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ASSESSMENT AND DEVELOPMENT OF REMOTE SENSING BASED ALGORITHMS FOR WATER QUALITY MONITORING IN OLUSHANDJA DAM, NORTH-CENTRAL NAMIBIA

BY

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Building Capacity for Water Resources Management in Southern Africa

In collaboration with

ASSESSMENT AND DEVELOPMENT OF REMOTE SENSING BASED ALGORITHMS FOR WATER QUALITY MONITORING IN OLUSHANDJA DAM, NORTH-CENTRAL NAMIBIA

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ABSTRACT

Olushandja Dam is amongst Namibia's inland water bodies that store and supply water to towns such as Outapi, Oshikuku and Oshakati. The dam is part of a complex water supply system that transports inter-basin water from the Kunene River Basin into Cuvelai Basin in the north-central regions of Namibia via a canal. There are potential sources of pollution along the route of the canal and around the dam which have effects on the water quality in the canal and eventually in the Olushandja Dam. Therefore, frequent and continuous monitoring of water quality is needed to allow timely decisions on the management of this critical resource. Specifically, the study sought to measure water quality at selected points in the dam and on the canal. This study used Landsat 8, 30 m resolution imagery to derive water quality parameters using retrieval algorithms. Water quality parameters included total suspended matter, turbidity, total nitrogen, nitrates, ammonia, total phosphorus and total algae counts. The study was carried out from November 2014 to June 2015. The retrieval algorithms were developed from a simple regression analysis between reflectance values of satellite images and field measurements. Statistical analyses were carried out to assess correlation between Landsat 8 predicted and field measured data. The field measurements showed that the dam and canal water is of low risk to human and is suitable for livestock watering. Turbidity levels exceeded the recommended limits set by NamWater is thus likely to cause complications in drinking water treatment as well as human and aquatic life. The study also found that all water quality parameter regression algorithms had high correlation coefficients (R^2) which was between 0.980-0.999. Therefore, the study concludes that the developed regression algorithms are best fit to predict water quality parameters from satellite data. Remote sensing is therefore recommended for frequent and continuous monitoring of Olushandja Dam as it has the ability to provide information about surface water quality and Namibia has cloud free sky most times of the year. However, accurate monitoring data acquired using traditional methods remain an important input into remote sensing process for prediction of water quality.

Key words: Olushandja Dam, Landsat, Remote Sensing, Retrieval algorithms, Water Quality.

DECLARATION

I, **Taimi Sofia Kapalanga,** declare that this thesis is my own original work (except where cited). It is being submitted for the partial fulfilment of the Master of Science Degree in Integrated Water Resources Management at the University of Zimbabwe. It has not been presented and will not be presented to any other university for any degree award.

I understand that my thesis may be made electronically available to the public.

Signature:

Date:

30 September 2015

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ABBREVIATIONS AND ACRONYMS

APHA	American Public Health Association
AWWA	American Water Works Association
CAN	Central Area of Namibia
DEM	Digital Elevation Model
DN	Digital Number
DWA	Directorate of Water Affair
EC	Electrical Conductivity
FLAASH	Fast Line-of-sight Atmospheric Analysis of Spectral Hypercubes
GDAL	Geospatial Data Abstraction Library
GIS	Geographical Information System
GTZ	German Technical Cooperation Agency
IWRMPJVN	Integrated Water Resources Management Plan Joint Venture Namibia
ILWIS	Integrated Land and Water Information System
MAWF	Ministry of Agriculture Water and Forestry
MERIS	Medium Resolution Imaging Spectrometer
NCN	Northern Central Namibia
SDP	Summer Desertification Programme
TOA	Top-of-Atmosphere
TN	Total Nitrogen
TP	Total Phosphorus
TSS	Total Suspended Solids
UN-DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environmental Programme
USGS	United State Geological Survey
UTM	Universal Transverse Mercator

DEFINITIONS

Algorithm – Is a formula or equation for solving a problem. In this context an algorithm is a model used to predict water quality and has been developed from regression equations.

Radiance - Is a measurement of energy radiated by an object. In other words, it is how much light the instrument "sees" from the object being observed. Radiance is most often measured in watt/ (steradian/square meter).

Reflectance - Is an inherent property of an object and is independent of time, location illumination intensity, atmospheric conditions and weather. It is a ratio of reflected energy to incident energy as a function of wavelength.

Remote sensing – Is the science of acquiring, processing and interpreting images that record interaction between electromagnetic energy and matter.

CHAPTER 1

1. INTRODUCTION

1.1 Background

Fresh water is a finite resource that is essential for human existence (UNEP, 2008). Without freshwater of adequate quantity and quality, sustainable development will not be possible (UN-Water, 2011). Water is of direct interest for the basic needs of the entire population, as well as for most developmental activities at central and state levels, municipalities, private sector, and non-governmental organizations (Biswas, 2004). Therefore, Integrated Water Resources Management (IWRM) is an essential approach as it emphases on effective management of water resources within the basin. IWRM seeks to promote the coordinated development and management of water, land and related resources in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems (GWP-TAC4, 2000).

The quality and quantity of water is, however, threatened by pollution which mainly comes from point and non-point sources (Gumbo *et al.*, 2008; UNEP, 2010). Point sources include discharge of industrial effluent, poor sanitation practices, discharge of partially or untreated sewage, disposal of solid waste, release of liquid from refuse dumps and discharge of food processing waste (Gumbo *et al.*, 2008; UNEP, 2010). Whereas non-point sources include run-off from agricultural lands (e.g. fertilizer, herbicides, pesticides) and solid waste dumps (Gumbo *et al.*, 2008).

In the Southern Africa Region, pollution of both surface and groundwater is on the increase, particularly from mining, agricultural and industrial activities (SADC, 2005). Man-made reservoirs such as dams and lakes are threatened by nutrient enrichment and heavy metals and their water quality is continuously degraded as a result (Oberholster and Ashton, 2008; Nhapi, 2009; Lehmann, 2010). The water quality in the Von Bach and Swakoppoort Dams in the central area of Namibia have been reported to be poor due to pollutants on wastewater from the City of Windhoek and Okahandja Town (Lehmann, 2010; NamWater, 2012). In the north central regions of Namibia, surface water that collect in hand dug wells and other sources are often contaminated and groundwater is mostly saline (Mendelsohn *et al.*, 2013). In Namibia and specifically the north central regions, poor sanitation practices are notably high (IWRMPJVN, 2010). The region is associated with dispersed high populations of about 847, 259 people (NSA, 2011), and more than half of this population practices open defecation (UN, 2010) in flood prone areas. Furthermore about 67% of the population has no access to improved sanitation facilities (UN, 2010). During flood events such as that of the 2008 and 2009 rainy season , a cholera outbreak was reported due to inadequate and poor sanitation in the area (UN, 2011).

Furthermore, bathing, washing clothes along the open Calueque-Oshakati Canal and agricultural activities in the area has been noted (Shuuya and Hoko, 2014). All these activities tend to affect the quantity and quality of water leading to an increase in the cost of treating water for human consumption water resources. Shuuya and Hoko (2014) found that the quality of water in the Calueque–Oshakati Canal is deteriorating from upstream to downstream due to human activities along the canal. This was noted, for example through analysis of the amount of coagulant dosage from upstream to downstream which was found to increase as turbidity increased.

However, sustainable management of water systems requires the systematic monitoring and assessment of water quality. Namibia's Vision 2030 recognises that the country is extremely vulnerable to the effects of water pollution due to its limited surface water and high dependency on groundwater sources (GRN, 2004). The Department of Water Affairs in the Ministry of Agriculture, Water and Forestry is responsible for water quantity, quality and pollution control below and above ground (FAO, 2001; Ruppel and Ruppel-Schlichting, 2013). However, there seems to be a non-systematic programme for water quality monitoring since the creation of the Namibia Water Utility (NamWater) as a separate entity from the Department of Water Affairs (FAO, 2001). This has led to confusion on responsibility for water quality monitoring.

The IWRMPJVN (2010) noted that lack of data and information, continuous monitoring and poor data management exist in the Namibian Water Sector. Monitoring in many Southern African countries has been noted to be hindered by lack of data, capacity and resources (SADC, 2005). However, water quality monitoring in Namibia has been noted to be one of the key issues that requires attention in the Integrated Water Resources Management Plan (IWRMPJVN, 2010). The Olushandja Dam, is an important part of a complex water supply system that builds the backbone of water supply for the Northern Central Namibia (SDP10, 2001; NamWater, 2013; DWA, 2014). But the few studies that are available focus on ad-hoc monitoring (Hambabi, 2015), and other studies focused on the quality of water in the canal that brings water into the dam and to the treatment plants (Shuuya and Hoko, 2014) and transport water from the dam (SDP10, 2001). The quality of water in the dam is, therefore, an important consideration for this study especially the role it plays in the basin.

However, high costs of determining water quality when using traditional techniques may be one of the major contributors to poor monitoring not only in Namibia but also in other countries or regions (IWRMPJVN, 2010). Traditional techniques for assessing and monitoring water quality are expensive and time consuming (Ritchie *et al.*, 2003). In addition, they do not give spatial or temporal view of water quality needed for accurate assessment of water bodies (Ritchie *et al.*, 2003). Using GIS and remote sensing data makes it easy to monitor water quality parameters continuously and also gives spatial view of water quality (Ritchie *et al.,* 2003). However the major constraints would be lack of reliable retrieval algorithms, cost of equipment for in-situ, on-site and laboratory measurements of water quality parameters (Bauer *et al.*, 2007)

1.2 Problem statement

Sustainable management of water resources requires regular monitoring and assessments of water quality. Olushandja Dam, in the north central Namibia, plays an important role of balancing and storing water for urban and rural supply, irrigation, fisheries and livestock watering (Kluge *et al.*, 2008; Mendelsohn *et al.*, 2013). However, there is an increase of irrigation projects in the vicinity of the dam and poor sanitation in the basin (IWRMPJVN, 2010). Also the presence of other substances from human and natural factors can negatively impact on water quality. Hence there is a need to test the applicability of methods that allow routine monitoring of water quality in an economic way and aid in management of water resources. Remote sensing based water quality techniques are therefore an economical way to monitor water quality, since they allow the monitoring of large areas in a short time on a repetitive basis (Hellweger *et al.*, 2004; Somvanshi *et al.*, 2012).

Thus, this study aimed to explore the applicability of remote sensing in combination with field measurements to predict selected water quality parameters in Olushandja Dam.

1.3 Justification

Water quality assessment and monitoring is a key activity of proper water management at sources and anticipating the effects of humans on the dam lake. Namibia is one of the countries with the most days of sunshine or cloud free sky which make it easy for remote sensing application. Olushandja Dam plays an important role in storing and supplying water to treatment plants in Northern Namibia as well as to horticultural farmers around the catchment. Information obtained from this study will help the institutions responsible for management of Olushandja Dam to understand the current status and be able to carry out continuous monitoring of the quality of water in an economical way. This will provide water quality information required in decision making, especially with regards to what management option should be put in place. The findings will also create a new knowledge base on the water quality status of the dam.

1.4 Objective

1.4.1 Main Objective

The main objective of this study was to quantify selected water quality parameters through field based measurements and satellite data in order to develop algorithms for predicting water quality from remote sensing data.

1.4.2 Specific Objectives

The specific Objectives of the study were:

1. To characterize the status of the quality of water in Olushandja Dam through field based measurements.
2. To develop algorithms for predicting selected water quality parameters through satellite and field based data.
3. To predict selected water quality parameters from remote sensing as a framework for continuous monitoring of water quality in Olushandja Dam.

CHAPTER 2

2. LITERATURE REVIEW

2.1. Global fresh water resources

Of all the water available globally, 97% is sea water leaving only 3% as freshwater (WBCSD, 2005). Out of the 3% of freshwater, 87% is not accessible (locked in ice) and only 13% accessible (about 0.5% of the global fresh water) in aquifers, rivers, lakes, and reservoirs that all the global human population and all ecosystems must rely on (WBCSD, 2005).

However, the distribution and availability of water differs from region to region and country to country (SADC, 2005). For example in Southern Africa, there is uneven water distribution, the availability depends on rainfall patterns (SADC, 1996) and access depends on where people have settled. The partitioning of rainfall in Southern Africa shows that of the rainfall received, 35% reach the ground (of this 20% potentially infiltrates and gets used up by plants and lost through transpiration, 14% becomes runoff to river systems and 1% groundwater), and 65% evaporates back to the atmosphere (Pallet, 1997). In Namibia it is estimated that only 2% of the rainfall ends up as surface run-off and a mere 1% becomes available to recharge groundwater (GTZ/MAWF, 2010). According to GTZ/MAWF (2010), the balance of 97% is lost through evaporation (83%) and evapotranspiration (14%) due to the dryness of the country's climatic conditions.

2.2 Water as a special good

There are trends or factors that increase pressure on water resources. These include population growth, climate change, rapid urbanization, expansion of business activities and increasing affluence. The world population is expected to reach 9 billion by 2050 (UN-DESA, 2004; WHO/UNICEF, 2010) and along with the growing economic activities and constant amount of water in the cycle, this will increase demand for scarce water (0.5%) as well as pollution of the water sources. Whereas increasing industrialization and intensive agriculture are having a profound effect on the quality of water resources (WHO/UNICEF, 2010). According to WHO/UNICEF, about 1 billion of the world's population are without any form of improved water supply and about 2.6 billion are without sanitation. Water is a prime carrier of diseases and this poses health risks to human life, aquatic life and the environment(UNICEF, 2008; WHO/UNICEF, 2010). Therefore, there is a strong need for wise management of water resources from global to local level perspectives.

2.3 Global Water Quality

It is not only important to have water available but it is crucial to have water of good quality. Water quality has become a global concern of increasing significance, as risks of degradation translate directly into social economic impacts (WWDRP, 2012). Increasing pressures from different developments lead to deteriorating surface water and groundwater quality (Meybeck and Vörösmarty, 2005). Therefore, water quality assessment and monitoring is an important action as it contributes both directly and indirectly to achieving the targets set out in all 8 (eight) Millennium Development Goals (MDGs), although it is most closely tied to specific targets of the goal, to ensure environmental sustainability (UNEP, 2008). UNEP (2008) stressed that indicators on water quality can be used to demonstrate progress toward the targets of meeting international agreements, by plotting trends in water quality over time and over space. However, this can only be achieved if there is a continuous monitoring and management of water quality.

2.4 Factors affecting water quality at source

Globally, declining water quality has become an issue of concern because as human populations grow, industrial and agricultural activities expand, and climate change threatens to cause major alterations to the hydrological cycle(UN-DESA, 2004). Water quality is a term used to describe the chemical, physical, and biological characteristics of water, usually in respect to its suitability for an intended purpose (Meybeck *et al.*, 1996; Gumbo *et al.*, 2008). Naturally, water is never absolutely pure, as it carries traces of other substances which bestow on it physical, chemical and bacteriological characteristics.

The quality of water at source is affected by both natural and human factors, individually or jointly. However, the degree of impact of these factors varies depending on the type and characteristics of the source involved (Gumbo *et al.*, 2008). Surface water such as that in rivers and lakes or impoundments is more vulnerable to contamination and negative effects of eutrophication because of their direct exposure to human activities. Furthermore, they have complex dynamics, relatively longer water *residence times* and their role as an integrating sink for pollutants from their drainage basins (UN-Water, 2011).

Water pollution and wasteful use of freshwater threatens all forms of life and development projects. For example, poor water quality leads to many economic costs such as degradation of ecosystem services; health-related costs; impacts on economic activities such as agriculture, industrial production and tourism; increased water treatment costs; and reduced property values among others (WWDRP, 2012). Pollution typically refers to chemicals or other substances in concentrations greater than would occur under natural conditions (WWDRP, 2009) . According to the world water development report, major water pollutants include microbes, nutrients, heavy metals, organic chemicals, oil and sediments; heat, which raises the temperature of the receiving water, can also be a pollutant. The factors that influence water quality at source are discussed below.

2.4.1 Natural factors

Natural factors that affect the quality of water at sources (dam, river) include climate; microbial growth; saltwater intrusion and thermal stratification of the water body (Gumbo *et al.*, 2008). Geological and climatic are the most important of the natural influences because they affect the quantity and the quality of available water (Meybeck *et al.*, 1996). According to Meybeck *et.al.* (1996) the influence of geological and climatic factors is greatest when available water quantities are low and maximum use should be made of the inadequate resource; for example, high salt content is a common problem in arid and coastal areas.

2.4.2 Human Factors

The human factors that affect water quality are divided into two categories or groups; point and non-point source pollution (Gumbo *et al.*, 2008; UNEP, 2008) . Point sources are sources of contamination characterized by a single or discrete conveyance, such as the terminus of a sewage pipe whereas non-point sources, in contrast, involve large and dispersed sources of contamination such as agricultural run-off (Gumbo *et al.*, 2008; UNEP, 2008; Gumbo *et al.*, 2008). Von Bach Dam in Namibia and Lake Chivero in Zimbabwe are some of the examples of water sources that have been affected by both point and non-point source pollution from their surrounding areas (Nhapi, 2004; Nhapi, 2009; Lehmann, 2010).

The concentration of nutrients (such as phosphorus and nitrogen) in the upper water level, from agricultural run-off, domestic and industrial effluent, and others sources, can induce an explosive bacterial growth. This is more prominent in dams or lakes in arid to semi-arid climates where evaporation is high; this can lead to rapid eutrophication and algal bloom (Oberholster and Ashton, 2008; UN-Water, 2011;). Therefore, pollution and inefficient use of freshwater sources are among human factors that contribute to water stress around the world.

