and towns via pipeline systems.

The canal system became operational in the 1970’s and it has now aged. It has been facing multiple challenges such as significant pollution, sedimentation, vandalism and severe water losses. With high rates of evaporation, infiltration and unauthorised water extraction, unquantified volumes of water are daily lost from this canal. To ensure efficient water supply, the canal therefore requires rehabilitation which may include covering it or wholly replacing it with a pipeline.

1.3 Statement of the problem

Namibia’s arid to semi-arid climate is characterised by its higher annual rates of potential evapotranspiration than annual precipitation [1]. This is a clear indication that more water is lost due to evaporation from land and water surfaces including the canal.

Published studies [3], [4] assessed the impacts of pollution on the water quality and the effect of the canal system on the fish fauna in the Central Northern Namibia, but no literature was found on the estimation of water losses to this date. The study [3] concluded that pollution load in the Calueque-Oshakati Canal showed an increasing trend from upstream to downstream. With unquantified volumes of water lost, the study therefore estimated the quantities of water lost due to evaporation from the Calueque-

Oshakati Canal. In addition, the study compared the water losses to the amounts supplied to the lower part of the Cuvelai-Etosha Basin via the canal.

1.4 Study objectives

The main aim of the study was to estimate the evaporation losses from the Calueque-Oshakati Canal and compare the amount of water lost to the amount of water supplied to the Cuvelai-Etosha Basin. The specific objectives were to:

1. Estimate the quantity of water lost due to evaporation from the Calueque-Oshakati Canal during the wet and dry seasons.

2. Compare the amount of water lost due to evaporation with the amount of water supplied to the lower Cuvelai-Etosha Basin.

1.5 Hypothesis of the study

The research hypotheses are:

H_o = There is no significant difference between the amount of water supplied to the CEB through the Calueque-Oshakati Canal and the amount that reaches the intended destinations, confidence interval of 95%.

H_a = There is a significant difference between the amount of water supplied to the CEB through the Calueque-Oshakati Canal and the amount that reaches the intended destinations, confidence interval of 95%.

1.6 Significance of the study

This study may be of great importance to Namwater as it may be used to assess the water budget. It may also be useful in the decision-making about choosing the efficient water transferring method. The study may also be essential for the calibration and validation of physically based hydrological models.

1.7 Limitations of the study

This kind of study would require the whole hydrological cycle (12 months) to collect the relevant data, but since this study is required in partial fulfilment, time allocated for this project was very limited. However, existing data were used in this study to fill in the gaps.

It would be very ideal to sample from the canal every week or at least every month and at very close ranges for very representative data. Due to the limited financial and logistical resources, sampling was only done in December 2018 and in April 2019 to represent the wet season. Water samples were collected at 9 sampling points, after every 20 km and at the Olushandja Dam canal outlet. Secondary data was however used to widely represent the seasons.

CHAPTER 2: THE STUDY AREA

2.1 Introduction

This chapter gives the geographical location of the area in which the research was conducted. It briefly gives a description of the area in terms climate, water resources, geology as well as water supply and uses.

2.2 Description of the study area

The study area was in the Central Northern part of Namibia as shown in Figure 1 specifically an elongated stretch along the Calueque-Oshakati canal from Mahenene Border Post, where the canal enters Namibia until Oshakati. This area entirely lies within the Namibian part of the Cuvelai-Etosha Basin (CEB), stretching across Omusati and Oshana Regions. The water carried via the canal is supplied to all the four Central Northern regions of Namibia after purification, specifically Omusati, Oshana, Ohangwena and Oshikoto, About 40 % of the Namibian population reside in this region, heavily depending on limited surface and groundwater resources [2].

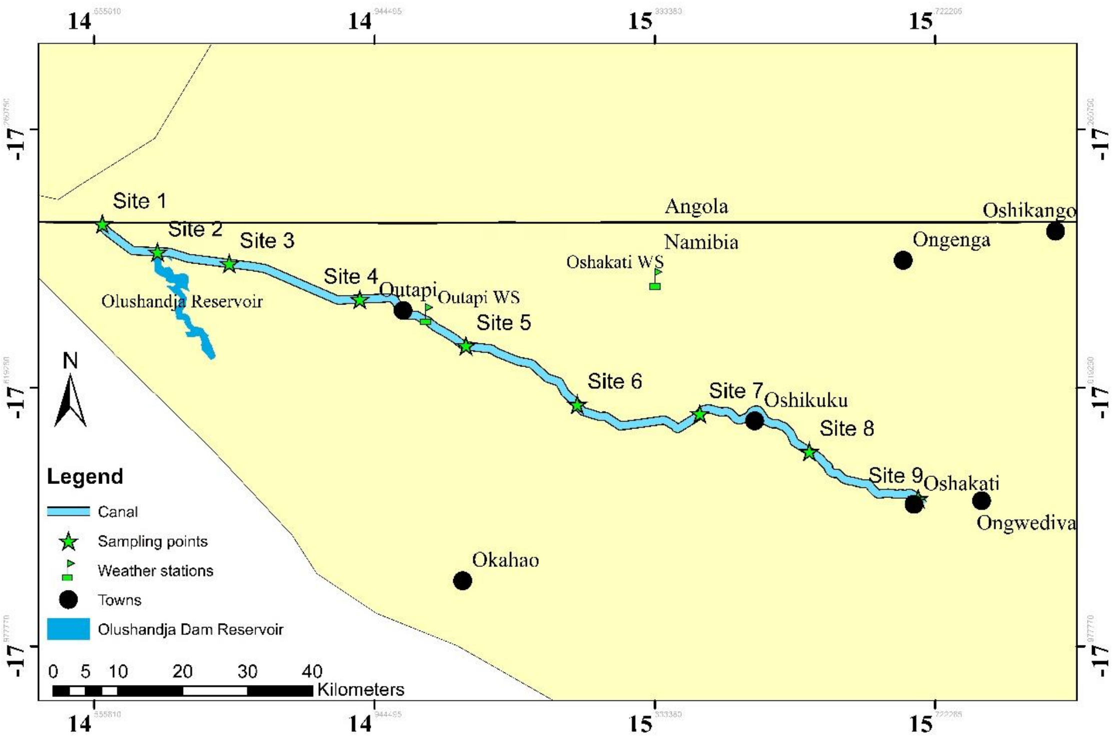

Figure 1: The map showing the central northern Namibia.

The CEB is bounded by the Kunene Basin in the west, Ugab-Huab Basin in the south as well as the Kavango-Omatako Basin in the east. Several kinds of landscapes have formed the region including the karstveld, salt pans, open plains, mopane shrub lands and the Kalahari woodlands [3] and it is characterised by an interconnected system of shallow watercourses.

2.3 Climate

The CEB climate is generally semi-arid, with a low mean annual precipitation of 250 mm in the west to a maximum of 550 mm in the east [1]. The annual evapotranspiration is much higher than precipitation as it ranges from 2800 – 3000 mm. Rainfall in the area is sporadically distributed in space and time. This region only receives significant rainfall in summer, from November to April, with high amounts usually received in January and February. The monthly mean temperature ranges from about 26°C in November to 15°C in July. The minimum monthly mean temperature may drop to 8°C in winter while in summer, the maximum monthly mean temperature reaches 35°C [2].

2.4 Geology and hydrology

From a geological perspective, the area belongs to the Kalahari Sequence, dominated by semi-consolidated to unconsolidated sediments. The Kalahari soils in the area consist of clayey sodic sands in the lower parts of the landscape and sodic sands on relatively higher ground [1]. It is in the huge sedimentary basin extending from the southern Angola highlands into northern Namibia covering 165 000 km^2 [2]. The CEB drainage system is characterised by an interconnected system of shallow ephemeral watercourses with low hydraulic gradients. During the extraordinary rainy events in the area and floods from Angola, the flat plains get flooded with surface and subsurface water flows directed southwards to the Omadhiya lakes and finally into the Etosha Pan in the South region of the basin [2].