2.5 Namibia's Water Resources, Supply and Access

Namibia, being the driest countries in Sub-Saharan Africa, water scarcity is a major challenge (Seely *et al.*, 2003). The country is characterized by ephemeral rivers in its interior and perennial rivers are only found along its northern (Kunene, Okavango and Zambezi River) and southern borders (Orange River) which are the only rivers with permanent surface water (Seely *et al.*, 2003; Mendelsohn *et al.*, 2013). Thus in the interior, dams have been constructed on ephemeral rivers around the country (NamWater, 2013). The NCN is sitting entirely in the ephemeral Cuvelai-Etosha Basin which has its origins in Angola and would flood when good rains fall over the catchment, Figure 1. Its catchment falls between that of Kunene River in the west and the Cubango/Okavango River in the east (Mendelsohn *et al.*, 2000). The Cuvelai River enters Namibia as a 130 km wide delta of ephemeral watercourses known as *Oshana* which converge to end up in the Etosha Pan (Mendelsohn *et al.*, 2013).

In the past, the main source of water in the basin has been surface water that is collected from earth dams and shallow hand dug wells (Klintenberg and Christiansson, 2005). Although they were introduced during colonial times (before 1990), they are still in use in the rural areas. The area is characterized with rapid population growth (current population about 847, 259 people (NSA, 2011) and this has direct effects on the water demand for different purposes. In response to the increasing population and generally very saline groundwater, a complex bulk water supply system was developed in 1960s and 1970s (Mendelsohn *et al.*, 2000; Niemann, 2002). This included the extension of the first canal westward and construction of the pipeline to transport water pumped from the Kunene River via the Calueque Dam in Angola and an open canal to different towns and Olushandja balancing dam on the Namibian side of the border.

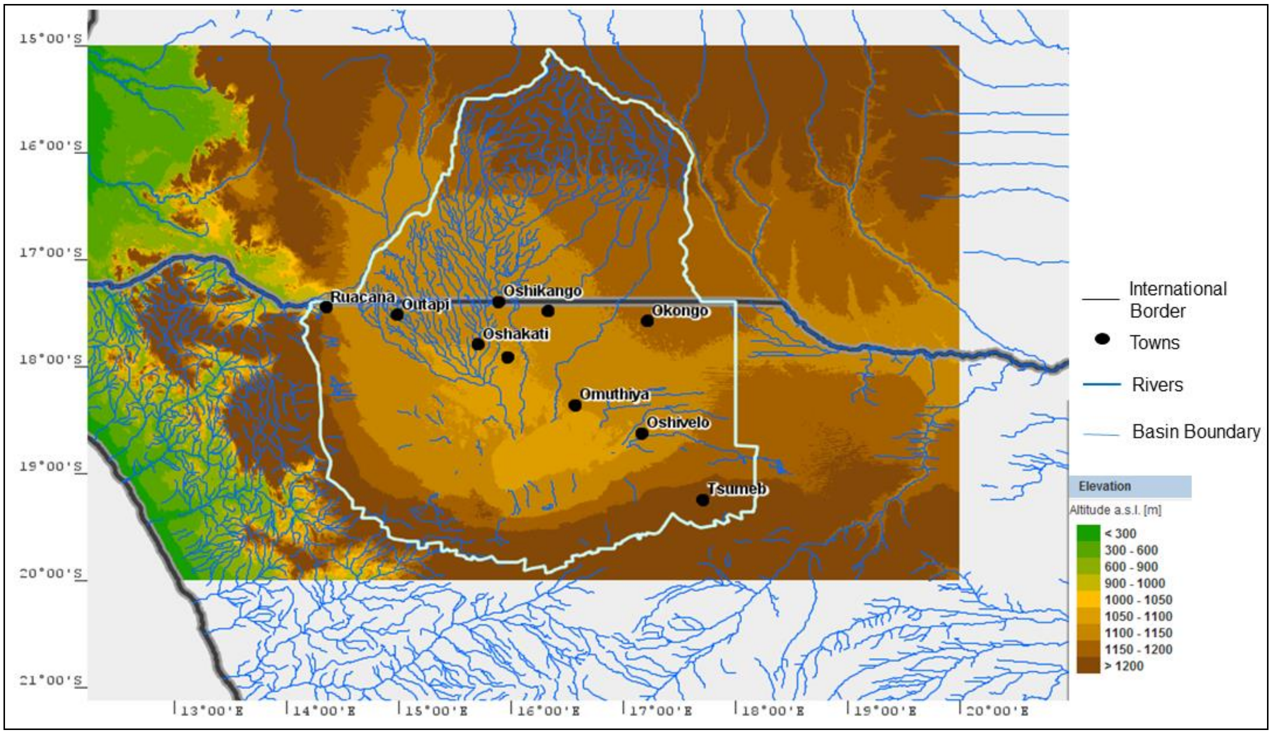

Figure 1: A map showing Cuvelai-Etosha Basin (CuveWaters, 2014).

According to Mendelsohn *et al*. (2000) the Olushandja Dam was designed to store water during excess flows of the Kunene River, and to provide a strategic reserve in the event of supplies from Calueque Dam being interrupted. The Olushandja Dam was also made to release water down the Etaka from time to time for livestock watering in Tsandi and Okahao areas (Mendelsohn *et al.*, 2000). Furthermore, the water is transferred in a canal to treatment works at Olushandja, Outapi, Ogongo and Oshakati where the surface raw water is purified before it is being pumped through the pipeline system to the consumers (Amakali, 2003; NamWater, 2013). However, along the way, it also provides water for people and animals that have access to the canal.

The complex network of dams, canals, pipelines and purification plants serving thousands of water points throughout the most densely populated areas is about 2,600 km long (Klintenberg *et al.*, 2007). The likely problem with the system of getting water from Kunene River would be that, if the Angolan government decides to use more water for irrigation projects in the Kunene's flood plains, then less would be available to be distributed to Namibia. The present agreement between Angola and Namibia dates back to 1964. According to Amakali (2007) cited in Klintenberg *et al*. (2007) Angola has asked to renegotiate the terms of this agreement, an indication that the amount of water distributed to Namibia might change in the near future. Therefore, Namibia needs to manage the available water sources and maintain good relationship with the Angolan government to be able to feed its own growing population.

Humans and animals along the canal and dam have access to water that they extract water for domestic use, drinking, horticultural, fishing and other activities. Water pollution from households, shops, and town's waste and other source are a major problem in the area. Vandalism of the canal wall and bridges has been noted. Such issues are therefore bringing up conflict between NamWater, the community along the canal, traditional leaders and councillors in the north central regions. In 2011, it was reported that vandalism of the canal costs NamWater N$ 600,00 per month on average to repair re-curing damages between Calueque and Oshakati (Hilukilwa, 2011). According to Hilukilwa (2011), NamWater appeals to the community, politicians and traditional leaders every now and then so that they sensitize the public on water resources management and protection.

2.6 Status of Water quality in Namibia

Water quality status in Namibia differs from source to source in both quantity and quality. Artificial water sources have good water quality because it is purified and available throughout the year, whereas traditional water sources are non-perennial and their water quality declines with time (Shanyengana *et al.*, 2004). Although the traditional water sources (shallow wells, *iishana* and dams, boreholes and hand dug wells) are often poor, some communities prefer to use them especially during the rainy season. This is because the quality is better this time of the year and the source can be nearer than artificial water sources.

Groundwater around the country is mostly saline (FAO, 2012). Total dissolved solids levels have been reported to be greater than 6000 mg/L in some area in Namibia and this is not favourable either for humans nor for livestock (SDP10, 2001; Mendelsohn *et al.*, 2013). Mendelsohn *et al.* (2013) demonstrated that groundwater in the central and southern part of Omusati Region is extremely saline and concentrations of sulphate and nitrates are also high. On the other hand, water in the shallow hand dug wells in these areas is often contaminated.

According to the proceedings by NamWater (2012), Von Bach and Swakoppoort Dams in the Central Area of Namibia (CAN) have become eutrophic and hypertrophic, respectively. A study on the status of water quality and sources of pollution in the Swakoppoort Dam confirmed that the dam is eutrophic and mainly affected by partially treated effluent water from the City of Windhoek and Okahandja town (Lehmann, 2010). Swakoppoort Dam is mainly dominated by blue-green algae and this made it to be the worst in terms of water quality (NamWater, 2012). Blue-green algae that are dominating are the anabaena and the microcytic, which have adverse effects on taste and produce toxic substances. This increases the risk of not having enough water to feed the growing population in the CAN.

In the north central regions, the canal water quality has also been notably deteriorating due to pollution and this increases costs of water treatment (Shuuya and Hoko, 2014). Poor water quality has negative effects on human, aquatic life and implicate on different kinds of developments. Thus protection of all water sources, including that from a shared basin, is very important not just for Namibia but the whole world in general.

2.7 Water quality assessment and monitoring

Although there have been some regional successes in improving water quality, there is no data to suggest that there has been an overall improvement in water quality on a global scale (WWDRP, 2012). In Namibia, the IWRMPJVN noted that there are data and information gaps, no/limited monitoring at irrigation projects, lack of continuous monitoring and poor data management in the Namibian Water Sector (IWRMPJVN, 2010). This applies to transboundary Kunene River Basin, where there is a lack of basin-level assessment of water quality, and there are settlements and potential industries development in the basin (Kunene Awareness Kit, 2014). Although the Kunene River water is said to be relatively unpolluted, this brings concerns about deteriorating water quality that is currently shared by Angola and Namibia through a pipeline and a man-made canal.

Studies that have been done on water quality assessment and monitoring have been focused more on traditional techniques which are limited in their spatial and temporal coverage, expensive and time consuming (Ritchie *et al.*, 2003). Researchers have tried to develop integrated ways of assessing and monitoring water quality from global to local scale. The integration of satellite remote sensing with in-situ measurement plays a significant role in providing reasonable and accurate information on water quality. Therefore, this study focuses on the assessment and monitoring of water quality in the canal as it enters Namibia and Olushandja Dam in terms of the physical and chemical characteristics. This is considered to be an important exercise to the basin and Namibia as a whole since Olushandja Dam is part of a complex system that supplies freshwater to a large population in the northern central Namibia. Managing water quality will make a significant contribution to the food production industry taking into account that Namibia is an arid land.

2.8 Application of remote sensing to water quality

Remote Sensing (RS) is a multidisciplinary integrated approach implemented to study and monitor the environment. According to Thomas *et al.(*2004), remote sensing can be defined as a science and art of obtaining information about an object or area through the analysis of data acquired by a device that is not in contact with the object or area under investigation. The use of remote sensing and GIS in water monitoring and management has been long recognized (Usali and Ismail, 2010). According to Ritchie *et al.*(2003) in water quality studies, the use of remote sensing in water quality dated back to 1970s.Using GIS and remote sensing data makes it easy to update water quality parameters, which allows continuous monitoring of water quality (Ritchie *et al.*, 2003). However, the major constraints would be lack of reliable retrieval algorithms, cost of satellite data and equipment's for in-situ, on-site and laboratory measurements of water quality parameters (Bauer *et al.*, 2007).

To retrieve water quality parameters from satellite data, a number of methods have been used. These methods ranged from empirical, semi-empirical techniques to analytical methods for estimating and producing quantitative water quality maps (Schalles *et al.*, 1998; Wang and Ma, 2001; Dekker *et al.*, 2002; Brando and Dekker, 2003; Vignolo *et al.*, 2006; Chen *et al.*, 2007; He *et al.*, 2008; Maillard and Pinheiro Santos, 2008; Salama *et al.*, 2009; Olet, 2010; Chawira *et al.*, 2013; Kibena *et al.*, 2014) with use of different sensors. Some of the studies above have developed and used different prediction models for water quality parameters in different water bodies using satellite spectral bands with several ratios or indices such as the Normalized Difference Vegetation Index (NDVI). The water quality parameters included chlorophyll-*a*, suspended matter and turbidity (Schalles *et al.*, 1998; Li, 2009; Salama *et al.*, 2009; Olet, 2010; Kibena *et al.*, 2014) as they most likely change the water colour.

A few studies have attempted to monitor and model nutrients (such as total nitrogen, phosphorus, nitrate etc.) since these models do not yield results as statistically strong or consistent as constituents that have optical properties (chlorophyll-a, turbidity and coloured organic matter) but proven the ability of remote sensing for these prediction (Alparslan *et al.*, 2007; He *et al.*, 2008; Chen and Quan, 2012). Most of the nutrient prediction models developed so far are based on statistical regression approaches. These approaches have been used by researchers around the world and have been successful in finding best fit regression models (Alparslan *et al.*, 2007; He *et al.*, 2008; Weiqi *et al.*, 2008; Li, 2009; Olet, 2010; El-Saadi *et al.*, 2014; Bonansea *et al.*, 2015).

Predicting water quality characteristics from remote sensing requires ground-truthing and validation (Blake *et al.*, 2013). Therefore, assessment and monitoring of water quality using the combination of remote sensing and in-situ measurements plays a significant role in providing reasonable and accurate optically constituents of water (Salama *et al.*, 2009). It is also recommended that field measurements and satellite overpass should coincide or within a short time window. The time difference between field and satellite measurements is an important aspect, because in a time gap the water quality can change (Hellweger *et al.*, 2004). A time window of ±4 days is deemed sufficient enough to allow match-ups between in-situ data and satellite imagery (Sriwongsitanon *et al.*, 2011). Cloud cover was another aspect that determined the use of satellite imagery because it affects the reflectivity of objects on the surface, thus making images not useful.

Remote sensing based water quality assessment and monitoring has been conducted using different satellite sensors. Although many have used the same method for retrieving or predicting water quality parameter, the type of sensor used may differ. These include MODIS, MERIS, SPOT, and Landsat and their characteristics which guided in the selection process are presented in Table 1.

Table 1: Satellite information of different selected sensors.

Sensor name	Spatial resolution (m)	Temporal (revisit time)	Spectral bands	No. of pixel (in 29 Km^2)
Landsat	30	16 days	8 Landsat 8 has 11	33,333
MODIS	250	16 days	36	480
MERIS	240	35 days	15	520
SPOT	20	26 days	5	75,000

Information gathered from (Tomppo *et al.*, 2002; USGS, 2013).

MODIS was launched on-board the Terra satellite in 1999. Although MODIS also have a shorter visiting time, but based on the size of the study area of 29 km^2, it gives very few pixels as it has fairly coarser resolution. On the other hand SPOT, with latest instruments launched in May 2002, also has good resolution (20 m x 20 m) and can give more pixels than MODIS, but the images are not available for free to the public. MERIS launched on-board the ESA Envisat in 2002, has longer revisiting time, fairly coarse resolution like MODIS. However, MERIS no longer provides images as the satellite mission disappeared into space in 2012 (ESA, 2015).

Therefore, Landsat has a fair revisit time and better resolution than other three sensors described in this exercise. In addition, Landsat imagery are available free of charge from an archive hosted by the USGS Earth Resources Observation and Science (EROS) Centre using the USGS Globalization Visualization Viewer (GLoVis) tool available at http://glovis.usgs.gov. The Landsat missions also represent the longest continuous satellite record of the earth, beginning in 1972 with Landsat 1 and currently with the operation of Landsat 8 (USGS, 2013). Figure 2 below shows the timeline for Landsat missions.

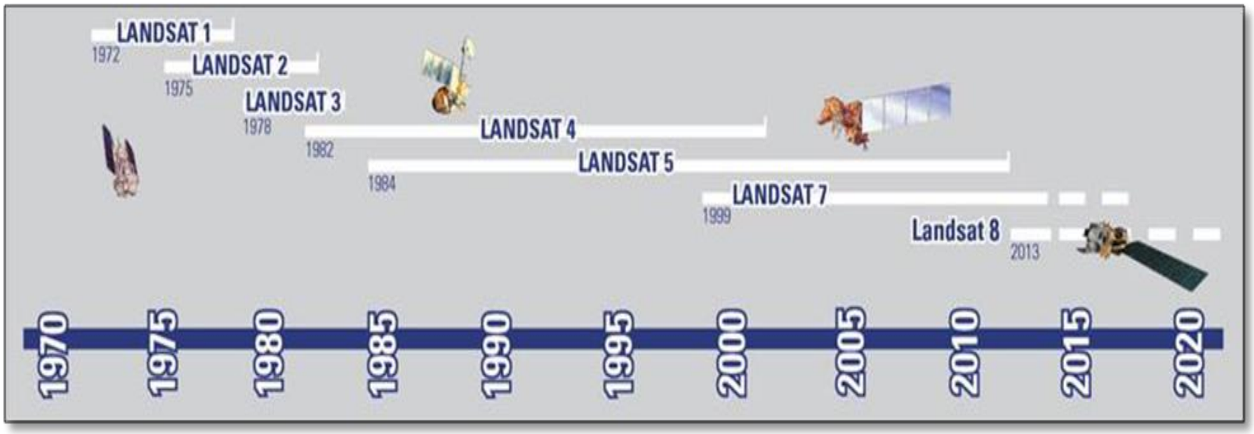

Figure 2: The timeline of Landsat Missions from 1970-2020 (http://www.USGS.gov).

The standard Landsat 8 product launched in 2013 consists of calibrated digital numbers (DN) representing multispectral image data acquired by both the Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (USGS, 2014). It has 11 bands of which only those in the very shortest wavelength are in visible range and others are in part of the spectrum that humans cannot see. The spectral bands of Landsat 8 OLI and their corresponding wavelengths along the electromagnetic spectrum (Loyd, 2013) are presented in Table 2. The sensors on different Landsat satellites were calibrated in a manner that allows for use of the data between satellites (USGS, 2013).

Table 2: Landsat 8 spectral bands, their wavelengths and resolutions

Band	**Wavelength (µm)**	**Resolution –pixel size (m x m)**
Band 1	0.435 – 0.451	30 m Coastal/Aerosol
Band 2	0.452 -0512	30 m Blue
Band 3	0.533 – 0.590	30 m Green
Band 4	0.636 – 0.673	30 m Red
Band 5	0.851 – 0.879	30 m NIR
Band 6	1.566 – 1.651	30 m SWIR-1
Band 7	2.107 – 2.294	30m SWIR-2
Band 8	0.503 – 1.385	15m Pan
Band 9	1.363 – 1.384	30m Cirrus
Band 10	*10.60 – 11.19*	*100 m TIR-1*
Band 11	*11.50 – 12.51*	*1. m TIR-2*

Data from USGS website.

Different Landsat satellite mission images have been used in water quality studies for example by (Zuccari *et al.*, 1993; Wang *et al.*, 2004; Vignolo *et al.*, 2006; Weiqi *et al.*, 2008; Olet, 2010; Somvanshi *et al.*, 2012; Waxter, 2014; Bonansea *et al.*, 2015) and it was considered fit looking at their properties and also the ability to reveal water quality. Both studies showed statistically significant correlations between the water quality parameters and remote sensing data in different water bodies that were studied. The best correlations were found mainly in the visible (blue, Green, Red) and near infrared spectral range.

2.9 Physical-chemical and biological characteristic of water

The water quality parameters assessed were selected based on the possible source of water pollution deemed to affect the area among others. The physical and chemical parameters of water quality measured were turbidity, pH, Electrical Conductivity (EC), total suspended solids (TSS), nutrients (total nitrogen, phosphorus, total phosphorus, ammonia, nitrates nitrogen) and total algae content.

2.9.1 Turbidity

Turbidity is an expression of the optical property that causes light to be scattered and absorbed rather than transmitted with no change in direction or flux level through the sample (APHA, 2012). It is a measure of water clarity in terms of how much the material suspended in water decreases the passage of light through the water. Suspended materials that cause water to be turbid include soil particles (clay, silt, and sand), algae, plankton, microscopic organisms, and other substances (MPCA, 2003). These come from activities such as soil erosion, waste discharges, urban runoff and excessive algal growth. Turbidity is measured in Nephelometric Turbidity Units (NTU) (APHA, 2012). Turbidity can affect the colour of the water and when it is high, it increases water temperatures due to suspended particles that absorb more heat. In turn, this reduces the concentration of dissolved oxygen as warm water hold less oxygen than cold. It also reduces the amount of light penetrating the water which in turn reduces the process of photosynthesis and production of dissolved oxygen.

2.9.2 pH

pH is used to express the intensity of acidity or alkalinity of a substance. It is ranked on a scale from 1.0 to 14.0 using a pH meter. The pH scale measures the logarithmic concentration of hydrogen (H^+) and hydroxide (OH^-) ions, which make up water ($H^+ + OH^- = H2O$). When both types of ions are in equal concentration, the pH is 7.0 or neutral (APHA, 2012). When the pH is below 7.0, the water is acidic and above 7.0, the water is alkaline, or basic. pH affects many chemical and biological processes in the water. The pH of water required by individual aquatic species varies but a wide variety of aquatic animals prefer a range of 6.5-8.5 (UNEP, 2006b). pH outside this range reduces the diversity in the stream because it stresses the physiological systems of most organisms and can reduce reproduction (APHA, 2012). Low pH can also allow toxic elements and compounds to become mobile and "available" for uptake by aquatic plants and animals.

2.9.3 Electrical Conductivity

Electrical Conductivity (EC) is a measure of the ability of water to carry an electric current. This ability depends on the presence of ions; on their total concentration, mobility, and valence; and on the temperature of measurement (APHA, 2012). Electrical conductivity is measured using a meter and basic unit is microsiemens per centimeter (µs/cm). Anthropogenic activities such as agriculture, urbanization and industrial increases in salinity and electrical conductivity in surface waters (UNEP, 2006a). For example, according to UNEP and based on a long-term monitoring of drainage basins in South Africa show contrasting trends in electrical conductivity as a result of human activities. Conductivity in the Orange River drainage basin increased significantly between 1980 and 2004 as a result of intensive irrigation practices and varying rainfall patterns, whereas conductivity decreased significantly in the Great Fish drainage basin over the same time period as a result of inter-basin transfers of water from the Orange River basin. EC is considered to be a rapid and good measure of dissolved solids (Gupta *et al.*, 2009; APHA, 2012).

2.9.4 Total Suspended Solids

The presence of suspended solids in water gives rise to turbidity (MPCA, 2003). Suspended solids may consist of clay, silt, airborne particulates, colloidal organic particles, plankton and other microscopic organisms. Higher concentrations of suspended solids can serve as carriers of toxins, which readily cling to suspended particles. This is particularly a concern where pesticides are being used on irrigated crops (APHA, 2012). Higher levels of solids can also clog irrigation devices and might become so high that irrigated plant roots will lose water rather than gain it.

2.9.5 Nutrients and Algae growth

Nutrients are essential for life. Of the major nutrients, nitrogen and phosphorus are the two elements that commonly limit maximum biomass of algae and aquatic plants in an aquatic ecosystem (UNEP, 2008). Nutrient sources include run-off water from agricultural lands, especially where there is extensive use of fertilizer and animal manure, as this result in significant concentrations of nitrogen. Untreated wastewater, rain water and sediments contain both nitrogen and phosphorus.

Nitrogen and phosphorus support the growth of algae and aquatic plants, which provide food and habitat for fish, shellfish and smaller organisms that live in water. A high concentration of these elements in the water causes algae to grow faster than ecosystems can handle and may result in deterioration of water quality, food resources and habitats, and decrease the oxygen that fish and other aquatic life need to survive (UNEP, 2006a). Large growths of algae can severely reduce or eliminate oxygen in the water, leading to illnesses in fish and the death of large numbers of fish. Some algal blooms are harmful to humans because they produce elevated toxins and bacterial growth that can make people sick (WHO/UNICEF, 2010; WHO, 2011).

Nitrogen in the aquatic environment occurs in four forms: ammonia (NH_3), nitrate (NO_3^-), nitrite (NO_2) and ammonium ion (NH_4^+). Total nitrogen represents the summation of ammonia nitrogen, nitrite plus nitrate nitrogen, and organic nitrogen, whereas *total phosphorus* test measures all the forms of phosphorus in the sample (orthophosphate, condensed phosphate, and organic phosphate) (EPA, 2001).

CHAPTER 3

3. STUDY AREA

3.1. Location

North Central Namibia is located entirely in the ephemeral Cuvelai-Etosha Basin which is sometimes called Owambo Basin (Mendelsohn *et al.*, 2013). The Cuvelai Basin originates in Angola and floods when good rains fall over the catchment. Its catchment falls between that of Kunene River in the west and the Cubango/Okavango River in the east (Mendelsohn *et al.*, 2000). The Cuvelai River enters Namibia as a 130km wide delta of ephemeral watercourse known as *Oshana* (or *iishana* if many) which converge to end up in the Etosha Pan (FAO, 2012). Most of the *iishana* are dry most time of the year. The Cuvelai Basin is a home to more than half of the Namibian population (Mendelsohn *et al.*, 2013). According to Mendelsohn *et al.* (2013), most people have settled in Owambo Basin because of relatively fertile soils and presence of shallow groundwater which allows them to grow crops and keep livestock. Figure 3 shows the study area and the Cuvelai-Etosha basin in the northern central Namibia.

3.2 Climate

The Cuvelai-Etosha Basin and Namibia as a whole is characterized by a semi-arid to arid climate and desert environment (Mendelsohn *et al.*, 2000; Mendelsohn *et al.*, 2013). The annual climatic patterns are divided into wet and dry season, whereby the wet season mainly occurs from the month of November to April and the dry season from May to October (Mendelsohn *et al.*, 2013). They further noted that the extreme south-western part of the sub-basin receives on average only around 250 millimetres per annum, while the northern part receives about 550 millimetres. The average temperatures vary between 20˚C and greater than 22˚C in most areas. However, highest temperatures in the country are experienced in the sub-basin and the Cuvelai-Etosha Basin as a whole in the early summer months. This translate to the potential evaporation that ranges between 2600 to 3200 mm per year, much higher than the yearly amount of rainfall (CuveWater, 2014).

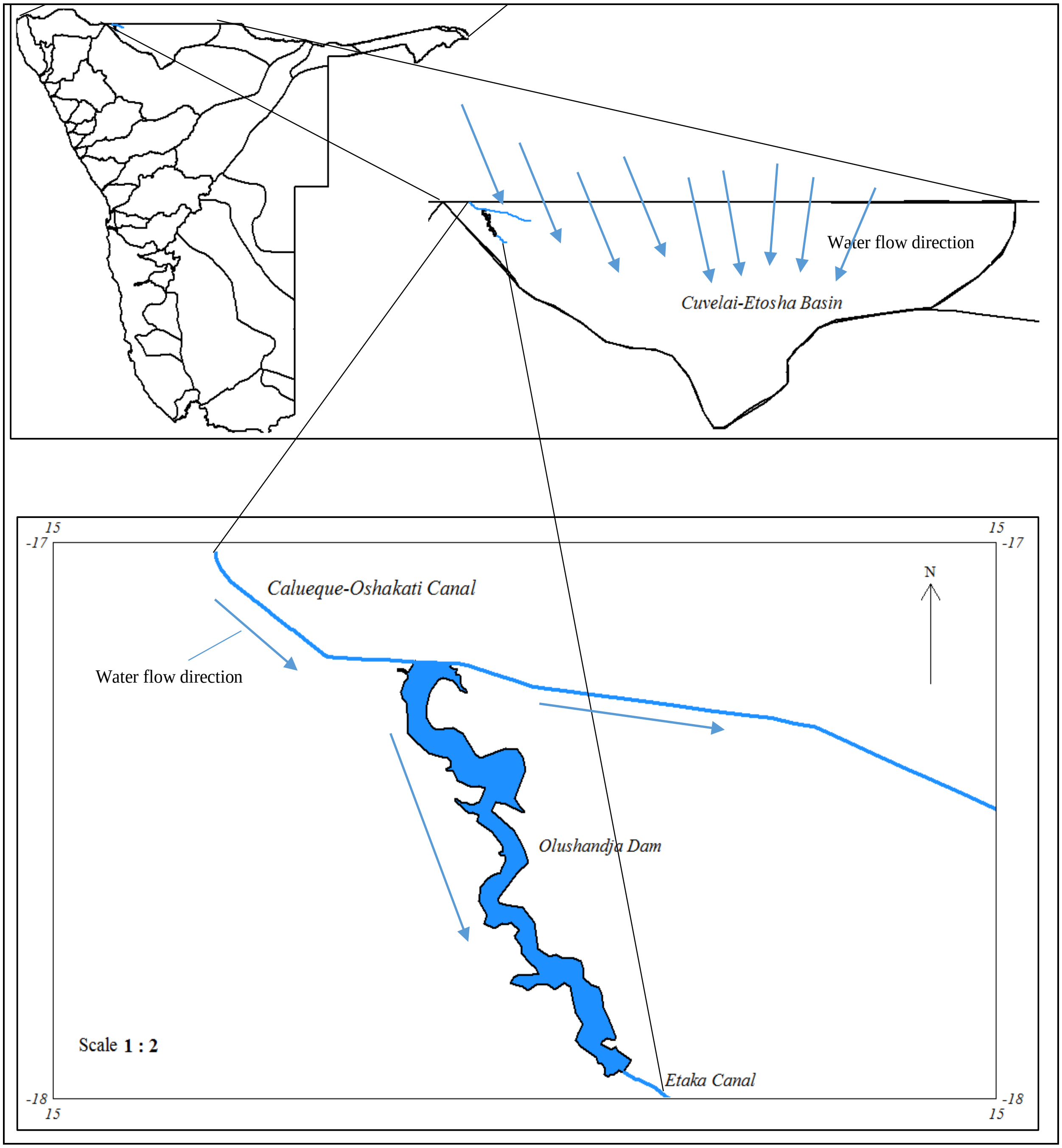

Figure 3: The Map showing the study area in relation to Cuvelai-Etosha Basin.

3.3 Geology and Drainage network

The Olushandja Dam is located in a flat depression of the Namibia *iishana* with the Western Kalahari landscape on the western and southern part (Mendelsohn *et al.*, 2013). Mendelsohn *et al.* (2013) also described the soils in the area as being dominated by clay sodic sands in the lower parts of the landscape and having high salt content. During floods, infiltration is low due to the hard-pan in the '*iishana*' and this causes salt to dissolve and be carried downstream by water where it makes sandy soils more saline (Mendelsohn *et al.*, 2013).The *iishana* dominate the basin and provide water to the people and animals during the rainy seasons.

3.4 Land use and land cover activities

In the north-central regions of Namibia, the land-use system is mainly applied on small-scale agriculture and livestock production on communal lands (Mendelsohn *et al.*, 2013). The majority of the population are engaged in the production of rain-fed crops such as mahangu and livestock production. These make the agricultural sector vulnerable to climate variability and poor marketing initiatives (FAO, 2012). The Cuvelai Basin comprises of different distinct landscapes which include the Cuvelai, mopane shrub land, eastern Kalahari woodlands, and salt pans and surrounding plains (Mendelsohn *et al.*, 2013).

3.5 Socio-Economic activities

The Olushandja Dam is located in Omusati Region with a total population of about 243,166 people (NSA, 2011). However the water system supports people across the four Northern Central Regions (Omusati, Oshana, Oshikoto and Ohangwena) with a total population of about 847, 259 people (NSA, 2011), 40% of the country's population. This includes the major towns namely Outapi and Oshakati with a total population of 6437 and 36 541 people respectively. The dam serves as an important source of fish for the people around the dam and the entire Cuvelai-Etosha Basin. Olushandja Dam is an area of interest for Namibia water resources development and tourism. There are more than 50 small-to-medium horticultural farmers, who are abstracting water from the dam for vegetable production. In addition to horticultural farmers, there are more than 100 households around the dam using water for domestic purposes (Mendelsohn *et al.*,

2000) and aquaculture interests. The dam also provides water and foraging for livestock in the area throughout the years and people also engage in swimming activities in the dam.

3.6 Olushandja Dam

Olushandja Dam is located in the upper western part of Omusati Region in Olushandja Sub-Basin of the Cuvelai-Etosha Basin in NCN (see Figure 3). The Olushandja Dam lies between 1100 and 1150 metres above sea level (CuveWater, 2014). Olushandja Dam has a surface area of about 29.0 km^2 and capacity of around 42.331 Mm^3 when full (NamWater, 2013). The dam is about 20 km long and varies between 200 m and 2000 m in width (Mendelsohn *et al.*, 2000). The dam was built in 1973 during the country's liberation struggle in the old Etaka Channel to store water for supply to settlements in the region. The Etaka Channel represents the remains of the main course of the Kunene River when it apparently drained into the region up to about two million years ago, it is not connected to the main Cuvelai system (Mendelsohn *et al.*, 2000).

Specifically, the dam was built to act as a balancing reservoir that stores water during excess flows of the Kunene River, and to provide a strategic reserve in the event of supplies from Calueque Dam in Angola being interrupted. In 1990 the system was renovated and now raw surface water is transferred from Calueque Dam in Angola through a concrete open canal into the dam and also to four treatment plants in the region. It was also designed in a way that water could be released periodically into the Etaka canal and to stimulate the development of local fisheries. In recent years it is most of the time held at half-full (50%) and since its construction, more than 100 households have been built in areas that would be flooded if the dam was filled (Mendelsohn *et al.*, 2000; NamWater, 2013).

As mentioned earlier, the Olushandja Dam has been filled with excess water from the canal but recently the Ministry of Agriculture, Water and Forestry (MAWF) has requested NamWater to pump more water into the dam when possible. However, when the water level in the canal drops, pumping into the dam will be manually stopped until the canal is full or has considerable amounts of water.

3.7 Basin management and water use

Olushandja sub-basin is a water management area managed by community chosen committee called Olushandja Sub-Basin Management Committee (OLBMC) (CuveWater, 2014). The OLBMC was established as a River Basin Management Committee in terms of the Water Resources Management Act No. 24 of 2004 as published in the Government Gazette of the Republic of Namibia, and all relevant national legislation and regulations pertinent to integrated water resources management (IWRM). This Committee serves in an advisory capacity to the Directorate of Resource Management of the Ministry of Agriculture, Water and Forestry and the Minister on water related issues affecting the Olushandja Sub Basin (CuveWater, 2014).On the other hand, NamWater, a water utility company is responsible for pumping water from Calueque in Angola into Namibia’s complex system of pipes and canal as well as Olushandja Dam. It is also responsible for maintenance of the pipes and canals.

Conflicts do exist especially between NamWater and small and medium horticultural producers and the general public when it comes to payments of water and better management of water resources (Hilukilwa, 2011). Communities living along the canal and dam access raw water for consumption, livestock watering, horticultural production, and other businesses such as bricklaying, and constructions. However, they do not pay for the water that they abstract from the canal and yet cause pollution and damage the infrastructure (Hilukilwa, 2011).

CHAPTER 4

4. MATERIALS AND METHODS

4.1 Study design

The study design includes the selection of the study area, sampling location, selection of parameters and time as well as frequency of sampling.

4.1.1 Selection of study area

The North Central Namibia in the Cuvelai Basin is characterized by rapid population growth with current population at about 847, 259 people (NSA, 2011). Olushandja Dam plays an important role of balancing and storing water for supply to 25% of the population in the basin and supports about 50 horticultural farmers and over 100 surrounding households, fisheries and livestock watering. Therefore, evaluating the quality of water of this dam is important to ensure it does not deteriorate and to reduce the impact on the health of human, animals and the environment. It will also affect the supply of fruits and vegetables to the Namibian market by farmers who are dependent on the dam as a source of water.

4.1.2 Selection of sampling location

The sampling points in the dam were selected systematically either to reflect on the impacts of major tributaries leading into the dam from the surrounding. Points were also selected after irrigation projects or abstraction points or where current monitoring samples are taken. In the canal, sample sites were at the entry point into Namibia and before it enter into the dam but after some settlements and gardens between Namibian border and Olushandja Dam. Figure 4 shows sampling point locations (two in the canal and six in the Olushandja Dam) and Table 3 presents their GPS locations and characteristics.