2.5 Water supply and usage

In the early years, people in the area fully relied on rain water that accumulated in lakes, ponds, iishanas and groundwater abstracted from shallow hand-dug and deep wells. As the population expanded and the water demand increased, an artificial system was built to convey water from Kunene River in Angola to the area of study. A 150 km long, 3.5

m wide and 1.5 m deep concrete lined Calueque-Oshakati canal was built in the 1970's to supply raw water to the lower CEB in Namibia where it is purified before it is distributed to the people in towns and villages by pipelines. Groundwater is also abstracted from the Ohangwena Kalahari Aquifer and the discontinuous perched aquifers to supply to the villages in the basin. The inhabitants in the area use that water for both domestic and commercial purposes. Domestic uses of water in the area involve potable uses, livestock watering and subsistence farming while the commercial activities that make use of water in this area include industrial activities and irrigation.

CHAPTER 3: LITERATURE REVIEW

3.1 Introduction

This chapter indicates what has already been investigated and published about the research topic and other aspects of this research. It presents a critical, summarised, synthesized and integrated literature review that demonstrate the need and justification of this study.

3.2 Review

3.2.1 Evaporation loss

Evaporation is a process by which water is transferred from land and water masses into the atmosphere in form of water vapour. It is directly proportional to the vapour pressure deficit between water surfaces and the atmosphere. Evaporation together with transpiration are known as evapotranspiration, which comprises physical evaporation from soil and surface water bodies as well as biological transpiration from plants and animals. It is controlled by temperature, humidity, wind, surface cover, available energy and most importantly by the availability of water. In arid and semi-arid climates, potential evapotranspiration exceeds precipitation. Namibia is dominated by arid to semi-arid climate, where evaporation losses average about 83%, vegetation uses up 14%, runoff constitutes 2% while groundwater recharge takes up only 1% of total precipitation [5].

Evaporation losses and subsequent water level fluctuations from surface water bodies such as rivers, lakes, ponds and wetlands are important elements of the terrestrial hydrological cycle [6], [7], [8]. Determining the evaporation losses is very challenging due to uncertainties in monitoring of water flow and measuring the volumes of water bodies [6]. Mass balance models can be used to estimate the actual evaporation [9]. It is most commonly computed indirectly through one or a combination of techniques including measured pan evaporation, energy balance, mass transfer, water balance and stable isotope composition technique. Selecting the best technique to use for evaporation computation largely depends on the data availability, type or state of the water body, size of the water body, and the required accuracy of the estimated evaporation [10].

3.2.2 Isotopes of water

Isotopes are atoms of two or more forms of a chemical element, having the same atomic number but different atomic weights. Heavier isotopes have a relatively high stability and consequently large natural occurrence than their lighter counterparts. The isotopes for water are ^{18}O, ^{17}O and ^{16}O for Oxygen; and ^{3}H (radioactive Tritium), ^{2}H or D (Deuterium) and ^{1}H for Hydrogen. The heavy water molecules are $^{1}H^{2}H^{16}O$ and $^{1}H^{1}H^{18}O$, commonly termed as stable water isotopes [11]. During phase changes (evaporation and condensation), isotopes get separated allowing stable isotopes to become enriched in one phase and depleted in the other [10]. This separation of isotopes is termed isotopic fractionation.

3.2.3 Observed isotope effects in precipitation

The stable isotopic composition of precipitation is mainly controlled by temperature which influences isotopic fractionation and the proportion of the original water vapour that remains in the air mass undergoing precipitation [12]. Geographical and temporal variations in the isotopic fractionation related to progressive evaporation and precipitation led to the observed effects in the hydrological cycle that were formulated in [11]. These empirical isotopes effects include the rainout effect, altitude effect, the latitude effect, the continental effect, the amount effect and the temperature or seasonal effect.

Rainout effect: The water vapour becomes progressively depleted in stable isotopes (^{18}O and ^{2}H) as it follows a trajectory from its source area to higher latitudes and over continents, cools and loses water as evaporation.

Altitude effect: The isotopic ratios of precipitation generally decrease with increasing altitude or elevation. This effect is caused by increased orographic precipitation at higher elevations due to the adiabatic cooling of the air mass. The increased fractionation at liquid and vapour at these low temperatures intensifies the progressive isotopic depletion.

Latitude effect: The latitude effect is based on the observation of a gradually depleted isotope ratios in precipitation towards higher latitudes. This is caused by increased rainout effect at cooler temperatures prevalent at higher latitudes.

Continental effect: This is based on the observation that the isotopic ratios of meteoric water decrease with increasing distance from the source (ocean). The condensing precipitation’s isotopic composition is more enriched than the remaining vapour due to isotopic fractionation during condensation [12]. The air mass is left more depleted as fractionation continues to remove heavy isotopes during the inland travel of the air mass (rainout effect).

Amount effect: It has been observed that areas with high annual precipitation amounts can exhibit significantly depleted isotopic ratios than areas with low precipitation. During light rain or early stage of the storm, the water that reaches the ground gets enriched in heavy isotopes by the evaporation of the light ones into the dry air. Air gets saturated during longer storms, reducing the evaporation and lessening the enrichment of water that reaches the ground.

Seasonal effect: The isotopic variations hugely depend on the local temperature and different areas show different seasonality. At cooler temperatures (winter), water generally exhibits depletion in stable isotopes while the stable isotope enrichment is prevalent at high temperatures (summer).

3.2.4 The uses of stable water isotopes in hydrology

The naturally occurring variations in the relative abundance of two rare, heavy isotopic species of water ($^1H^2H^{16}O$ and $^1H^1H^{18}O$) with respect to the common light isotopic species ($^1H^1H^{16}O$), which arises from phase changes and mixing as water passes through the hydrologic cycle has allowed the use of stable oxygen and hydrogen isotopes in hydrologic studies [13]. As mentioned in [2], stable isotopes of water may be used as tracers for the understanding of hydrogeological and ecohydrological functioning. This includes the investigation of precipitation patterns, understanding the origin of groundwater recharge and the surface-groundwater interactions as well as water transport in the unsaturated zone. In addition, stable isotopes are used in understanding spatial and temporal flow processes within a catchment, root water uptake, evapotranspiration partitioning, evaluation of the evaporative influence and to evaluate water recycling [2]. It was indicated in [6] that the analyses of the water stable isotope composition (^{18}O and ^{2}H) are useful in estimation of evaporative losses from specific water bodies. The change in isotopic composition of a water sample is expressed as the deviation of the isotopic ratio from the standard in parts per thousand (‰) and depicted using the notation:

$$\delta = \frac{\text{Rsample} - \text{Rstandard}}{\text{Rstandard}} \times 10^{3}\ ‰, [13]$$

where delta (δ) is the change in isotopic fractionation, Rsample is the sample isotope ratio ($^{18}O/^{16}O$ or $^{2}H/^{1}H$), while Rstandard is the reference standard. The reference standard to which the water sample isotopic values are normalised is the Standard Mean Ocean Water (SMOW) (Figure 2).