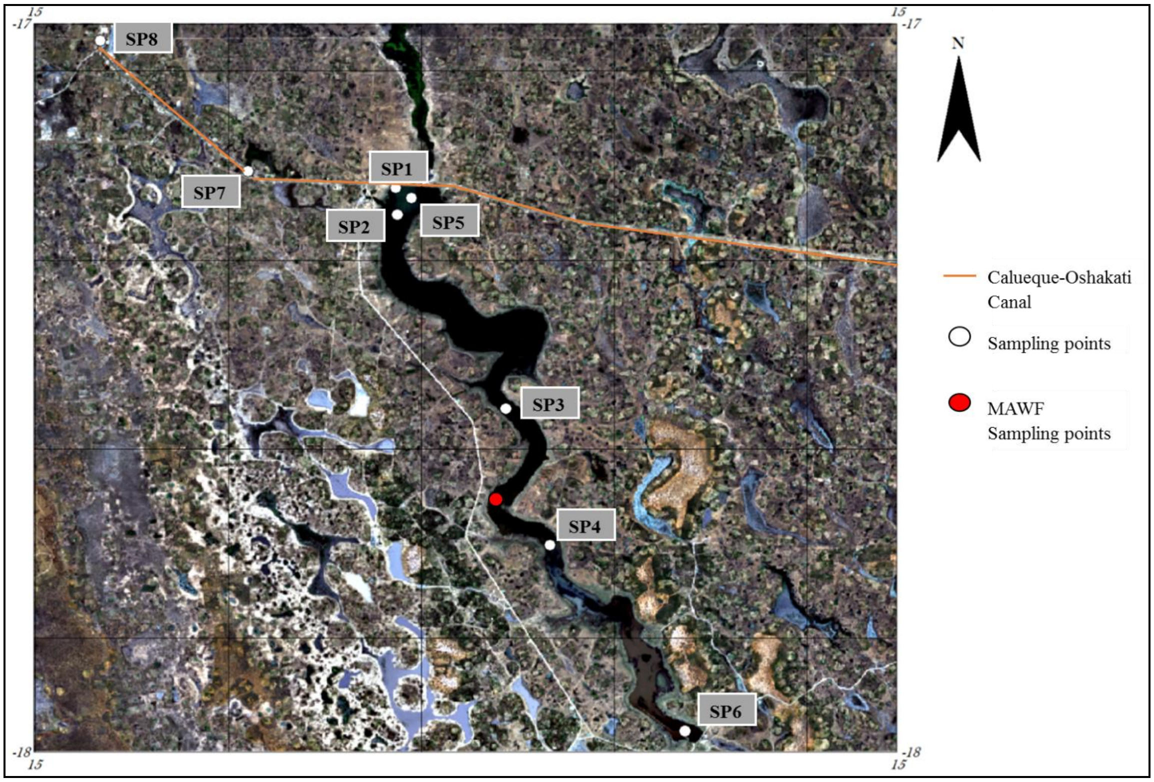

Figure 4: Sampling points location on a corrected Landsat 8 OLI of 30 March 2014.

Table 3: The location and description of sampling points.

Sampling Point	Easting (E)	Southing (S)	Description
SP1	14.64689	-17.4307	At entry point from canal into the dam
SP2	14.64258	-17.4380	In the dam about 3-4 km South Point 1
SP3	14.67128	-17.4901	In the dam
SP4	14.68258	-17.5253	In the dam through Elago Project
SP5	14.64939	-17.4363	In the dam and East of point 1
SP6	14.72022	-17.5779	At the Southern end of the dam about 600m before water pumps
SP7	14.60511	-17.4263	In the Calueque-Olushandja Canal about 4km from point 8
SP8	14.56689	-17.3918	In the Canal where it enter into Namibia about 10m to the bridge

4.1.3 Selection of water quality parameters

The selection of parameters that were measured carefully took into account the possible sources of pollution. It also took into account the relationship of different sources of pollution with different parameters and their potential impacts on human, aquatic life and environmental health.

The presence of irrigation projects and human settlements around the dam is noted as some of the major concerns to water quality (Shuuya and Hoko, 2014). Therefore it is suspected that there is a release of nutrients from the use of fertilizers in horticultural production, livestock and human waste, and many other human activities. The study assessed several physical, chemical and biological water quality parameters in estimating the status of pollution. These include turbidity, pH, Electrical Conductivity (EC), nitrate nitrogen (NO_3-N), Total Nitrogen (TN), ammonia (NH_3) and Total Phosphorus (TP), and total algae count.

Algae has been noted in the canal that transports water into the dam and treatment plants and this is a major concern on treatment cost for NamWater (Shuuya and Hoko, 2014). In addition, this study also included parameters such as turbidity, algae and nutrients that are known to be successfully retrieved from satellite data (Zuccari *et al.*, 1993; Hellweger *et al.*, 2004; Wang *et al.*, 2004; He *et al.*, 2008; Li, 2009; Olet, 2010; Irenosen *et al.*, 2012; Chawira *et al.*, 2013; Waxter, 2014; Bonansea *et al.*, 2015).

4.1.4 Sampling time and frequency

Water samples were collected following the Landsat imagery capturing calendar obtained from USGS at http://landsat.usgs.gov/tools_L8_acquisition_calendar.php. The sampling campaigns were done every 16 days (about twice a month) between January and April 2015. Samples were collected between 08:30am to 14:00pm with a starting point where the canal from Calueque Dam enters Namibia (SP8 Namibia-Angola border) and the last point at the end of the Olushandja Dam (SP6). Table 4 below shows the schedule that was followed for all the sampling campaigns and acquisition of images.

Table 4: Landsat 8 acquisition and field sampling dates and times

Acquisition image date	**Sampling date**	**Time taken**
25 January 2015	25 January 2015	All field sampling: 08:30am to 14:00pm and Landsat 8 images: 09:00-09:30 am
10 February 2015	10 February 2015	
26 February 2015	26 February 2015	
14 March 2015	14 March 2015	
30 March 2015	30 March 2015	
15 April 2015	15 April 2015	

4.2 Field data collection and analysis

This section describes the materials and methods that were used to collect, process and analyse the field to achieve the study Objective 1; to characterize the status of quality of water in Olushandja Dam through field and laboratory based measurements.

4.2.1 Field measurements

Field measurements include both on-site and laboratory analysis of water quality parameters. Representative water samples were collected from eight systematically selected locations (two along the Calueque-Olushandja Canal and six in the Olushandja Dam). A Global Positioning System (GPS) receiver was used to determine the position of each sampling point. The water samples were collected, preserved and analysed according to the Standard Methods for Water and Wastewater described by (APHA, 2012). At each sampling point, grab water samples were taken at about 10cm below the surface using a two litre bottles. Immediately after sampling, the sample was divided into three 500 ml bottles with screw-cap. First bottle was for algae, second for chemical and third for turbidity for testing under laboratory environment. Electrical conductivity and pH were tested immediately after sampling at each location. Turbidity was measured at the NamWater Olushandja Water Treatment Plant Laboratory within two hours from the time the sample was taken. Table 5 shows the instruments/methods used to determine water quality parameters in the field.

Table 5: The field measured parameters and instruments/methods of determination.

Parameters and units	**Instrument/Method of determination**
pH	pH Electrode on Hach Multi-meter (HQ40d)
Electrical conductivity (µm/cm)	Conductivity electrode on Hach Multi-meter (HQ40d)
Turbidity (NTU)	Hach 2100AN Turbidity meter (Nephelometric method)

Other samples for laboratory analysis were stored in a cool box with ice and send to Windhoek the same evening and arrived the following morning, in time for analysis within 24 hours as suggested by APHA (2012). The concentration of other physico-chemical parameters such as suspended solids, nutrient and total algae concentration in the water samples were analysed at NamWater Laboratory in Windhoek using standard methods. Table 6 provides a list of parameters, their units and selected method of determination under laboratory environment.

Table 6: The laboratory measured parameters and their selected method of determination

Parameters and units	**Instruments/Methods of determination**
Total Suspended Solids (mg/L)	APHA 2540 D, Gravimetric method
Nitrate as Nitrogen (mg/L)	APHA 4500 F; Cadmium reduction
Ammonia as Nitrogen (mg/L)	AWWA / APHA 4500 D; Photometric
Total Nitrogen (mg/L)	ISO 11905-1; Photometric
Total phosphate as Phosphorus (mg/L)	APHA 4500 E; Photometric
Total algae content (cells/ml)	APHA 10200 H; Filtration method

4.2.2 Historical field data

In addition to current measurements, historical dataset was obtained from the Department of Water Affair (DWA) under the Ministry of Agriculture, Water and Forestry (MWAF). This was a single raw water sample collected on 7 July 2014 in Olushandja dam as part of ad-hoc monitoring for pollution control (DWA, 2014). In this study, the DWA sample location falls between sampling point 3 and 4 (refer to Figure 4) and were compared. Water quality characteristics analysed in a laboratory environment included turbidity, pH, nitrate nitrogen, colour, total dissolved solids, and electrical conductivity. There is no other historical dataset found on the quality of water in Olushandja Dam.

4.2.3 Analysis of field data

Descriptive statistics which include the mean, standard deviation, minimum and maximum values for different parameters were compared to recommended limits for different uses at local and international level. These include the NamWater Guidelines for Evaluation of Raw Water for Drinking Water treatment (1998) (Appendix B), Canadian Guidelines for Recreational Purposes (2012), the FAO Water Quality for Agriculture (1994) and ECE Standards Statistical Classification of Surface Freshwater Quality for Maintenance of Aquatic Life. Spatial variation of measured water quality parameters was also determined through interpolation of point map for each parameter concentration through Ordinary Kriging technique in ILWIS program. All these were done to give a summary of physical and chemical characteristics of water to determine the status of water quality and highlight variations among the sampling points and over the dam

4.3 Satellite data collection and analysis

Landsat 8 images of Path 180; Row 072 which covers Olushandja Dam were downloaded from Landsat imagery archive hosted by the USGS Earth Resources Observation and Science (EROS) Centre using the USGS Globalization Visualization Viewer (GLoVis) tool available at http://glovis.usgs.govvia a file transfer protocol (FTP) as level 1T products. Figure 5 displays a sample of Landsat 8 image tile that covers Olushandja Dam.

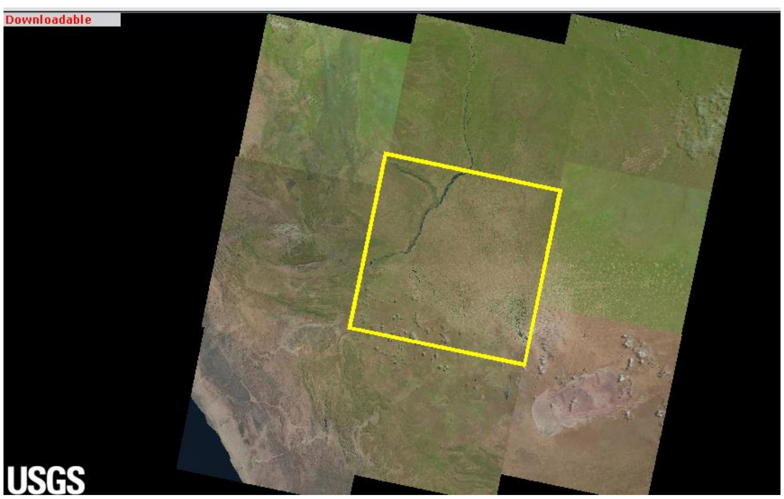

Figure 5: Landsat 8 image tile of path 180; row 072 (in a yellow square) on 15thApril 2015.

The Digital Elevation Model (DEM) map covering the study area was obtained from USGS Earth Explorer http:/www.earthexplorer.usgs.gov and four ground control points (GCP) were established. The GCPs were used to create a coordinate system and geo-reference file for the study area. The dam and canal outline was obtained by digitizing boundary in Google Earth satellite image and converted to a shape file format in Quantum GIS (QGIS) software. Sampling points were entered into excel and saved as text file. All files were then imported into ILWIS and were assigned to the same coordinate system as that of the study area.

4.3.1 Image pre-processing and processing

The Landsat 8 imagery which were cloud free or have low percent of cloud cover (<10%) over the area were selected for analysis. Some of the satellite image tiles had high cloud cover percentages but if the specific study area had considerable pixels without clouds, the images were deemed usable. The equations for converting DN to radiance and then to TOA reflectance are presented in Appendix A as described by Chander *et al*. (2009) and USGS (2013). Radiometric Calibration to convert Digital Numbers (DN) values to physical units, at sensor spectral radiance (Watts/(m^2/srad/µm)) and then to Top-of-Atmosphere (TOA) Reflectance was done in a Geographical Information system (GIS) software, ENVI 5.0.3.

ENVI is an automated program used for different pre-processing of images but using the same equations described by Chander *et al.*(2009) and USGS (2013). The MTL file that came with image tiles was imported into ENVI as the entire dataset plus metadata needed for calibration (ENVI, 2013). Radiometric Calibration was selected to calibrate the image to radiance which is required as input to FLAASH tool. The images were then corrected for atmospheric effect through FLAASH Atmospheric Correction Model in ENVI program. FLAASH aimed at retrieving spectral reflectance from hyperspectral and multispectral images (ENVI, 2013) and correct images for atmospheric effects. Surface reflectance values which range between 0 and 1 were obtained. Therefore, in ENVI program, a band math expression was applied to rescale the floating reflectance value to surface reflectance of between 0 and 1.

4.3.2 Image processing and extraction of reflectance values

After the radiometric calibration and atmospheric correction, pre-processed bands with reflectance were imported in ILWIS. This program converted them into ILWIS raster maps and was ready for further processing. The image raster maps were geometrically corrected by using

Nearest Neighbours Re-sampling Technique and assigning the correct Geo-reference file as that of the study area.

The pixel reflectance values of the first four bands (visible and near infrared) and combination of Landsat has been used and significantly correlated with field data (Alparslan *et al.*, 2007; He *et al.*, 2008; Li, 2009; Kibena *et al.*, 2014). This study used pixel reflectance values for the four bands, 2- 5 (visible and near infrared) of Landsat 8 images for each selected date based on the GPS locations of every sampling point. This was done in ILWIS through the 'map cross' operation that match-up sampling point raster map with a raster map of each processed bands (after image re-sample). Reflectance values of each band on every image at specific sampling point were determined.

4.3.3 Development of algorithms

The algorithms were developed through a simple linear regression analysis to determine the best fit model. The surface reflectance of each band and water quality parameter values at a specific sampling point were regressed. Reflectance values of all bands were selected to be independent of each water quality variable. Independent variables that form relationship with reflectance by showing a high R^2 will be selected (Alparslan *et al.*, 2007; He *et al.*, 2008; El-Saadi *et al.*, 2014). The coefficient of determination (R^2) was estimated in each combination of variables. The R^2 compares estimated and actual y-values, and ranges in value from 0 to 1. A value of 1 denotes a strong correlation in the sample, meaning there is no difference between the estimated value and the actual value. On the other extreme, if the coefficient of determination is 0, the regression equation is not helpful in predicting a y-value (Alparslan *et al.*, 2007).

4.3.4 Application of algorithms

The developed algorithms were applied to re-sampled multispectral reflectance image bands. This was done in a GIS environment and produced raster maps for every parameter from each image.

The predicted values for each parameter were extracted from every parameter satellite raster map based on GPS location. The predicted values were validated against field measured data to test whether the satellite was able to estimate water quality parameters. This was done by simple regression analysis using field data (for 25 January and 10 February 2015) that were randomly selected from main dataset. It should be noted that the data used for validation were not used in the development of the algorithms to reduce errors.

Furthermore, to assess detailed spatial distribution of water quality in Olushandja Dam, maps were produced for each predicted water quality parameter in ILWIS program. These were produced after applying algorithms to the Landsat datasets. The re-sampled raster maps of each parameter were crossed with the raster map of the dam to delineate. As a result, quantitative attribute maps for each parameter from each image were created and processed for visual presentation.

Finally, a remote sensing based framework for predicting various water quality parameters was proposed. This was done to make it easy for the institution/s responsible for water quality monitoring and management of water in Olushandja Dam and its tributaries to be able to apply remote sensing based techniques for retrieval of water quality parameters. A schematic view of the methodology for retrieving water quality variables from remote sensing as used in this study was suggested.

4.4 Quality assurance and control

Assurance and control of data for quality were done for all phases of data collection and analysis both in the field, laboratory and during processing and validation. Protocols for field and laboratory were followed to make sure that all measurements were done as stipulated in the standard methods. Field kit (Multi-meter) was tested and calibrated accordingly before fieldwork. In the field, each sample was tested three times to verify that the initial reading was correct. Sampling bottles were handled with care to avoid contamination during sample collection, preservation and transportation. No sampling bottles were re-used. Methods for analysis were confirmed by witnessing the processes involved in different tests at the laboratory. Data was also reviewed. All laboratory equipments were checked regularly in order to maintain data quality standard.

CHAPTER 5

5. RESULTS AND DISCUSSION

5.1 Field assessment of water quality status

Results in this section are based on field and laboratory measurements of water quality. The results of water quality parameters for six sampling points in the dam and two points in the canal for six sampling campaigns are presented in Table 7.

Table 7: A summary of water quality levels in the Dam and Canal for January–April 2015.