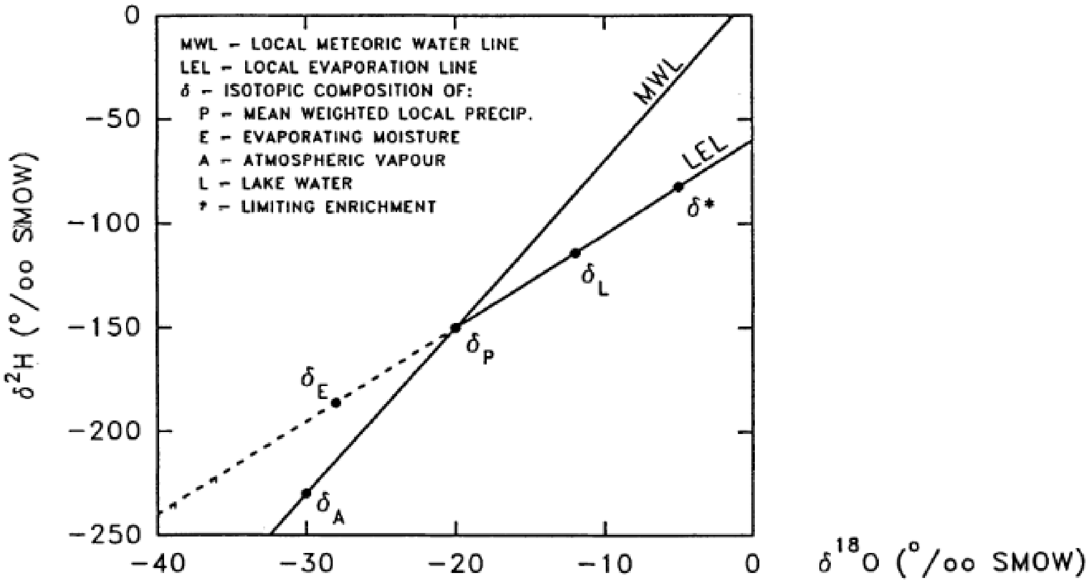

Figure 2: The generalised δ18O vs δ2H plot, [13]

The isotope compositions of precipitation and surface waters in simple catchments typically define two distinct linear trends (Figure 2), where the stable oxygen and hydrogen isotope composition of water that has not gone through evaporation such as precipitation and some groundwater, would plot along the meteoric water line (MWL) [13]. The meteoric water that has undergone evaporation (δ_L) gets enriched in the stable isotopes (^{18}O and ^{2}H) and plot along a local evaporation line (LEL), that indicates a divergence from the MWL as shown in Figure 2. The slope of a LEL usually ranges between 4 and 6, less than the MWL slope which is about 8 [13]. The intersection of the LEL and MWL gives an estimate of the weighted mean isotopic composition of annual precipitation in the catchment. On the LEL also plots the isotopic compositions of vapour derived from the evaporating water body (δ_E) and the limiting isotopic enrichment (δ_*) while the isotopic compositions of ambient atmospheric vapour (δ_A) plots on the MWL. The stable isotope composition of the moisture in the ambient air can be determined in three different ways based on the adopted approach and the availability of data [6]. This parameter can be directly measured in the field, or calculated only based on the known local precipitation stable isotope composition or calculated based on the known local precipitation stable isotope composition but corrected using the known LEL.

3.2.5 The use of stable isotopes to estimate evaporation

The stable isotope composition changes in water with climatic parameters are used in the quantification of evaporation losses from both steady and non-steady state models of water bodies. According to [6], the evaporation calculation principles are based on the so-called Craig–Gordon (C-G) model [14]. The theoretical C-G model describes how the stable isotope compositions of liquid water and vapour (δ^2H and δ^{18}O) respond to the climatic conditions during the progressive evaporation process. This model has been revised by many, including [15] where it was proposed to use the stable isotope signature of local precipitation and the LEL for the improved estimation of the stable isotope composition of ambient air moisture, as one of the required variables in the estimation of evaporation losses [6].

The hydrocalculator was proposed in [6], based on mathematical reformulation of the C-G model equations. Its algorithm has excluded a few minor parameters used in the C-G model such as wind, direct sunlight, and surrounding topography and the size and depth of the water body which may cause variations in ambient air moisture and stable isotope composition. The main variables required in the use hydro-calculator include the stable isotope composition of water, air temperature and relative humidity as well as the stable isotope composition of ambient air. The results of the hydro-calculator are issued as evaporation over inflow ratio (E/I) for the steady state model and as the evaporated fraction of the water body volume (f) for the non-steady state model. For the water body considered in the study, the flow model is the steady state type, characterised by progressive inflow and outflow. The hydro-calculator can be found as an online web-based calculator or an offline downloadable Microsoft Excel data or calculation sheet acquirable on http://hydrocalculator.gskrzypek.com.

3.2.6 The Calueque-Oshakati canal

As part of the Water Master Plan in the 1970's, a 154 km long concrete lined canal was built with the last stretch of the canal between Ogongo and Oshakati only commissioned in 1997 [3]. A canal system became operational in 1972 for the transfer of water from the Calueque Dam on the Kunene River inside Angola to the interior of Owambo [4]. This infrastructure initially suffered demolition inside Angola during the civil war. The open canal passes through villages and towns and it is therefore exposed to the consequences of countless human activities and subjected to natural processes. During floods, surface water level rises and washes sediments and pollutants into the canal. Pollution showed an increasing trend from upstream to downstream [3].

Serious water losses are also encountered in the canal such as evaporation, infiltration and illegal withdrawals. Some parts of the canal are made of small concrete blocks joined together by bitumen. Now that it has aged, some water seeps through small openings between blocks. It has also been a victim to vandalism as people in the surrounding communities break or completely remove some blocks in attempts to pave ways for water to fill up the dry shallow iishana. The arid climate of the basin and the nature of water transfer system have made it favourable for evaporation losses. More water is lost from the canal, reducing the amount supplied and increasing the concentrations of the constituents in water. These integrated problems generate high maintenance and water purification costs.

CHAPTER 4: METHODOLOGY

4.1 Introduction

This chapter describes in details the experiments as it clearly gives information on the research design and experimental design used to obtain the results. It states the research instruments and measures that were used and clearly gives step by step procedures on how the instruments were used to collect data. Specific strategies that were employed to analyse data are also provided in this chapter. It includes the reliability and validity of the measurements carried out in the study as well as the ethical considerations.

4.2 Research Design

In order to reach the objectives of the study, a quantitative and comparative research was carried out to quantify and compare the evaporation losses in both dry and wet seasons. The comparisons were also made between the volumetric losses from the canal and the amounts of water supplied to the Namibian part of the Cuvelai-Etosha Basin through the Calueque-Oshakati canal. In the estimation of evaporation losses, Numeric data (climatic parameters and isotopic values) was required for the calculations.

4.3 Research Instruments

This study used several instruments supplied by different institutions and departments in order to measure different variables required to meet the study objectives. The variables and instruments used in the calculations of evaporative losses are indicated in Table 1.

Table 1: Variables to be measured and instruments

Variable	Instrument	Units	Institution/Department
Air temperature	Thermometer *obtained from weather stations	°C	Meteorological Services of Namibia
Electric Conductivity	Electric Conductivity meter	µS/cm	University of Namibia, Geology Department
Water depth, Width	Measuring rod, Measuring tape	m	University of Namibia, Civil and Environmental Engineering Department
Flow rate	Flow meter (propeller)	m/s	Ministry of Agriculture, Water and Forestry, Hydrology Department
Relative Humidity	Hygrometer *obtained from weather stations	%	Meteorological Services of Namibia
Stable isotope composition	Liquid-Water isotope analyser	‰	University of Namibia, Geology Department

4.4 Procedures

4.4.1 Sampling

The water samples were taken from the raw water canal at two different sessions. The first sampling was done on the 22nd December 2018, at 9 sampling sites. While the second sampling took place on the 24th April 2019, at 9 sampling sites including the Olushandja Dam canal outlet. The sampling sites were selected at an interval of 20 km with the furthest being at the Angola-Namibian borders at Mahenene Border Post. Samples were taken all the way up to the crossing bridge at the open markets in Oshakati. The water samples were kept in properly sealed and labelled 50 ml bottles until the stable isotope composition analysis was carried out. Variables such water temperature and electric conductivity were measured in-situ (Figure 3), using a portable electric conductivity meter and flow measurements were also made at every sampling site during the second sampling session.