		Algae **(cells/ml)**	***Turbidity*** **(NTU)**	***pH***	***EC*** **(µS/cm)**	***NO_3^-*** **(mg/L)**	***NH_3*** **(mg/L)**	***TN*** **(mg/L)**	***TP*** **(mg/L)**	***TSS*** **(mg/L)**
Dam	Average ±stdev	1513 ±1996	24.1 ±24.3	7.95 ±0.50	267 ±340	-	0.06 ± 0.08	1.46 ±1.40	0.14 ±0.18	20.5 ±26.6
	Range	99-8132	3.4-129	7.06-9.17	55.7-1084	<0.5	<0.01-0.33	<0.10-4.70	0.02-0.64	1.20-147
Canal	Average ±stdev	113 ±87	53.3 ±52.7	8.11 ±0.34	147 ±130	-	0.04 ±0.03	0.57 ±0.57	0.07 ±0.02	19.3 ±11.6
	Range	28-297	21.8-209	7.59-8.56	47.2-396	<0.5	<0.01-0.13	<0.1-1.9	0.04-0.12	4.3-42.4
NamWater		-	5	6.0-9	300 mS/m	20	-	-	-	-
Canadian		-	50	5.0-9.0	-		-	-	-	-
FAO		-	-	6.5-8.4	-	<5 (none)	-	-	-	-
UNECE		-	-	6.5-9.0	-	-	-	<300	<10	-

Notes:

i. *The results are presented as average± standard deviation and range based on values of six sampling campaigns.*

ii. *EC =Electrical conductivity, NO_3^-N = Nitrate nitrogen, NH_3 = Ammonia, TN = Total nitrogen, TP = total phosphorus and TSS = total suspended solids.*

5.1.1 Canal Water Quality

Turbidity: The turbidity levels over the entire sampling period are presented in Figure 6. The levels of turbidity ranged from 21.8 to 209 NTU with a mean of 53.3±52.7 NTU as shown in Table 7. The highest value was recorded downstream of the dam at SP7 on 25th January 2015 and lowest upstream of the dam at SP8 on 26th February 2015. The results showed a significant variation between the two points on the canal ($p<0.05$) and levels generally increased downstream suggesting an increasing trend of pollution. At each point there was also variation among the sampling days with a coefficient of variation of 99%. The average levels of turbidity exceeded the NamWater Standards for determinants with physical implications on human health and livestock watering, but were within the Canadian Guidelines for recreational purposes most of the times. However considering all values, the turbidity values exceeded the NamWater in 95% of the times and the Canadian standard in 25% of the time. However, based on the statistics, the quality of water has been classified as low risk according to NamWater Standards.

The results are comparable to the results of February to April 2008 found by Shuuya and Hoko (2014) with a range of 29-253 NTU in the same part of the canal. This study was conducted during the rainy season and increase in turbidity levels from upstream (SP8) to downstream (SP7) can be attributed to storm water run-off and human activities along the canal. Thus turbidity levels in the canal exceeded the NamWater Standard values in most of the cases. This is likely to cause implications on the quality of water and the amount of chlorine required for disinfection increases as the increase in turbidity affects water treatment cost (EPA, 2001; Shuuya and Hoko, 2014).

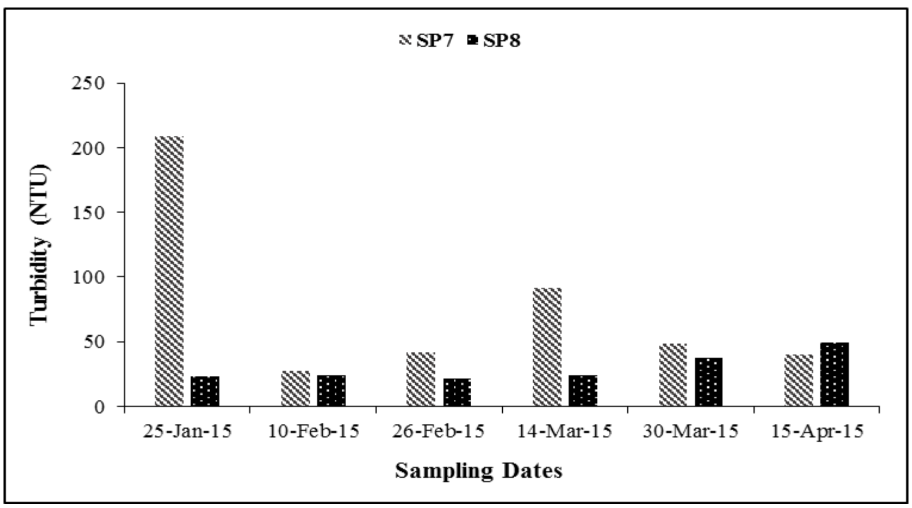

Figure 6: Variations of turbidity levels among sampling points (SP) - Jan to April 2015.

pH levels: The pH levels in the canal ranged from 7.6 to 8.6 with a mean of 8.11±0.34 at the two sampling points as presented in Table 7. The level of pH was highest at sampling point 7 and lowest at point 8 on the 27th February 2015 as shown on Figure 7. The results showed no significant variation between the two points on the canal and among the sampling days which is demonstrated by coefficient of variation of 4%. The average levels of pH were within the NamWater, WHO, Canadian, FAO and UNECE limits 90% of the times.

There is an increase in pH values from 2008 to 2015 when compared to the findings of Shuuya and Hoko (2014) who found pH levels in the range of 6.3-7.5 during the same period in the same area. This suggest that high pH levels in water affect chemical and biological process and low pH can also allow toxic elements and compounds to become mobile and available to aquatic plants and animals. For example, most aquatic life requires pH range of 6.5-8.5 (UNEP, 2006b) while pH outside this range affect diversity (APHA, 2012).

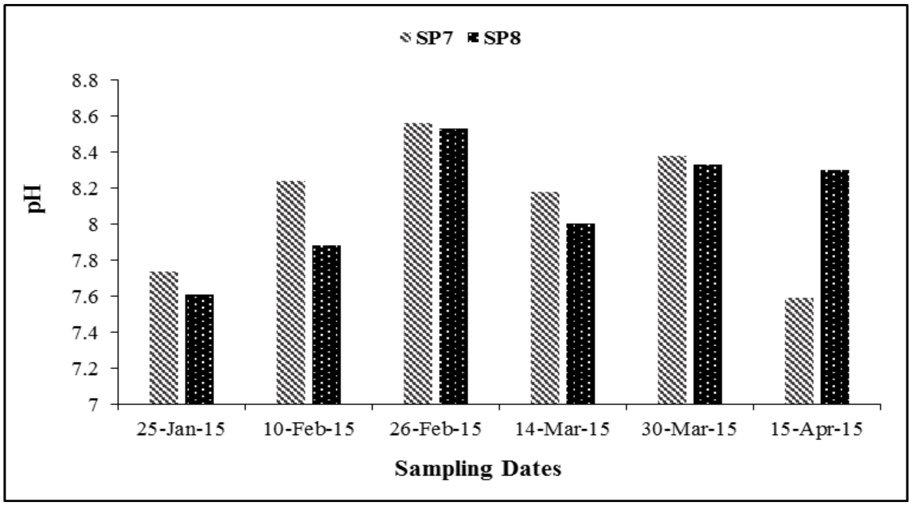

Figure 7: Variations of pH levels among sampling points (SP) - January to April 2015.

Electrical Conductivity levels: The average levels of electrical conductivity over the entire sampling period are presented in Figure 8. EC mean values were 147±130 with lowest value of 47.2 µS/cm and highest value of 396 µS/cm as indicated in Table 7. The results showed significant variation among the sampling periods with a coefficient of variation of 89%. The average level of EC was however within the NamWater limits. Thus, based on NamWater classification of EC levels, the quality of water is good. Human activities such as agriculture increase salinity and electrical conductivity in surface waters (UNEP, 2006a). This could be the case in this study since a lot of agriculture and other activities are taking place along the canal.

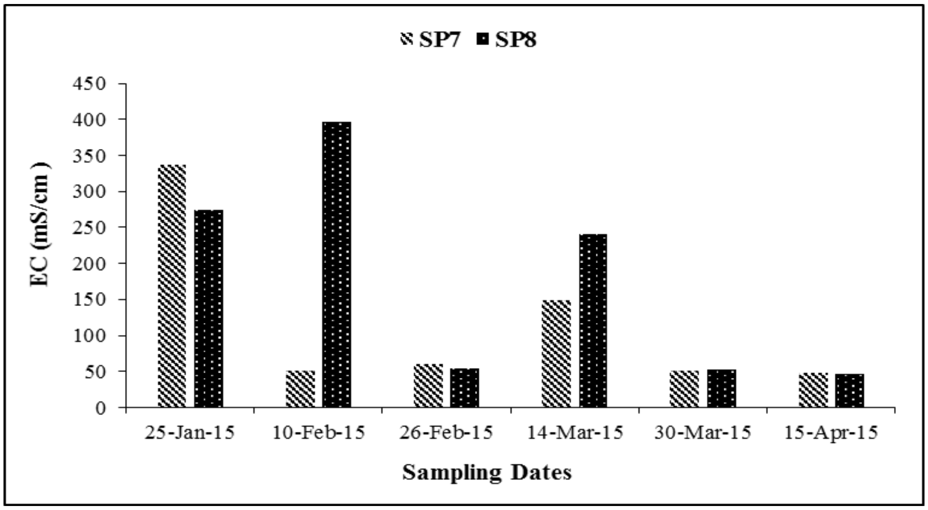

Figure 8: Variations of EC levels among sampling points (SP) - January to April 2015.

Total Algae Counts: Total algae content ranged from 28 to 267 cells/ml with a mean value of 113±87 cells/ml as indicated in Table 7 and are presented on Figure 9. The results showed significant variation between the sampling periods with a coefficient of variation of 78%. No limit outlined for total algae under the standard considered.

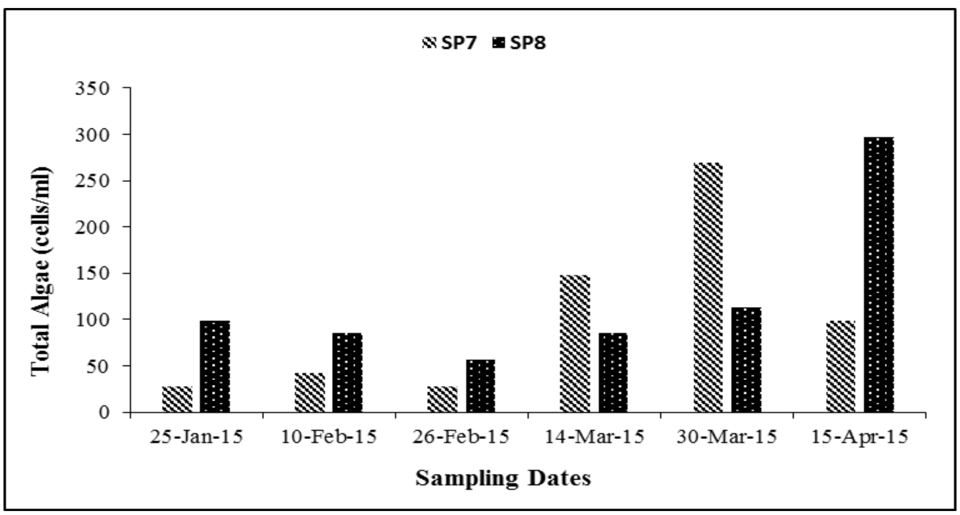

Figure 9: Variations of Total Algae content among sampling points (SP) - January to April 2015.

Nitrate Nitrogen levels: The concentration of nitrates was<0.05 mg/L most of the time at the two sampling points. The results showed that there is no significant variation among sampling point and between the sampling periods. The average levels of nitrate were 100% of the time within the NamWater, WHO and FAO limits. The result of this study is similar to the findings by Shuuya and Hoko (2014), who found the concentration of <0.1mg/L at a sampling point in the same area. Nitrate nitrogen in drinking water affects infants, thus it is important to monitor it.

Ammonia Nitrogen levels: On the other hand, ammonia ranged between <0.01 to 0.13 mg/L with a mean value of 0.04±0.03 mg/L (Table 7 and Figure 10). The results showed significant variation between the sampling periods with a coefficient of variation of 98%. No limit set under the standard considered.

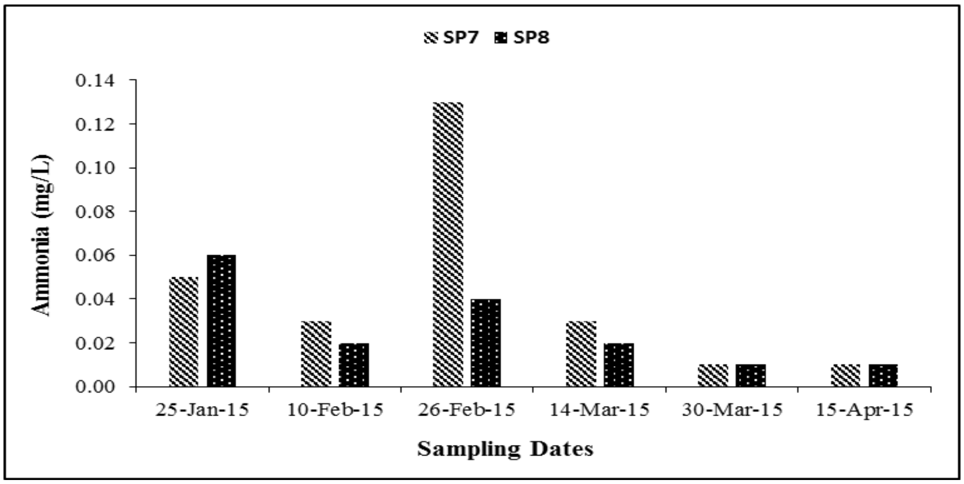

Figure 10: Variations of Ammonia levels among sampling points (SP) - Jan to April 2015.

Total Nitrogen levels: Total nitrogen levels ranged between 0.10 to 1.90 mg/L with a mean value of 0.57±0.57 mg/L. The results showed significant variation between the sampling periods and at each point with a coefficient of variation of 100%. The average levels of total nitrogen are however within the UNECE standard (<300 mg/L). The average statistics are presented on Figure 11.

According to Shuuya and Hoko (2014) the level of total nitrogen at Omahenene Border Post which is around SP 8 in the canal was ranging between 9 to13 mg/L with a mean of 9.2±3.0 mg/L. This was high compared to the finding of this study but both show low variation. The difference could be attributed to the time of the year when these studies were carried out.

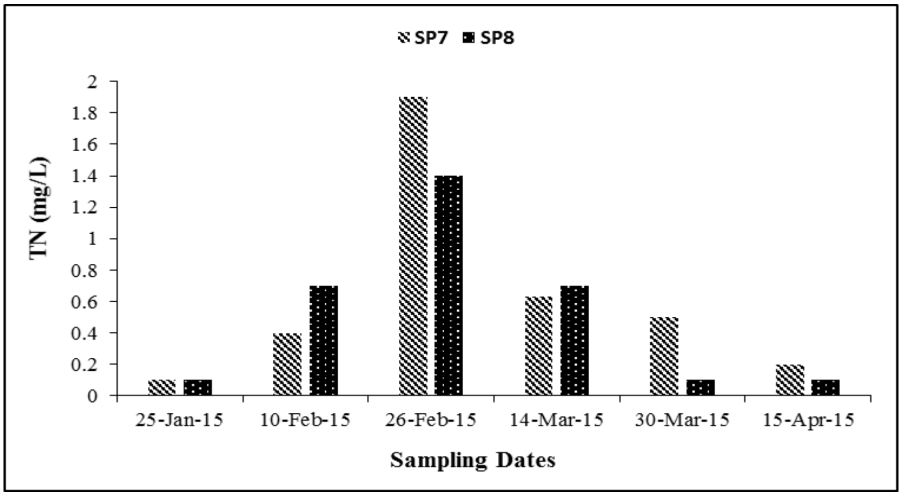

Figure 11: Variations of TN levels among sampling points (SP) - Jan to April 2015.

Total Phosphorus levels: The total phosphorus concentrations ranged between 0.04 to 0.12 mg/L with a mean value of 0.07±0.02 mg/L as shown in Table 7. The results showed low variation of total phosphorus during the sampling period between and within each point, with a coefficient of variation of 89%. The average levels of phosphorus are however within the ECE standard limits. The average values are presented on Figure 12.

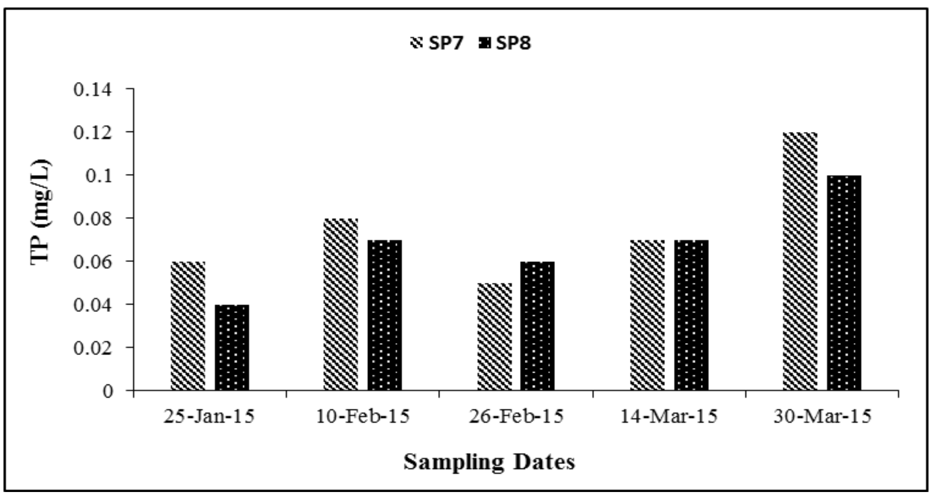

Figure 12: Variations of TP levels among sampling points (SP) - January to April 2015.

Total Suspended Solid levels: The total suspended solids ranged from 4.3 to 42.4 mg/L with a mean value of 19.3±11.6 mg/L as depicted in Table 7 and Figure 13. The results showed a significant variation between the sampling periods and points, with a coefficient of variation of

60%. None of the standards considered specified the limit for total suspended solids. The increase in total suspended solids in the canal could be attributed to run-off. The study was conducted during the rainy season.