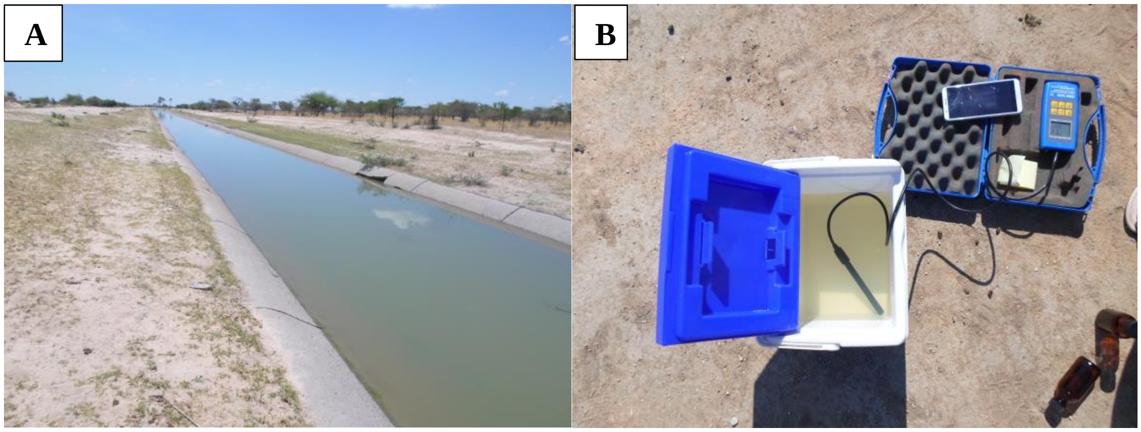

Figure 3: A. The Calueque-Oshakati canal, B. the on-site measurement of water temperature and electric conductivity.

4.4.2 Climatic data collection

The hydro-calculator model uses climatic data input of air temperature and relative humidity to calculate evaporation losses. This climatic data was obtained from the Meteorological Services of Namibia and the Southern African Science Service Centre for Climate Change and Adaptive Land Management (SASSCAL) (http://www.sasscalweathernet.org/) (Table 10 in the Appendices).

4.4.3 Flow measurements

The water flow rate in the canal was measure at every sampling site (1-9) using a propeller-type flow meter. The flow rate measurements together with wetted cross-sectional area calculations were made according to the setup shown by a sketch of a trapezoidal canal cross-section in Figure 4.

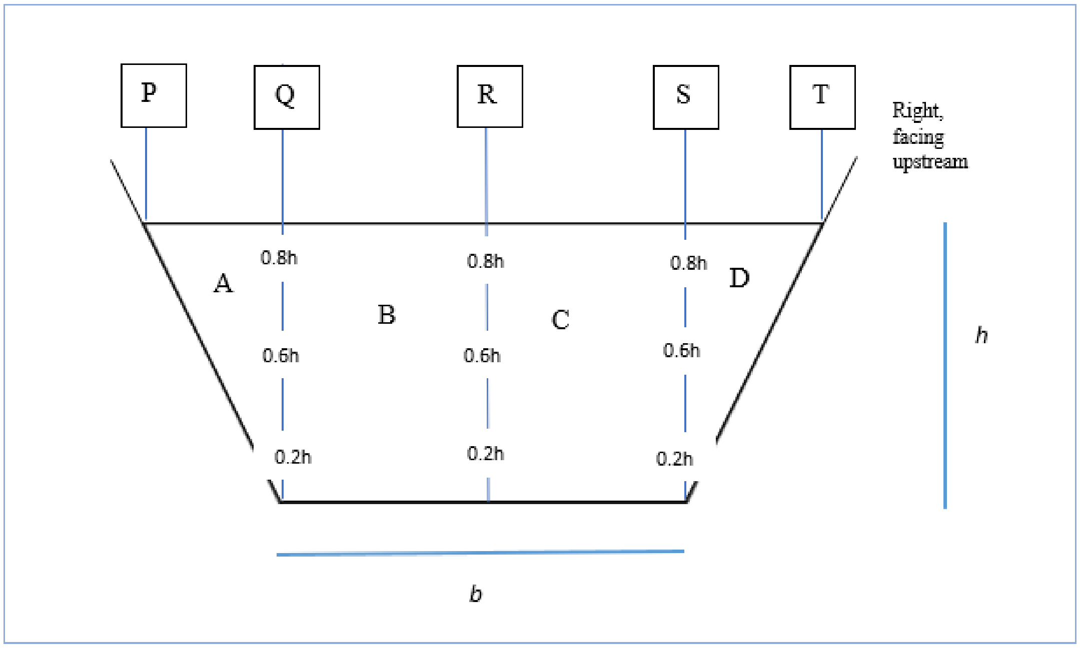

Figure 4: Sketch of the canal cross-section showing flow measuring points

A measuring tape was used to measure the top width (PT) and the bottom width (QS) of the water while a measuring rod was used to measure the hydraulic depth (h) of water in the canal (Figure 3). The measuring rod was vertically placed in the canal to form vertical boundary lines Q, R and S; and eventually create four sub-sections A, B, C and D. At each of the three boundary lines, a propeller flow meter was attached to the rod at three depths (0.2h, 0.6h and 0.8h) facing upstream to measure flow velocity (v) at those heights. The arithmetic mean value of the velocities measured was considered as a representative flow velocity at each boundary line. The flow velocity at P and T is almost zero.

In order to compute discharge (Q) at each sub-section, wetted cross-sectional areas and mean flow velocities between the two boundary lines were required. A mean-section method was used to calculate sub-sectional discharges that total into an overall cross-sectional discharge (Q_{Total}). The mean-section method uses a formula that equates the total discharge with the sum of the products of sub-sectional areas and the average flow velocities at the two vertical bounding lines as notated below:

$$Q\ (Total) = A1\left(\frac{V0+V1}{2}\right) + A2\left(\frac{V1+V2}{2}\right) + \cdots,$$

Where, $Q_{(\text{Total})}$ = Total Discharge (m^3/s)

$A_1, A_2, \ldots$ = Area of sub-section 1, 2, … (m^2)

$V_0, V_1, V_2, \ldots$ = mean flow velocities at boundary lines 0,1,2 … (m/s)

4.4.4 Stable Isotope Composition Analysis

The stable isotope composition of water is usually analysed in a laboratory with an uncertainty of about 0.1‰ for $\delta^{18}O$ and 1‰ for $\delta^{2}H$. This stable isotope composition analysis was performed in the laboratory at the University of Namibia (Main Campus) in Windhoek, using an automated liquid-water isotope analyser (Figure 5). It was performed to obtain the stable isotopic ratios of water as required as an input for evaporation losses calculations in the hydro-calculator. The analyser performs four automated injections per sample and provides mean values the isotope compositions. One analysis took about 15 hours.

Figure 5: An automated liquid-water analyser performing the stable isotope composition analysis.

4.5 Data Analysis

The stable isotope compositions obtained from the laboratory were entered into a hydro-calculator together with climatic parameters (air temperature and humidity) to calculate the evaporative losses. The climatic parameters were recorded at Oshakati and Outapi weather stations, and obtained from the Meteorological Services of Namibia. The results were obtained as evaporation to inflow ratios, and statistically analysed using the Statistical Package for Social Scientists (SPSS) to produce graphs and descriptive statistics.

4.6 Validity, Reliability and Ethics

In order to conduct this study, an approved ethical clearance and a research permission letter was obtained from the University of Namibia (UNAM). For accuracy, instruments were calibrated to minimize significant errors and the International System (SI) units were used. Uncertainties associated with the models used were discussed in the study. Other people’s work and ideas were properly acknowledged and cited to avoid plagiarism.

CHAPTER 5: RESULTS

5.1 Introduction

This chapter reports and presents the field observations as well as in-situ and laboratory measurements. It also summarises the findings of the entire research that have been obtained through the methodology.

5.2 Field observations and measurements

The canal is found along the road from Angola through Mahenene Border Post to Olushandja Dam. It extends all the way through Outapi, Ogongo, Oshikuku and it ends up in Namwater reservoir in Oshakati. It is mostly open, with very short portions concealed underground especially at Olushandja Dam and across some depressions (iishana). The canal is a bit wider towards the borders as well as Oshakati comparing it with the narrow width across the middle areas such as Ogongo and Oshikuku. Its depth also varies, with greater depths noticed at narrow widths. Small water pumps have been set up along the canal supplying water for construction and bricks manufacturing as well as small-scale agricultural activities. During sampling, on-site measurements of water temperature and electrical conductivity were measured and presented with site observations in Table 2.

Table 2: Presentation of the site observations and in-situ measurements

SITE	Location / Coordinates	Site Observations	Field Measurements	
			Dec 2018	April 2019
Site 1	Mahenene	This is the canal inlet to	T (°C): 26.2	T (°C): 25.3

	Border Post -17.39182 14.56695	Namibia at the Angola-Namibia borders. Sampling and measurements were done at a bridge across the canal. The site is surrounded by thorns and mopane trees. There are buildings on the other side of the road, which is about 50 m E of the 6.5 m wide canal.	EC (μS/cm): 71 Sample ID: CEBD1	EC (μS/cm): 66 Sample ID: CEBW1
Site 2	Olushandja Dam -17.43075 14.64351	This is the canal inlet into the Olushandja Dam Reservoir. Here the canal is concealed underground for about 300 m upstream and 500 m downstream, along the dam embankment. There are mopane and thorn trees in the vicinity, and reeds within the dam reservoir.	T (°C): 26.1 EC (μS/cm): 72 Sample ID: CEBD2	T (°C): 24.3 EC (μS/cm): 58 Sample ID: CEBW2
Site 3	Okafa -17.44674 14.74294	At the bridge across the concrete block-made canal. The site is surrounded by mopane trees, with a fence close to 50 m S of the canal and a tarred road about 50 m N of the site. The canal is about 6 meters wide.	T (°C): 27.2 EC (μS/cm): 71 Sample ID: CEBD3	T (°C): 25.7 EC (μS/cm): 61 Sample ID: CEBW3
Site 4	Okahwa ka Mbandjele -17.49634 14.92407	The canal is about 6 m wide, and made of small concrete brocks. The site is surrounded by mopane and thorn trees. About 50 m S of the crossing bridge at which sampling and measurements were made is a fence, while a tarred appears about 50 m N of the site.	T (°C): 27.7 EC (μS/cm): 74 Sample ID: CEBD4	T (°C): 26.2 EC (μS/cm): 63 Sample ID: CEBW4

Site 5	-17.56051 15.07116	At a crossing bridge, a canal is about 4 m wide. It is surrounded by mopane trees and a fence appears about 50 m S of the point.	T (°C): 27.8 EC (µS/cm): 71 Sample ID: CEBD5	T (°C): 25.8 EC (µS/cm): 62 Sample ID: CEBW5
Site 6	Ogongo -17.64208 15.22566	The 3 m wide canal is concrete-lined. There is a crossing bridge, and two fences appearing along the E-W stretching canal, about 40 m N and S of the canal.	T (°C): 28.9 EC (µS/cm): 75 Sample ID: CEBD6	T (°C): 26.4 EC (µS/cm): 64 Sample ID: CEBW6
Site 7	Oshipanda -17.65487 15.39564	At a broken crossing bridge, the concrete-lined canal is about 5 m wide. The site is surrounded by thorn bushes and palm trees. The site is about 50 m E of the tarred road and there is a fence about 20 m E of the sampling point.	T (°C): 28.6 EC (µS/cm): 79 Sample ID: CEBD7	T (°C): 25.8 EC (µS/cm): 63 Sample ID: CEBW7
Site 8	-17.70745 15.54757	The site is surrounded by thorn bushes and palm trees. There is a bridge across the 5 m wide E-W stretching canal. The tarred road is about 50m N of the site.	T (°C): 29.3 EC (µS/cm): 80 Sample ID: CEBD8	T (°C): 27.2 EC (µS/cm): 67 Sample ID: CEBW8
Site 9	Oshakati Open Market -17.77271 15.69873	The site is in town, at small bridge behind the Oshakati open market. There are different building structures surrounding the site and the tarred road cuts across the canal at about 60 m upstream. The canal is about 6 m wide.	T (°C): 28.8 EC (µS/cm): 79 Sample ID: CEBD9	T (°C): 28.3 EC (µS/cm): 68 Sample ID: CEBW9

5.3 Isotopic ratios and evaporation factors

The isotopic ratios of water in the canal were calculated and evaporation factors were determined for both wet and dry seasons. The isotopic ratios of the samples collected in December 2018 and April 2019 and representing the wet period are presented in Table 3, with the evaporation over canal inflow factors.

Table 3: Water stable isotope compositions and evaporation/inflow ratio in wet season.

SITE	**December 2018**				**April 2019**			
	Isotope Composition		**Evapo. / Inflow factor**		**Isotope Composition**		**Evapo. / Inflow factor**	
	$\delta^{18}O$	**$\delta^{2}H$**	**^{2}H**	**^{18}O**	**$\delta^{18}O$**	**$\delta^{2}H$**	**^{2}H**	**^{18}O**
Site 1	-1.42	-12.90	0.0132	0.0061	-2.93	-15.54	0.0103	0.0053
Site 2	-1.30	-12.10	0.0132	0.0061	-2.81	-14.73	0.0103	0.0053
Site 3	-1.29	-12.10	0.0000	0.0000	-3.37	-17.57	-0.0366	-0.0249
Site 4	-1.43	-10.58	0.0251	-0.0070	-3.23	-16.41	0.0152	0.0062
Site 5	-1.31	-9.84	0.0123	0.0061	-3.19	-16.70	-0.0038	0.0022
Site 6	-0.74	-11.30	-0.0236	0.0284	-2.98	-16.05	0.0093	0.0097
Site 7	**	**	**	**	-2.92	-15.24	0.0117	0.0028
Site 8	**	**	**	**	-2.38	-13.70	0.0222	0.0251
Site 9	-0.65	-6.86	0.0729	0.0045	-2.34	-12.94	0.0110	0.0019
E/I Tot.			**0.1131**	**0.0442**			**0.0496**	**0.0336**
Ave.			**0.0814**	**0.0389**			**0.0814**	**0.0389**

** - no data (broken sampling bottles)

Water in the canal had lower isotopic ratios in April than in December as shown in Table 3 by both oxygen and hydrogen isotopes. Despite that, the evaporation over inflow factors were higher in December than in April. The evaporation analysis is based on both oxygen and hydrogen isotopic ratios, and evaporation factors based on hydrogen isotopic ratios are higher than the evaporation factors based on oxygen isotopic ratios. Both of the sessions are in the wet season according to the hydrologic calendar, and therefore, the evaporation to inflow factor based on stable hydrogen isotope is 0.08 and 0.04 based on the stable oxygen isotope, on average.

The secondary data used was provided by the UNAM Geology Department and compared with the primary data that was obtained during the wet season. This water data was used to represent the canal water in the dry season and it is presented in Table 4.

Table 4: Stable isotope compositions of water in the canal for May 2018.