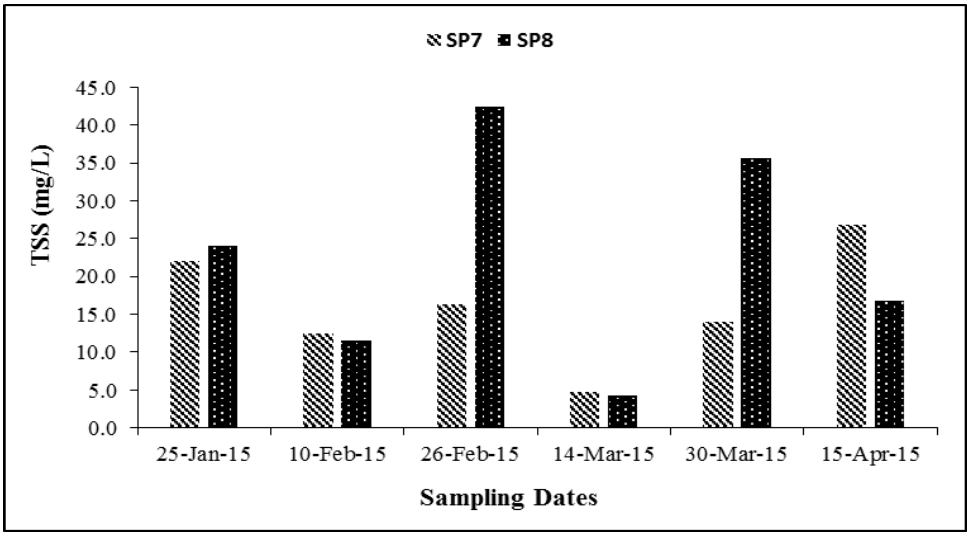

Figure 13: Variations of TSS concentration among sampling points - Jan to April 2015.

Summary: Turbidity levels were found to be above the recommended limit of NamWater and of 5.0 NTU for drinking water and Canadian guidelines for recreational of 50 NTU. PH, nitrate nitrogen, total nitrogen, and total phosphorus were below the recommended limits. However, the status of water quality fall under group C of NamWater classification which define it as water of low risk to human consumption but suitable for livestock. Turbidity is among other parameters which were considered in classification. Human and livestock interaction as well as natural factors are the main contributor to deteriorating water quality in the canal.

5.1.2 Dam Water Quality

Spatial variation maps determined through interpolation of point map for each parameter's concentration through Ordinary Kriging Technique are also presented.

Turbidity levels: The levels of turbidity in the dam ranged between 3.4 to 129 NTU with a mean of 24.1±24.3 NTU as indicated in Table 7 and presented on Figure 14. The results showed a significant variation between the six sampling points over the dam and levels generally increased from upstream (beginning of the dam) to downstream (end of the dam) suggesting an increasing trend of pollution. At each point there was also some variation among the sampling days with a coefficient of variation of 132% for all points. The variation could be attributed to low or no flow toward the end of the dam, water plants, and human interactions. The average level of turbidity exceeded the NamWater 5.0 NTU for drinking water and Canadian guidelines for recreational of 50 NTU (NAMWATER, 1998; CMH, 2012). However, considering all values, the turbidity values exceeded the NamWater in 96% of the times and the Canadian standard in 20% of the time. Thus based on the statistics the quality of water is poor and would have impact to human recreation but suited for livestock watering as suggested by the NamWater classification of 1998.

The results by DWA (2014) showed a turbidity level of 13 NTU which is in the range of findings of this study for the specific points. This study was undertaken during rainy season and rainfall was received occasionally. According to AWWA (1990), rainfall cause re-suspension and increase turbidity due to associated high runoff.

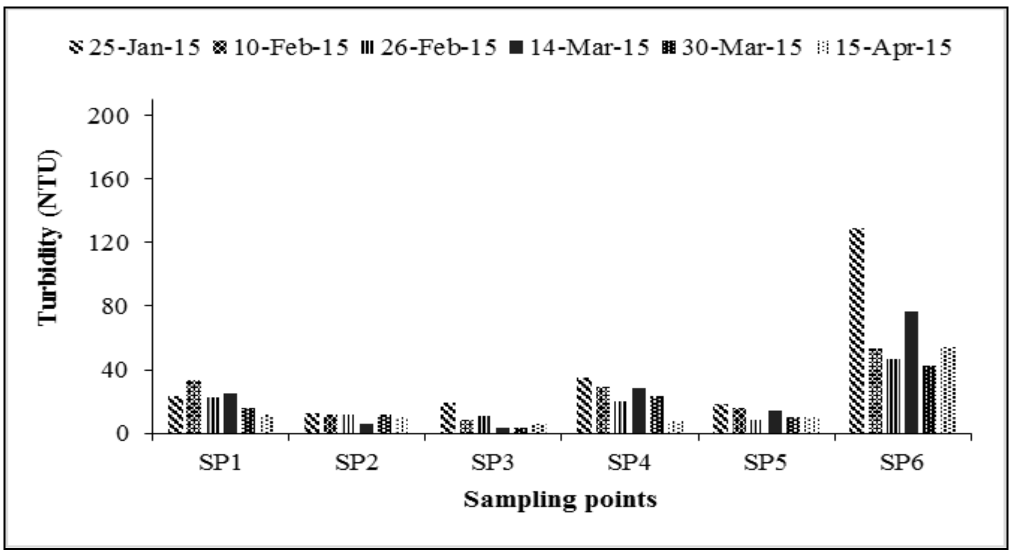

Figure 14: Variations of Turbidity levels among sampling points (SP)– Jan to April 2015.

Spatially, water samples from sampling point 6 located at end of the dam (downstream) showed the highest turbidity values. The levels of turbidity were in highest range of 46 to 60.6 NTU from the middle to the lower part of the dam (covering SP 3, 4 and 6) as shown in Figure 15 at same depth. The values decreased to 9.4 NTU lowest at the upper part or beginning of the dam at same depth.

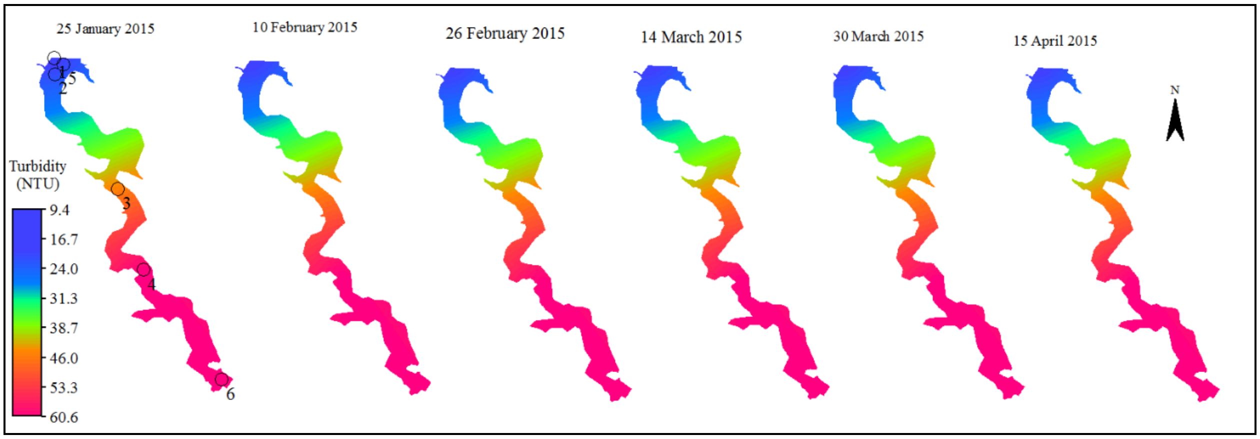

Figure 15: Spatial distribution of turbidity among sampling points - January to April 2015.

In summary, the results clearly demonstrate that there is a high variation of turbidity levels among sampling points and over the entire dam. Turbidity levels exceeded the recommended limits for drinking water standards by NamWater and Canadian standards for recreation at some parts of the dam. Thus it is likely to affect the aesthetic quality of water and cost of treatment. The amount of chlorine required for disinfection also increases as turbidity increases.

pH levels: The pH of water samples ranged from 7.1 to 9.2 in the dam with a mean value of 7.95±0.50 as indicated in Table 7. The standard deviation of the mean demonstrate that there is less variance among sampling points and this is also clearly shown in Figure 16. The result showed no significant variation between the data collected over six sampling campaign in the dam. There was low variation among sampling days and points with a coefficient of variation of 6%. Most average levels of pH are within the NamWater Guideline for Drinking water (NAMWATER, 1998) which is 6-9 for group A – water with excellent quality. Most of the values also fall within a range of 6-9 of the Canadian standards for recreational (CMH, 2012), 6.5 -8.4 for agriculture (Ayers and Westcot, 1994) and 6.5 – 9.0 (UNECE, 1994) and 6.5 – 8.7 (EPA, 1996) both for maintenance of aquatic life.

According to a similar study in the area conducted by Shuuya and Hoko (2014) pH was also found to be in the same range. Although pH does not have health effects, it affects the chemical and biological processes in the aquatic environment, therefore it is considered to be an important parameter to study. Water with a pH value <4.0 is acidic. According to EPA(2001) water with a higher pH values increases the formation in water heating apparatus and reduces germicidal potential of chlorine. In water treatment, pH required for effective chlorination is less than 8.5 (UNICEF, 2005).

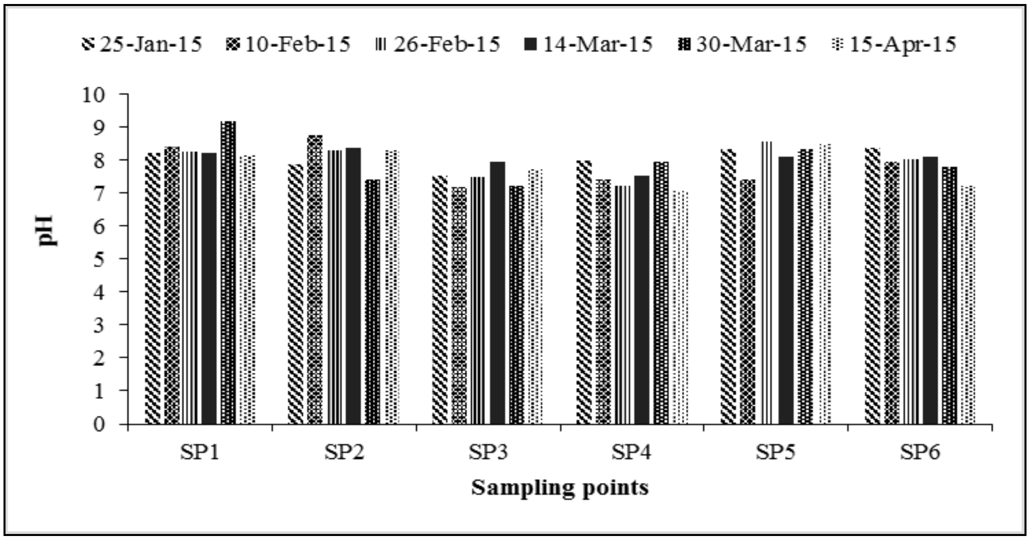

Figure 16: Variations of pH levels among sampling points (SP) - January to April 2015.

Spatially, levels of pH ranged from 7.6 to 8.23 over the study period as indicated by Figure 18. In all the days, the pH values were highest (7.9 to 8.20) at the beginning of the dam and lowest (7.6 to 8.02) as one move to the end of the dam except on the 25 January 2015. The spatial maps for pH clearly show that there is less variance among sampling points and between dates of sampling. Considering both measured and spatially interpolated values, pH values were found to be within the NamWater, WHO, Canadian, ECE and FAO limits in 95% of the times.

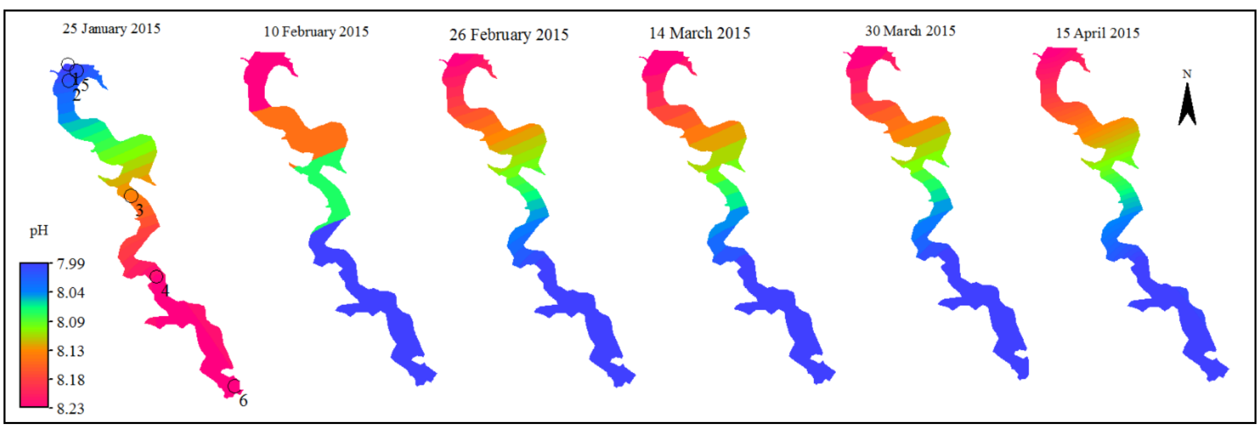

Figure 17: Spatial distribution of pH among sampling points - January to April 2015.

Electrical conductivity levels: The electrical conductivity (EC) values ranged from 55.7 to 1084 µS/cm in the dam water samples as depicted by Figure 18 and also shown in Table 7. The dam had highest values of EC recorded at SP 6 (1084 µS/cm) and lowest at SP1 (55.7 µS/cm) on the 25th January 2015 as presented on Figure 18. Based on the results, there is a significant variation between levels of EC in the dam and levels increased from upstream (beginning of the dam) to downstream (end of the dam). There was also variation among sampling points with coefficient of variation of 127%. The average levels of EC are however within the recommended limits for NamWater group B (3µm/m) for good quality water 100% of the time.

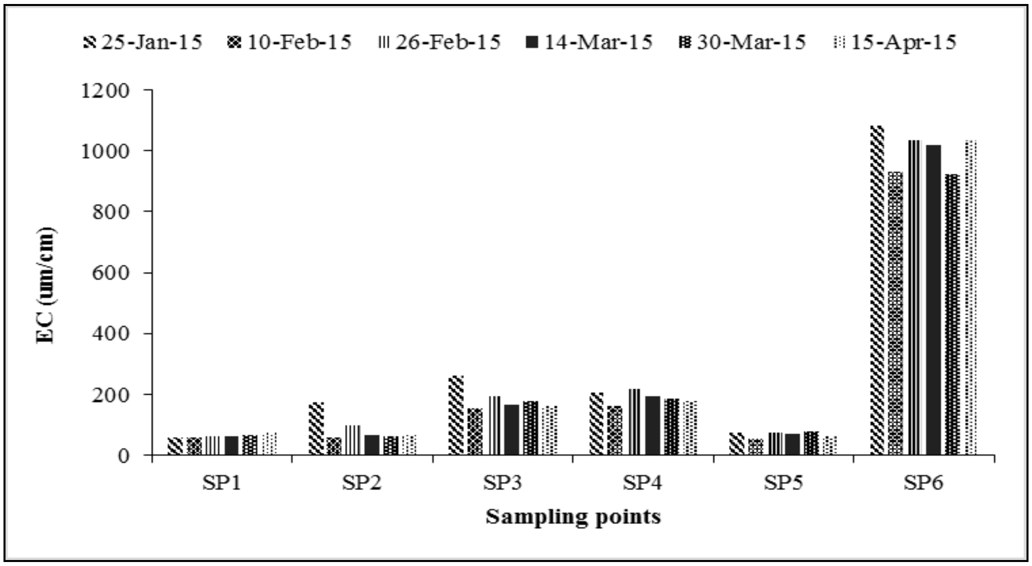

Figure18: Variation of EC levels among sampling points (SP) - January to April 2015.

EC concentration also varies spatially among sampling points on different days. The values of conductivity ranged from 90.2 to 454.1 µS/cm over the study period as indicated on Figure 19. The values increases moving from beginning (sampling point 1) to the lower end (sampling point 6) of the dam which had the highest range of 393 to 454 µS/cm. In summary EC is high at the lower end of the dam; however the concentration is within the NamWater limits Group B and for livestock watering.

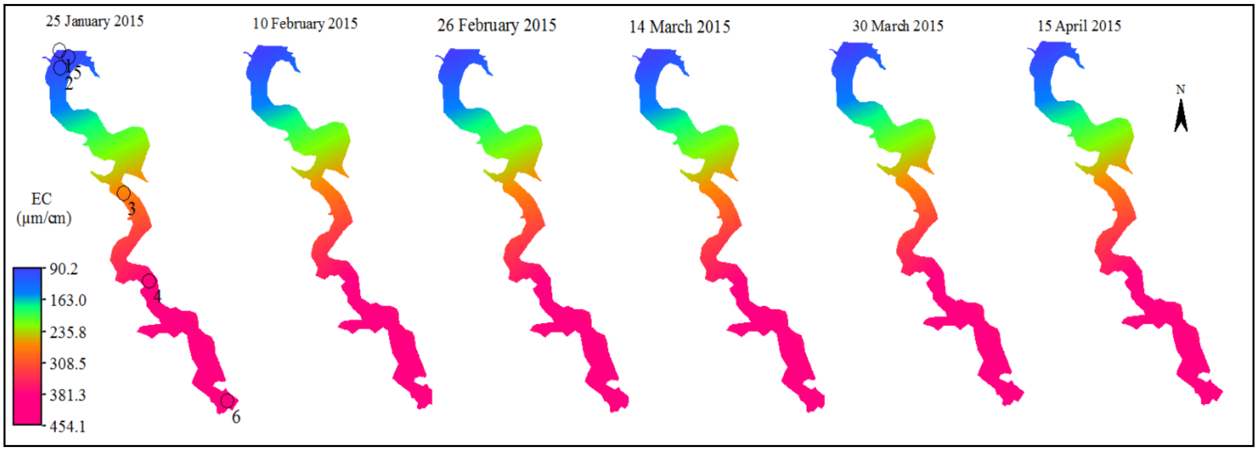

Figure 19: Spatial distribution of EC among sampling points - January to April 2015.