ID	Longitude	Latitude	Type	$\delta^{18}O$	$\delta^{2}H$	E/I_H	E/I_O
CH-02	15.68326	-17.76658	Canal	-5.31	-37.78	0.0578	0.0564
CH-03	15.30146	-17.67025	Canal	-5.33	-37.33	0.0497	0.0484
CH-25	14.60735	-17.42809	Canal	-5.54	-35.67	0.0040	0.0038
CH-26	14.63961	-17.43969	Olushandja Dam	-1.62	-18.49	0.1673	0.1625
CH-27	14.63957	-17.45333	Olushandja Dam	-2.98	-24.74	0.1158	0.1121
CH-28	14.72109	-17.44404	Canal	-5.44	-36.13	0.0221	0.0213
CH-29	15.01816	-17.52662	Canal	-5.58	-35.79	0.0018	0.0018
E/I Tot.						**0.1931**	**0.1317**

These canal water samples exhibit much lower isotopic ratios than those of the wet season in Table 3. This is confirmed by more negative isotopic ratios and high total progressive evaporation factors in the dry season than in the wet season. Based on the stable hydrogen isotope, the total evaporation factor is shown as 0.19 whereas, the evaporation factor based on oxygen isotope is 0.13. Using these factors or their percentages, the volumetric evaporation estimates are determined as they are applied onto the measured discharge flowing in the canal.

Table 5 shows a summary of the descriptive statistics of the isotopic data for all the three sessions presented in Table 3 and Table 4 of the results.

Table 5: Descriptive statistics of the Calueque-Oshakati canal water date for 3 different sessions.

Session	**May 2018**		**December 2018**		**April 2019**	
Stable Isotope	**$\delta^{18}O$**	**$\delta^{2}H$**	**$\delta^{18}O$**	**$\delta^{2}H$**	**$\delta^{18}O$**	**$\delta^{2}H$**
Mean	-4.54	-32.27	-1.16	-10.81	-2.90	-15.43
Standard dev.	1.47	6.99	0.30	1.87	0.34	1.38
Maximum	-1.62	-18.49	-0.65	-6.86	-2.34	-12.94
Minimum	-5.58	-37.78	-1.43	-12.90	-3.37	-17.57
Median	-5.33	-35.79	-1.30	-11.30	-2.93	-15.54
Mode	N/A	N/A	N/A	-12.1	N/A	N/A

The canal water in May generally has lowest isotopic ratios for both oxygen and hydrogen isotopes (-4.54 ‰ and -32.27 ‰). The standard deviations of both isotopes are 1.47 and 6.99 respectively. December has the highest water isotopic ratios where oxygen has -1.16 ‰ (SD = 0.30) and hydrogen has -10.81 ‰ (SD = 1.87). The intermediate isotopic ratios of water in April are -2.90 ‰ for oxygen and -15.43 for hydrogen. The lowest isotopic ratios calculated in the entire cycle are -5.58 ‰ for oxygen -37.78 ‰ for hydrogen in the dry season while -0.65 ‰ for oxygen and -6.86 ‰ for hydrogen are the highest isotopic ratios of the cycle.

5.4 Flow measurements

In order to estimate the amount of water supplied to the basin through the canal transfer system, discharge (Q) was calculated at 8 sites as a product of cross-sectional areas and flow velocities. No flow measurements were able to be made in the Olushandja Dam reservoir (Site 2). The flow velocities of water in the canal are presented in Table 6 as measured at different measuring points of each canal cross-profile (Figure 4).

Table 6: Flow velocities at different at different water depths along the vertical boundary lines across the cross-sections at each site.

Boundary Line	Depth	Site 1	Site 3	Site 4	Site 5	Site 6	Site 7	Site 8	Site 9
Q	**0.8h**	2.07	1.52	1.31	1.57	1.82	1.33	1.21	0.90
	0.6h	2.17	1.36	1.36	1.54	1.85	1.36	1.21	0.89
	0.2h	1.85	1.35	1.03	1.14	1.56	1.16	0.98	0.64
	mean v	2.03	1.41	1.23	1.42	1.74	1.28	1.13	0.81
R	**0.8h**	2.57	1.41	1.40	1.86	1.94	1.43	1.22	0.90
	0.6h	1.97	1.39	1.35	1.84	1.92	1.48	1.14	0.87
	0.2h	1.87	1.14	1.08	1.13	1.53	1.31	0.98	0.65
	mean v	2.14	1.31	1.28	1.61	1.80	1.41	1.11	0.81
S	**0.8h**	2.51	1.50	1.43	1.54	1.44	1.24	1.33	0.74
	0.6h	2.18	1.50	1.35	1.24	1.86	1.33	1.15	0.85
	0.2h	1.83	1.30	1.12	1.14	1.64	1.14	1.01	0.64
	mean v	2.17	1.43	1.30	1.31	1.65	1.24	1.16	0.74

Table 6 shows different flow velocities (m/s) at three different heights of different boundary lines (Q, R and S). These velocities generally show an increasing trend from the bottom of the canal towards the shallow depths. The highest velocity recorded is 2.57 m/s at the hydraulic depth of 0.8h of the boundary line R, at Site 1 while the lowest value was measured at the 0.2h depth of Q and S boundary lines of Site 9. The mean values of all the 5 boundary lines appear in Table 7.

Table 7: Cross profile dimensions (depth and width) and mean velocities at all the sites.

Site	**Hydraulic Depth h** (m)	**Top width PT** (m)	**Bottom width QS** (m)	**v at Q** (m/s)	**v at R** (m/s)	**v at S** (m/s)
Site 1	0.80	6.10	3.70	2.03	2.14	2.17
Site 3	0.80	5.78	2.62	1.41	1.31	1.43
Site 4	0.92	5.50	2.10	1.23	1.28	1.30
Site 5	1.18	3.40	1.70	1.42	1.61	1.31
Site 6	1.25	3.10	0.90	1.74	1.80	1.65
Site 7	0.87	4.80	1.80	1.28	1.41	1.24
Site 8	1.10	4.60	1.60	1.13	1.11	1.16
Site 9	1.28	5.60	2.60	0.81	0.81	0.74

The canal width and depth vary independently as presented in Table 7. The canal is wider (6.10 m) and also shallower (0.8 m) towards the borders (Site 1). The middle section of the canal around site 5 and 6 is the narrowest, with great depths while it widens and deepens as you move towards Oshakati (Site 9). There is a general decreasing trend in the flow velocity as you move downstream. This is indicated by the highest velocities at site 1 and lowest velocities at site 9. It is also observable that the flow of water at the centre of the canal (vertical boundary line R) is faster than the flow closer to the banks of the canal. There is no flow exactly at the banks (P and T).

Since the canal has a trapezoidal shape, the boundary lines across the canal profile have split it into triangular and rectangular shapes that were used to calculate the sub-sectional areas. The cross-sectional areas of the fours sub-sections (A-D as indicated in Figure 4) are presented in Table 8, with the final values of flow discharge (Q).

Table 8: Sub-sectional areas and discharges along the canal.

Site	**Area A** (m^2)	**Area B** (m^2)	**Area C** (m^2)	**Area D** (m^2)	**Area Tot.** (m^2)	**Q (A)** (m^3/s)	**Q (B)** (m^3/s)	**Q (C)** (m^3/s)	**Q (D)** (m^3/s)	**Q Total** (m^3/s)
Site 1	0.48	1.48	1.48	0.48	**3.92**	0.49	3.08	3.18	0.52	**7.27**
Site 3	0.63	1.05	1.05	0.63	**3.36**	0.44	1.43	1.40	0.45	**3.72**
Site 4	0.78	0.97	0.97	0.78	**3.49**	0.48	1.21	1.25	0.51	**3.45**
Site 5	0.50	1.00	1.00	0.50	**3.01**	0.36	1.52	1.46	0.33	**3.67**
Site 6	0.69	0.56	0.56	0.69	**2.50**	0.60	0.99	0.97	0.57	**3.13**
Site 7	0.65	0.78	0.78	0.65	**2.86**	0.42	1.05	1.03	0.40	**2.90**
Site 8	0.83	0.88	0.88	0.83	**3.42**	0.47	0.99	1.00	0.48	**2.93**
Site 9	0.96	1.66	1.66	0.69	**4.97**	0.39	1.34	1.29	0.36	**3.38**
Ave.					**3.44**					**3.81**

The cross-sectional area varies along the canal, with largest area at Site 9 while Site 6 shows the smallest wetted cross-sectional area. On average, the canal has a wetted cross-sectional area of 3.44 m^2. Discharge is much higher at Site 1, but it drops to almost half of the initial value at Site 3. It then keeps fluctuating within an average of 3.31 m^3/s all the way to Site 9. On average, the flow rate within the canal is 3.81 m^3/s.

Applying the calculated evaporation factors on the mean flow rate (3.81 m^3/s) in the canal gives the actual volumetric estimates of evaporation from the canal. The evaporation losses from the canal in both seasons appear in Table 9.

Table 9: Actual evaporation losses based on canal inflow.

Season	**Wet season**		**Dry season**	
	Based on ^2H	**Based on ^{18}O**	**Based on ^2H**	**Based on ^{18}O**
Evaporation / Inflow factor	0.0814	0.039	0.1931	0.1317
Evaporation loss (m^3/s)	0.31	0.15	0.74	0.50

The evaporation analysis based on the stable hydrogen isotope produced higher losses of 0.31 m^3/s for the wet season and 0.74 m^3/s for the dry season, while the analysis based on the stable oxygen isotope produced lower amounts of 0.15 m^3/s during the wet season and 0.50 m^3/s during the dry season.

CHAPTER 6: DISCUSSION

6.1 Introduction

This chapter discusses and interpret the findings of the study in relation to the hypothesis, objectives as well as the literature reviewed.

6.2 Field Measurements

Both of the measured water temperature and electric conductivity in the Calueque-Oshakati canal show an increasing trend as you move downstream. According to [16], the electric conductivity-temperature relation of natural water is linear. This is evident in Table 2 of the results where the two parameters are presented for two sampling sessions. Both parameters generally increase in the canal from the Angola-Namibian borders towards Oshakati. This trend confirms that evaporation is taking place in the canal. Conductivity of water is its capability to pass electrical flow, which is directly related to the concentration of ions in the water. The concentration of conductive ions in water increases as fresh water escapes the system during evaporation, leaving the system more enriched in ions than before. The differences in electric conductivity of two sessions also indicate the differences in the intensity of evaporation. On that basis, evaporation was much higher in December than in April. In the central-northern part of Namibia, it is usually hotter and dryer in December than in April, which is favourable for high evaporation.

6.3 Isotopic ratios and evaporation factors

The isotopic compositions of water vary throughout the cycle (Table 5). Both isotopic ratios for December and April represent the wet season according to the hydrological calendar, which indicates that the canal water is less depleted in ^{16}O and ^{1}H or less enriched in ^{18}O and ^{2}H. The depletion of lighter isotopes (^{16}O and ^{1}H) works hand in hand with the enrichment of heavy or stable isotopes (^{18}O and ^{2}H) in water during the evaporation process [10]. During the dry season (May), the lower isotopic ratios result from a high depletion of lighter isotopes as well as high stable isotopes enrichment.

As described in [13], the oxygen and hydrogen isotope compositions of precipitation and surface waters in simple catchments typically define two distinct linear trends in $\delta^{18}O$ vs $\delta^{2}H$ plots. This as well applies in the CEB as it is evident in Figure 6, Figure 7 and Figure 8. The precipitation $\delta^{18}O$ and $\delta^{2}H$ values exhibit a predictable behaviour globally, with the tendency to fall along the global meteoric water line (GMWL) as defined in [17]. This line appears in all plots with a slope of 8, expressing the $\delta^{2}H$ and $\delta^{18}O$ ratio which indicates that hydrogen is 8 times greater than oxygen. After undergoing some evaporation, the water samples get enriched in ^{18}O and ^{2}H, and diverge from the GMWL to form a linear pattern along evaporation lines (EL). Evaporation lines' slopes are often in the range of 4 to 6 [14], and for the 3 sets of water samples examined in the study, evaporation lines' slopes are 4.7 for May 2018, 3.9 for December 2018 and 4.0 for April 2019. From the regression analysis, Figure 6 and Figure 8 have shown higher R-squared values of 0.9 and 0.9 respectively. This means the data (isotopic values) is closer to the fitted regression line and the variability of the data is more around its mean than in Figure 7 which has a lower value ($R^2 = 0.39$).

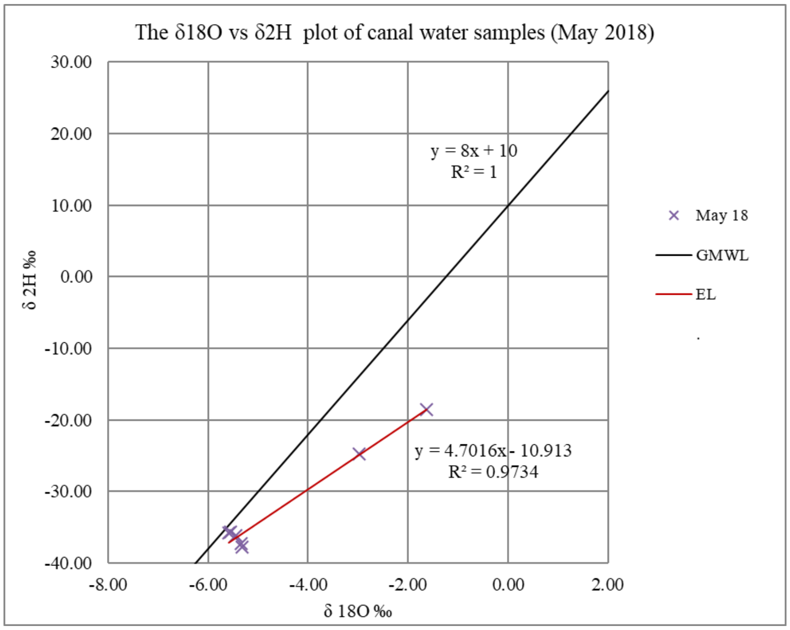

Figure 6: Dry season's stable isotopic values of Calueque-Oshakati canal water (May 2018).

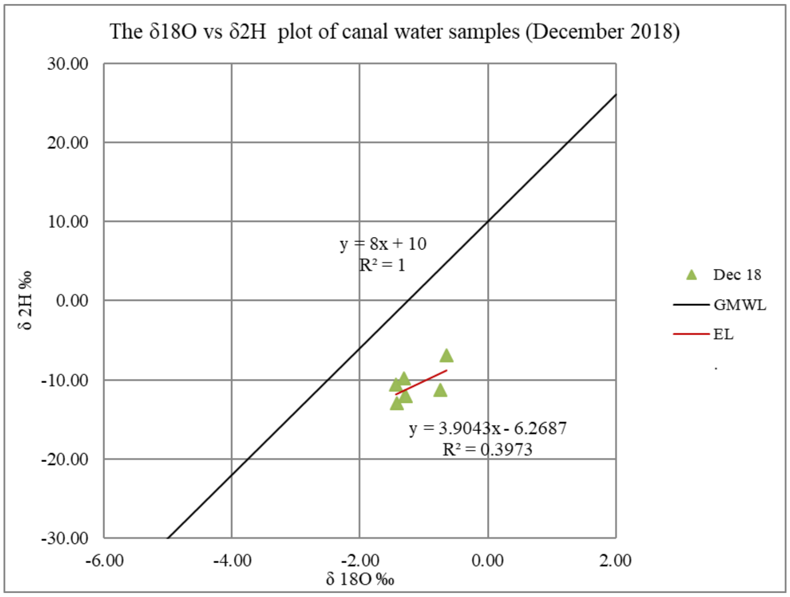

Figure 7: Wet season's stable isotopic values of Calueque-Oshakati canal water (December 2018).