Total Algae contents: The total algae count ranged from 99 to 8132 cells/ml with a mean value of 1513±1996 cells/ml in the dam as shown in Table 7. The highest values of total algae counts were found at SP 6 during the whole sampling period and lowest at SP1 as shown in Figure 20. The results show that there is high variation in the levels of total algae counts among sampling points and levels of increased downstream. On each sampling date, there was variation among sampling points with a coefficient of variation of 132%. There is no standard found for total algae content but cyano-bacteria (blue green algae) was found to be common in the water samples However, it was within the Canadian standard for recreational water, ≤100,000 cells/ml.

The blue green algae are well known as they produce toxin that have negative effects on both human and animals (Chorus and Bartram, 1999). For example, phosphates and nitrates load into Lake Chivero in Zimbabwe have encouraged the establishment of dense blooms of blue-green algae and water hyacinth. Children have been reported to be suffering from gastro-enteritis disease at the same time when there is blue green algae bloom every year they consume drinking water from the reservoir (Annadotter, 1995). According to NamWater officers, algae in canals and dams is problematic to NamWater, hence the need for thorough research on its causes, types, effects and treatments.

Although nitrate nitrogen was found to be lower, other nitrogen element were slightly significant at some sites which could give a rise to total algae content and specifically blue-green algae. This could be due to increased accumulation of nutrient concentration from runoff and the presence of water plants which promote algae growth when they decompose in the water. In the Central Area of Namibia and near Windhoek, high nutrient load has led to algal bloom and poor water quality in Swakoppoort Dam (Lehmann, 2010).

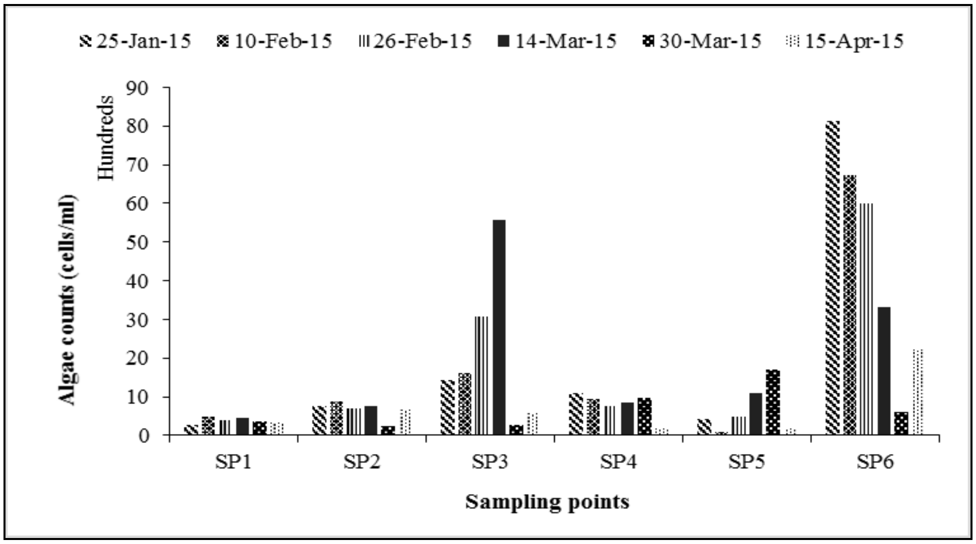

Figure 20: Variations of total algae among sampling points (SP) - Jan to April 2015.

Spatially, water samples from sampling point 6 showed the highest total algae contents. The values of total algae ranged from 276 to 3215 cells/ml over the study period as shown in Figure 21. The highest values ranging from 849 to 3215 cells/ml of total algae are at the lower end of the dam and decreased between 276 to 1089 cells/cm at the beginning of the dam. In Summary, total algae content is quite significant and continuous monitoring is critical to reduce impacts on water treatment, human, livestock and aquatic life health.

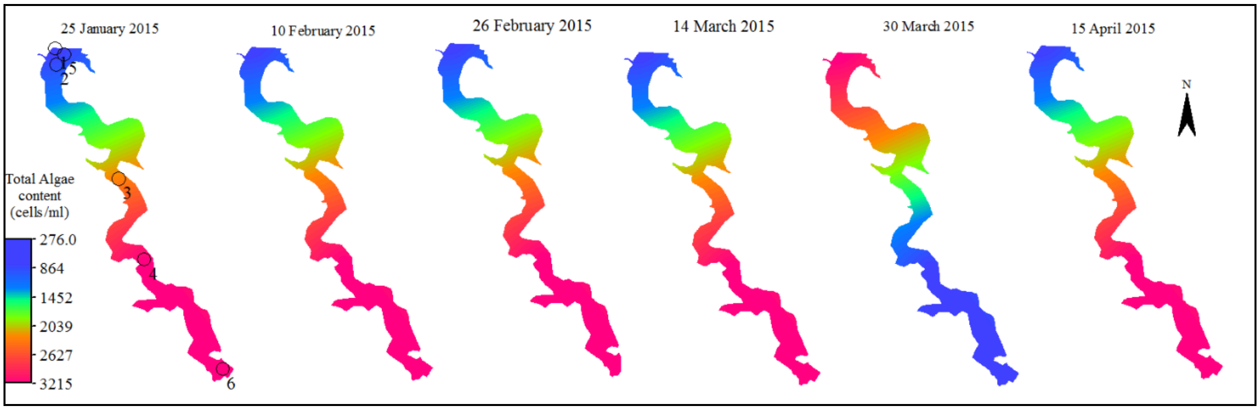

Figure 21: Spatial distribution of Total Algae among sampling points – Jan to April 2015.

Nitrate Nitrogen concentrations: The nitrate nitrogen level in the dam water samples was found mainly to be <0.05mg/L as indicated in Table 7. The results showed no significant variation between sampling days and points in the dam. This study shows that nitrate concentrations are within the 10 mg/L of NamWater and less than 5mg/L of the FAO guidelines for irrigation water. Considering all values of nitrate nitrogen, they are all 100% within recommend limits. However, the use of fertilizer in horticultural production and poor sanitation in the settlements (human and animal waste) along the canal and around the dam is expected to increase in future. Therefore monitoring of nitrate nitrogen is important. Similar studies in central area of Namibia confirmed that Swakoppoort Dam showed high levels of nitrates in water sources due to input of sewage effluent (Lehmann, 2010). High (above 40 mg/L) nitrate concentration in water may lead to "methamoglobinemia" or "blue baby" disease in children (Gupta *et al.*, 2009).

Ammonia Nitrogen concentrations: The level of ammonia nitrogen in the dam ranged between <0.01 to 0.33 mg/L with a mean value of 0.06± 0.08 mg/L as indicated in Table 7. SP 6 has high values of ammonia and this can be attributed to accumulation of nutrients from different sources along the lake, based on its position.

The level of ammonia does not vary much among sampling points over the study period as indicated in Figure 22. At each point there was variation between sampling days with coefficient of variation of 147%. NamWater and all international standards and guidelines do not have recommended limits for ammonia, but according to the Namibia general standards for effluent, the threshold is 10mg/L. However the presence of ammonia indicates the possibility of sewage pollution and possible possibility of pathogenic micro-organisms (EPA, 2001). The results of this study show that the values are quite low and within the general effluent standards for Namibia.

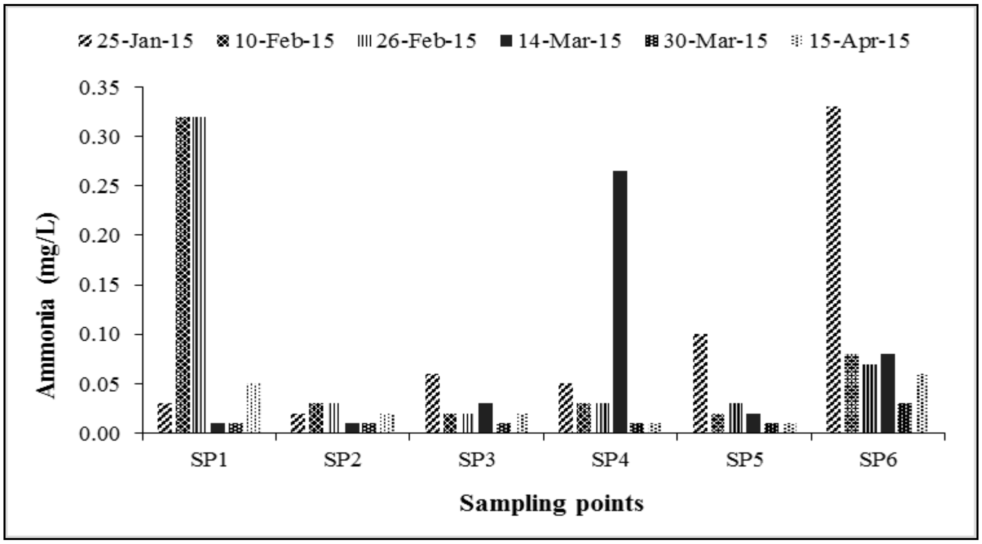

Figure 22: Variations of ammonia levels among sampling points - January to April 2015.

Spatially, the highest concentration of ammonia (0.14 -0.46 mg/L) was observed towards the end of the dam around SP 4 and 6 as shown in Figure 23. The value increased to a range of 0.05 to 0.10 mg/L at the beginning of the dam on the 25 January and 14 March 2015. On the 10th of February, the values were high at the beginning of the dam and decreased as one move towards the end of the dam. Ammonia distribution is not uniform over days and has shown a low variation among sampling points as depicted by Figure 22. Low concentrations of 0.01 to 0.04 mg/L were observed on 26 February, 30 March and 15 April 2015 among sampling points.

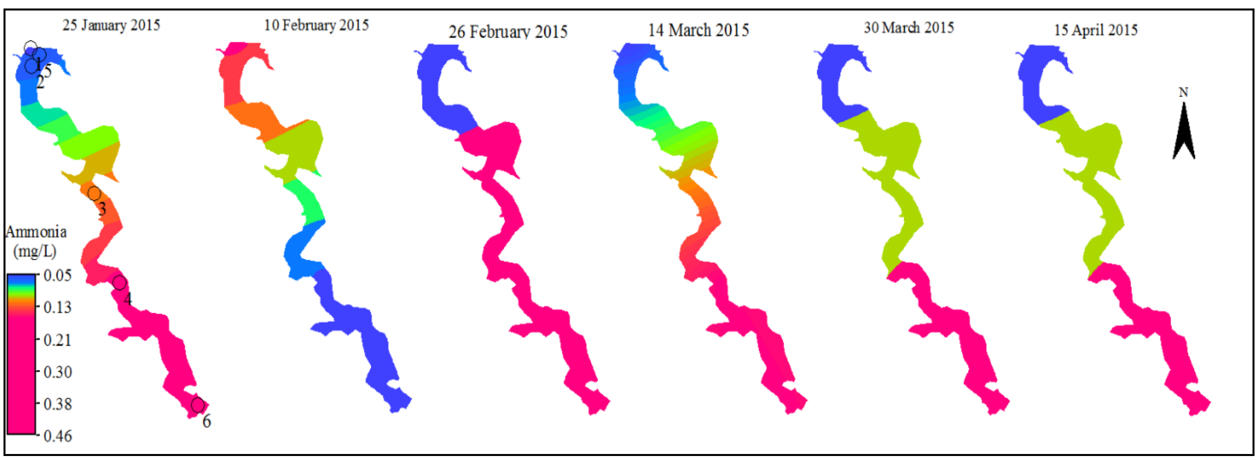

Figure 23: Spatial distribution of Ammonia among sampling points - Jan to April 2015.

Total Nitrogen: The mean total nitrogen concentration was 1.46±1.40 mg/L with a range from 0.10 to 4.70 mg/L in the dam as presented on Table 7. Figure 24 demonstrated that SP 6 had highest measured values of total nitrogen during all campaigns. The result showed a significant variation between sampling points and levels increased downstream from upstream suggesting an increasing trend of pollution. The coefficient of variation of 96% was found among sampling points. The average levels of total nitrogen are 100% within the UNECE standards.

In Rwanda, Lake Muhazi has a total nitrogen level of 0.85±0.22mg/L (Wali *et al.*, 2011) which is lower than the findings of this study in Olushandja Dam. Nitrogen has effect on infants and it is an indication of water purity which may affect different use. The high concentration of nitrogen also gives a rise to algae and other water plants. Runoff from agricultural fields and around the area may be rich in nitrogen. It have also been noted that sanitation is poor in the area. Human and animal waste also contribute significantly to organic compound concentrations in water ways (EPA, 1996).

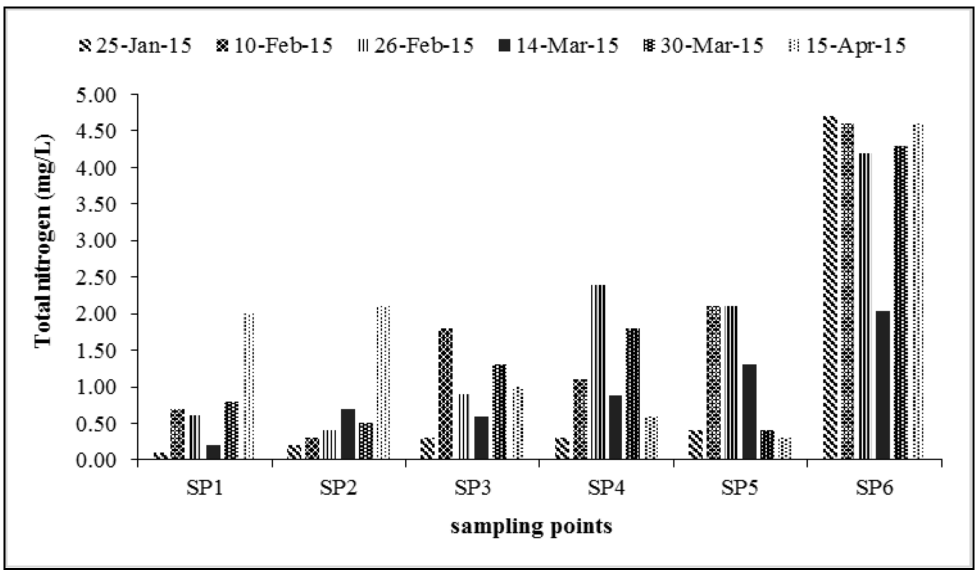

Figure 24: Variation of TN levels among sampling points (SP) - January to April 2015.

Spatially, total nitrogen concentration ranges from 0.29 to 2.90 mg/L over the study period as shown in Figure 25. The concentrations were in highest range of 1.80 to 2.90 mg/L around sampling point 6 at the lower end of the dam. The values decreased to a range of 0.29 to 1.83at the beginning of the dam and increased downstream suggesting increasing trend of pollution. The values are within the recommended UNECE standards.

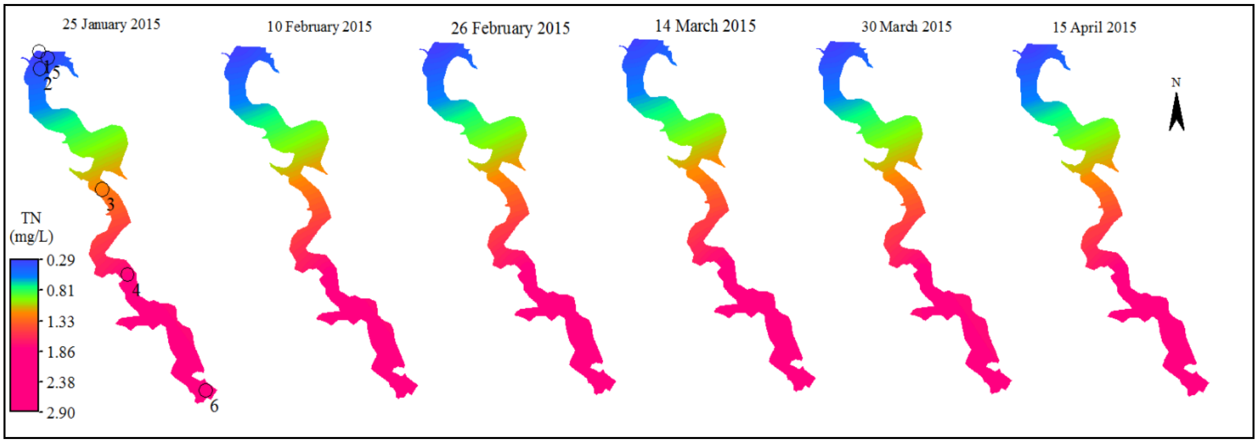

Figure 25: Spatial distribution of TN among sampling points - January to April 2015.

Total Phosphorus: The concentration of total phosphorus ranged from 0.02 to 0.64 mg/L with a mean value of 0.14±0.18 mg/L in the dam as shown in Table 7. The highest values were found at SP 6 during all campaign in dam (0.20 -0.64 mg/L) but lower among other sites as presented on Figure 26.

Based on the results, there is variance in the concentration of phosphorus among sampling points with coefficient of variation of 132%. The average levels of total phosphorus exceeded the EPA recommended limits (0.1 mg/L) and are within class I of the UNECE limit of <10mg/L. However, considering all values, the total phosphorus exceeded the EPA standards 20% of the time and within the UNECE 98% of the time.

The levels increased downstream suggesting an increasing trend of pollution. In a similar study, total phosphorus in Swakoppoort Dam was found to be 0.3 mg/L on average which is much higher than the EPA recommended values of 0.1 mg/L(Lehmann, 2010). A study by Wali *et al.*,(2011) in Rwanda found that in Lake Muhazi, total phosphorous level was 0.29±0.15mg/l which was slightly higher than this study. Higher phosphorus in a water body contributes significantly to the growth of algae and poor water quality.