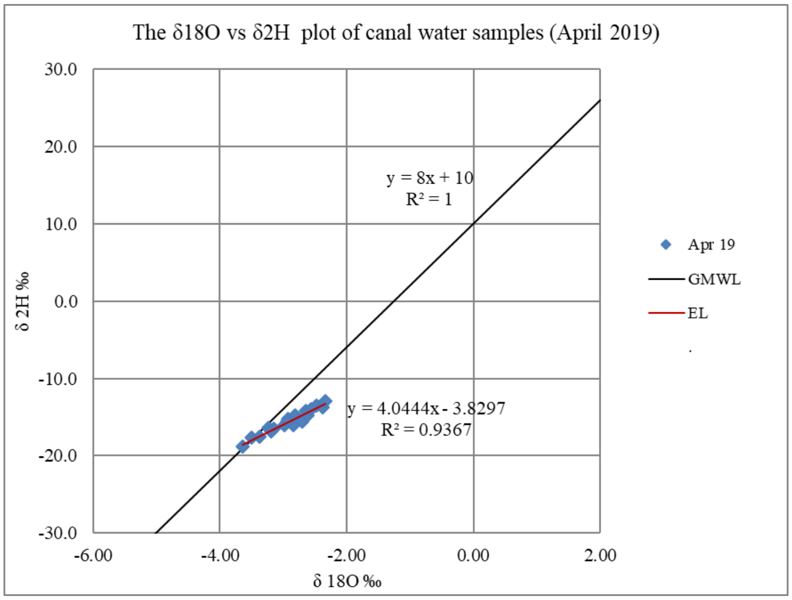

Figure 8: Wet season's stable isotopic values of Calueque-Oshakati canal water (April 2019).

The isotopic signatures of the canal water in CEB indicate a seasonal effect, observable from significantly different isotopic ratios in different seasons. This effect is directly related temperature, which influences isotopic fractionation [11]. During the dry season, the canal water exhibits highly enriched stable isotopic compositions than the wet season.

The calculated evaporation factors (Table 3 and Table 4) also show seasonality. Factors of 0.08 and 0.04 were determined for the wet season on the basis of hydrogen and oxygen respectively. For the dry season, higher evaporation factors of 0.19 and 0.13 were determined. From these factors, it can be interpreted that from any amount of water that flow in the canal, as much as 8 % of it is lost due to evaporation during the wet season while up to about 19 % is lost during the dry season. The actual volumetric losses from the canal can be as high as 0.31 m^3/s and 0.74 m^3/s in wet and dry season respectively (Table 9).

The seasonal differences in evaporation losses are strongly influenced by climatic parameters such as temperature, relative humidity and wind speed that vary with seasons. Different evaporation factors are also related to the stable isotopic composition of water running in the canal and that of moisture in the ambient air. Direct measurement of air moisture’s stable isotopic composition in the field is very challenging [6], but it can be determined using the isotopic composition of local precipitation only or precipitation isotopic composition with a local evaporation line (LEL) slope. For the CEB, no LEL has been determined to this date so the local precipitation isotopic composition alone was used. This precipitation isotopic composition differs throughout the cycle, allowing the evaporation factors to differ as well.

6.4 Flow rate measurements

As presented in Table 8, water in the Calueque-Oshakati canal flows at a mean rate of 3.81 m^3/s (321 184 m^3/day). Generally, the canal discharge reduces towards Oshakati which signifies water uses and losses. The initial amount of water that is supplied to Namibia from Calueque Dam per time unit (7.27 m^3/s) through the canal system reduces to almost half (3.72 m^3/s) as measured at the second measuring point (Site 2). This huge drop in discharge results from a canal outlet into Olushandja Dam reservoir and pipeline to Etunda Irrigation Scheme in Ruacana. The water transfer method used to convey water to Etunda for irrigation is safe from evaporation while the water that enters Olushandja Dam reservoir continues to evaporate under non-steady state conditions that no further outflow from the water pool and the volume decreases from the reservoir mainly due to evaporation. This explains why the mean flow rate was used instead of the higher initial canal inflow to determine the volumetric losses in the canal that flows under steady-state conditions.

There are few insignificant increases in discharge from site to site, which could indicate canal recharge in between. This is possible during the rainy season but during the flow measurements, no rainfall had been recorded in the area. This possibly resulted from measurement uncertainties. The canal passes through treatment plants where reservoir facilities have been set up. If these reservoirs also feed the canal when they are full, this could also result in rises in discharge. Along the canal, water pumps have been set up unlawfully extracting water to water gardens and livestock. Larger unbilled amounts are extracted for bricks manufacturing and construction. Other water losses are the evaporation losses and seepage where the canal has been broken.

6.5 Uncertainties in the evaporative loss estimation

The uncertainty in the calculated evaporation factors mainly depends on uncertainty associated with model inputs such as the stable isotope composition of water, ambient air moisture, climatic parameters and others [6]. The hydro-calculator model is less sensitive to uncertainty accompanying climatic variables such as temperature and humidity. A difference of 1 °C in temperature will result only in a difference in the calculated factors of <0.1% based on both $\delta^{18}O$ and $\delta^{2}H$ [6]. The uncertainty associated with the analysis of stable isotope composition of water is usually about 0.1‰ for $\delta^{18}O$ and 1‰ for $\delta^{2}H$. The model used is highly sensitive to the uncertainty associated with ambient air moisture or the stable isotope composition of precipitation used for estimation of stable isotope composition of ambient air moisture [13]. The use of precipitation isotopic composition with the LEL slope in the study to determine the stable isotope composition of ambient air moisture would yield different evaporation factors by up to a maximum of 0.8% for δ18O and 1.7% for δ2H [6].

CHAPTER 7: CONCLUSION

The study has demonstrated the applicability of stable isotopes and climatic data in the estimation of evaporation losses using the hydro-calculator and it highlighted the significant difference in loss of water through evaporation between the wet and dry season. The study emphasised that the amount of water pumped at Calueque Dam doesn’t wholly reach the intended destinations as volumes are lost due to evaporation along the way. The first objective of the study was met and the findings have shown that more water is lost from the canal during the dry season (19 %) than in the wet season (8 %). In response to the second study objective, the study also highlighted that 7.27 m^3/s is supplied to the lower CEB, and only about 3.81 m^3/s (about 330 000 m^3 per day) flows in the canal to Oshakati. It was estimated in this study that as much as 0.74 m^3/s (about 64 000 m^3/day) is lost due to evaporation during the dry season while as much as 0.31 m^3/s (about 27 000 m^3/day) is lost during the wet season.

CHAPTER 8: RECOMMENDATIONS

There is a need to switch to the effective method of conveying raw water to the treatment plants. It is highly recommended to cover the canal or replace it with a pipeline to prevent the evaporation and other water losses and to control water pollution.

A social impact assessment will be required to find out how the open canal impacts the people along it. It could be required to set up a few water points along the canal, where people can be allowed to collect water and the outflow can be regulated and/or billed.

Where a similar study may be required, it is recommended to collect water samples and climatic data throughout the entire hydrological cycle (monthly or more) to obtain well representative data.

There is a need to establish the local evaporation line (LEL) for the northern region of Namibia, the slope of which is used to correct the stable isotope composition of moisture in ambient air for improved estimation of evaporation factors.

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APPENDICES

Appendix A

Table 10: Climatic data as extracted from the Meteorological services of Namibia's weather database.

Meteorological Services of Namibia		Hourly Mean Data	
Weather Station	Date	Humidity	Temperature
Ondangwa	15 05 2018	70.5	31.6
	22 12 2018	39.9	
	24 04 2019	33.8	
Oshakati	24 04 2019	51.5	27.8
Outapi	15 05 2018	52.7	22.1
	24 04 2019	26.3	26.4