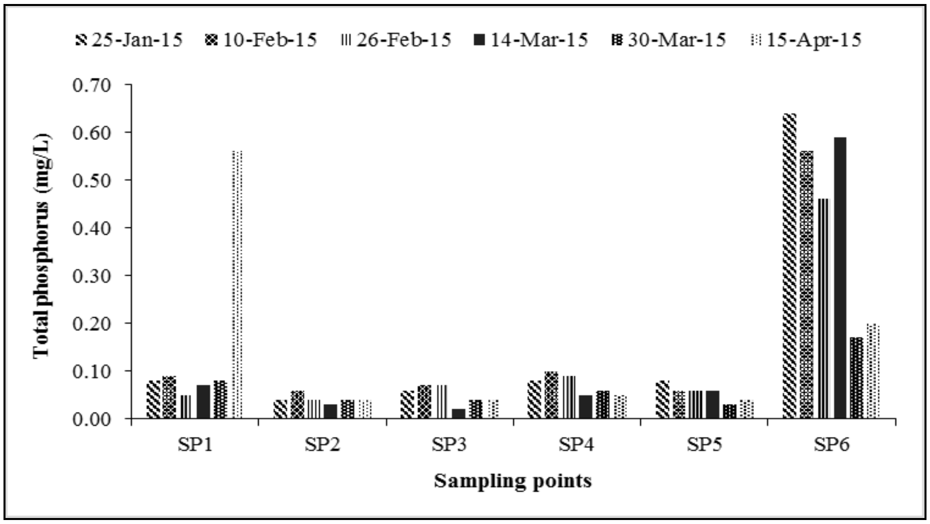

Figure 26: Variation of TP levels among sampling points (SP) - January to April 2015.

Spatially, the concentration of total phosphorus ranged between 0.04 mg/L to 0.27 mg/L over the sampling period. The concentration was highest (0.20 to 0.27 mg/L) at sampling point 6 and decrease to between 0.04 to 0.07 mg/L at sampling point 1. Figure 27 clearly show that there is spatial variation among sites in the amount of total phosphorus and levels increased downstream suggesting increasing trend of water pollution.

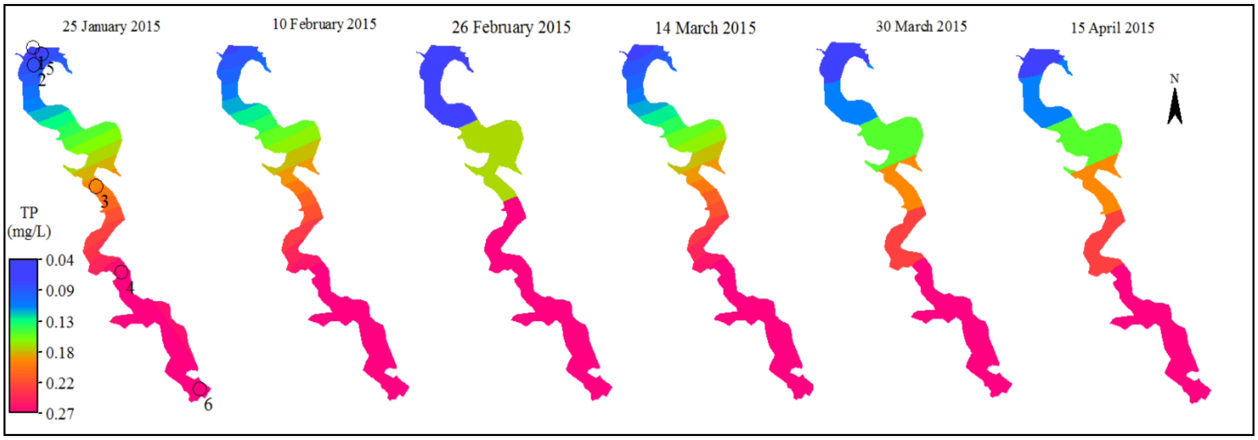

Figure 27: Spatial distribution of TP among sampling points - January to April 2015.

Total Suspended Solids (TSS): The mean value of total suspended solids ranged from 1.20 to 147 mg/L with a mean value of 20.5±26.6 mg/L as shown in Table 7. The highest amount of TSS in water samples was found at SP 6 on 25 January and lowest at SP 2 on 26 February 2015 as presented on Figure 28. The results show quite a high variance of suspended solids concentrations among sampling points and days with a coefficient of variation of 130%. The value varies as one moves from the beginning (SP1) to the end of the dam (SP6) suggesting increasing trend of pollution.

There was no standard limit found for suspended solids but the presence of solids in water may consist of algal growth thus a good indicator for severely eutrophic condition (EPA, 2001). Suspended solids also reduce the amount of light penetrating in the water and can affect fish life. According to MPCA suspended solids actually give rise to turbidity whenever it occurs in water (MPCA, 2003). Higher concentrations of suspended solids in water can also serve as carriers of toxics.

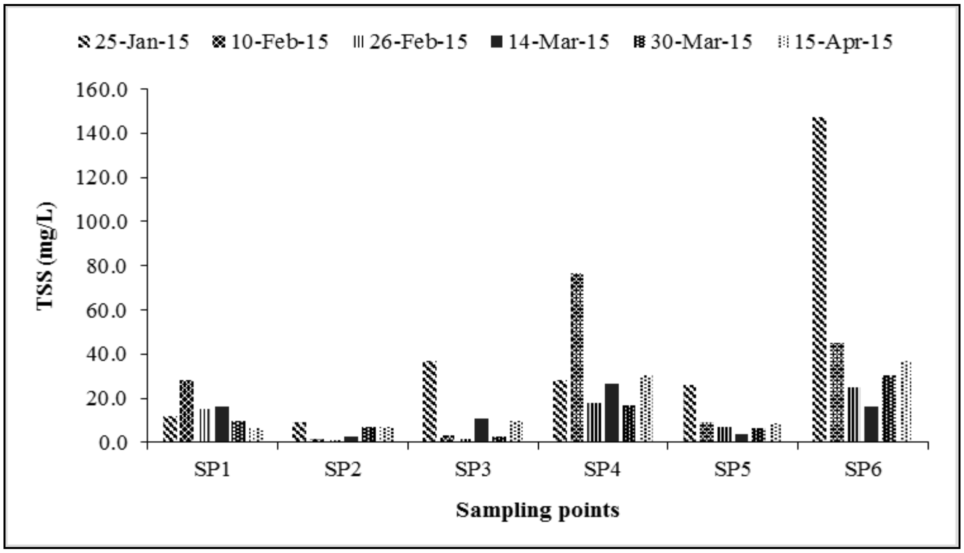

Figure 28: Variation of TSS levels among sampling points (SP) - January to April 2015.

Spatially, the concentration of total suspended solids ranged from 5.6 to 67.0 mg/L over the study period as presented in Figure 29. The highest values were observed toward end of the dam around sampling point 6 with a range between 15.5 to 67.0 mg/L. The lowest value ranges of 5.6 to 22.4 mg/L were observed at the beginning of the dam around sampling point 1. The map shows clearly that suspended solids increase as one moves from the beginning to the end of the dam (Figure 30). The levels increased downstream suggesting increasing trend of pollution.

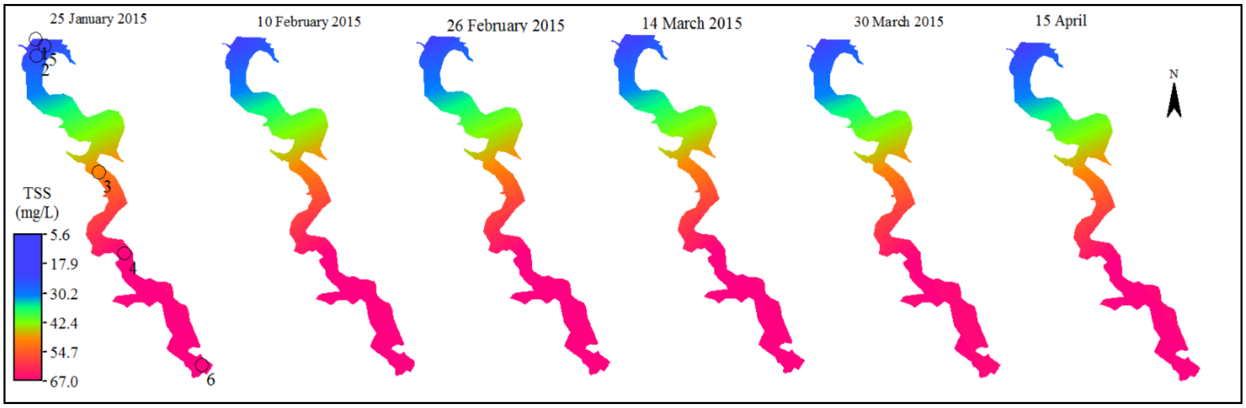

Figure 29: Spatial distribution of TSS among sampling points - January to April 2015.

5.1.3 Statistical difference among water samples in the dam

Since variation in concentrations of measured water quality parameters between sampling points has been established, further statistical analysis was carried out to determine the significant level. From the results most parameters show a clear trend (low at beginning of the dam and high at the end of the dam). However it is difficult to tell how significant the difference is, thus a paired t-test was conducted between two sampling sets which divide the dam into two sections. These are North to Middle (N-M) section comprising of sampling points 1, 2 and 5 and middle to South (M-S) section with points 3, 4 and 6.

The results in Table 8 confirms that there is a difference (alpha = 0.005) in the levels of water quality parameters measured at the N-M section and M-S section of the dam. Total algae content and concentration of turbidity, EC, TN, and TSS were significantly different with p-value of 0.007, 0.036, 0.004 and 0.014, respectively. On the other hand, NH_3 and TP shows no significant difference (p=0.401 and p=0.113) between the two sections.

Table 8: Paired samples t-test of water quality parameters between sampling sets

Paired	Paired differences					t	df	Sig. (2 tailed)
	Mean	Std. Deviation	Std. Error Mean	95% CI of difference				
				Lower	Upper			
Algae_N-M - Algae_M-S	-1.89E+03	2618.23	617.12	-3192.79	-588.77	-3.064	17	0.007
Turb_N-M - Turb_M-S	-18.0644	33.571	7.913	-34.759	-1.37	-2.283	17	0.036
EC_N-M - EC_M-S	-3.86E+02	402.107	94.778	-585.997	-186.07	-4.073	17	0.001
NH3_N-M - NH3_M-S	-0.06444	0.31722	0.0748	-0.2222	0.0933	-0.862	17	0.401
TN_N-M - TN_M-S	-1.23222	1.55228	0.36588	-2.00415	-0.46029	-3.368	17	0.004
TP_N-M - TP_M-S	-0.10222	0.25942	0.06115	-0.23123	0.02679	-1.672	17	0.113
TSS_N-M - TSS_M-S	-2.14E+01	33.04431	7.78862	-37.84921	-4.98412	-2.75	17	0.014

Note:
Turb = Turbidity, EC = electrical conductivity, NH_3 = ammonia, TN = Total nitrogen, TP = total phosphorus and TSS = total suspended solids, N-M = Northern -Middle (SP 1, 2&5) and M-S = Middle to Southern (SP3, 4 &6) part of the Dam; SP=Sampling Points; CI= Confidence Interval.

5.2 Algorithms for predicting water quality parameters

Landsat 8 imagery acquired on 26 February, 14 March, 30 March and 15 April 2015 were found to have zero % or low cloud cover % over Olushandja Dam. Images obtained on 25 January and 10 February 2015 was found to have high percentages of cloud cover and after analysis no pixel could be retrieved so they were not considered. The spectral band reflectance values at each sampling point on selected images (26 February to 30 March 2015) are given in Table 9 and field data corresponding to the same dates presented in Table 10 were used for model development.

Table 9: Average spectral band reflectance for four sampling campaigns in Olushandja Dam.

Sampling Point	Band2	Band3	Band4	Band5
1	0.011	0.042	0.035	0.095
2	0.016	0.047	0.026	0.020
3	0.059	0.057	0.057	0.057
4	0.004	0.012	0.012	0.008
5	0.010	0.050	0.027	0.015
6	0.000	0.004	0.024	0.004

The low reflectance values in the water body could be due to the fact that water is relatively clean (not heavily polluted) and this makes it have low reflective spectral radiation (He *et al.*, 2008). Band 5's low reflectance values can also be due to the fact that it is good for detecting near-infra red which is important for ecology (health plants reflect it) and for detecting land-water interference (Loyd, 2013; USGS, 2013), thus giving low values over water.

Table 10: Average values of measured data for four sampling campaign in Olushandja Dam.

Sampling Point	Algae counts (cells/ml)	Turbidity (NTU)	NH3 (mg/L)	TN (mg/L)	TPU (mg/L)	TSS (mg/L)
1	380	18.70	0.10	0.90	0.19	11.75
2	590	9.88	0.02	0.93	0.04	4.50
3	2374	5.97	0.02	0.95	0.04	6.13
4	684	19.74	0.33	1.42	0.06	22.88
5	864	10.77	0.02	1.03	0.05	6.33
6	3028	54.97	0.06	3.78	0.36	27.20

Note:
NH_3 = Ammonia, TN = Total nitrogen, TP = total phosphorus and TSS = total suspended solids.

The study then used a regression analysis to derive algorithms for retrieving the water quality parameters of Olushandja Dam, which is part of the complex water supply system in the northern central Namibia from remote sensing. Field measured data (Table 10) were regressed with reflectance values (given in Table 9) and regression models were formulated using a simple linear regression method. The results of the regression models are given in Table 11 and these can be used to predict water quality parameters anywhere in the dam.

Looking at the R^2 (coefficient of determination) and F-values, the results of regression analysis can be interpreted as follows; All the derived regression models had good regressive correlation for all parameters (i.e. total algae, turbidity, TN, TP, TSS and NH_3). Total algae, turbidity, TN, TP and TSS had R^2 values of 0.999, 0.986, 0.987, 0.980, 0.988, and 0.917 respectively. The R^2 values show that there is a high accuracy in predicting all the water quality parameters for the whole dam.

Through ANOVA, the calculated F-values show that all algorithms exceeded the 95% level of confidence. Li (2009) also found algorithms for turbidity in Shakespeare Bay to exceed 90%

confidence level. NH_3 showed no significant correlation with satellite data and had low F-value (less than 4.53), thus it was excluded in the prediction.

According to the results, the R^2 values for all water quality parameters were high and close to 1, which shows that there is a significant relationships between satellite data and field measurement. Alparsan *et al*.(2007) used Landsat ETM pixel reflectance and also found suspended solid matter and total phosphate to have high R^2 of 0.9999 and 0.9906, respectively. On the other hand, Reza (2008) has shown that there is a relationship between the level of suspended solids and MODIS radiance or reflectance. Furthermore, He *et al*. (2008) found a fairly high correlation between Landsat TM imagery DN values with water quality variables (algae, turbidity, TN and TP). All studies have concluded that water quality can be derived through remote sensing data.

Table 11: Derived retrieval algorithms for each parameter through regression analyses.

Water quality variables	R square (R^2)	Derived Algorithms
Algae	0.999	= -54.7081-26766.6(λ2)-42687.5(λ3)+137000.1(λ4) -23819.7(λ5)
Turbidity	0.986	= 15.31856-956.806(λ2) -747.376 (λ3)+1742.455 (λ4)+165.173(λ5)
TN	0.987	= 1.047532 -54.928 (λ2)-46.2947(λ3) +120.8943 (λ4)-19.223(λ5)
TP	0.98	= -0.00309-8.78139(λ2)-4.99958(λ3)+15.31713(λ4)-0.3916(λ5)
TSS	0.988	= 27.08987+10.80036(λ2)-507.708(λ3)+ 95.37331(λ4)+27.8424(λ5)

Note: *TN = Total nitrogen, TP = total phosphorus and TSS = total suspended solids. λ = pixel reflectance values at band 2 - 5.*

Relationships existed between algae content versus turbidity (0.587), TN (0.732), TP (0.546) and TSS (0.399); Turbidity versus TN (0.968), TP (0.937) and TSS (0.855); NH3 versus TSS (0.600); TN versus TP (0.861) and TSS (0.808); and TP versus TSS (0.715). Based on the correlation coefficient between parameters, highly significant ($p<0.05$) relationships were observed between turbidity and TN, TP and TSS as well as TN and TP. This is because some water quality parameters are related to each other or affect others. For example nutrients support algae growth and aquatic plants in water (UNEP, 2008), and high level of the growth of algae can reduce nutrient and oxygen level, and this will have an impact on the aquatic life (UNEP, 2006a).

Furthermore, turbid water corresponds to high levels of algae, suspended solids and nutrients (TN and TP in this case). The presence of suspended solids in a water body gives a rise to turbidity (MPCA, 2003). Li (2009) found that there was significant correlation between chlorophyll concentrations (which is related to algae) and turbidity levels.

Based on these results, the study conclude that pixel reflectance values of Landsat 8's visible and near infrared bands are good predictors for the five water quality parameters in Olushandja Dam. Thus the developed algorithms can be used to compute water quality parameters anywhere in the dam.

5.3 Prediction of water quality parameter from satellite data

The study demonstrated that all four bands of Landsat 8 data contribute to derived water quality parameters. The equations in Table 11 were applied to multispectral Landsat datasets to predict water quality parameters over the entire dam and at each sampling point. Therefore, this forms a base for testing the application of remote sensing as a framework for predicting water quality parameters in Olushandja Dam. The validation of Landsat predicted values, the relationships between predicted values and field measured data at each sampling point as well as the time-series spatial distribution maps of water quality parameters in Olushandja Dam are presented and discussed below.

5.3.1 Validation of predicted Landsat 8 water quality parameters

Five water quality variables in Olushandja Dam (total algae counts, turbidity and concentration of total nitrogen, total phosphorus and total suspended solids) were derived from Landsat 8 imagery on 26 February, 14 and 30 March as well as 15 April 2015. This was done after applying the developed algorithms to original bands with surface reflectance. Field measured data for the above mentioned selected parameters for 15 April was used to validate the Landsat modelled data.

5.3.2 Relationship between Landsat predicted and measured data

The relationship investigated on the water quality parameters were based on Landsat data for 15 April 2015. The relationship between Landsat predicted values and field measurement water quality parameters at each sampling points are presented in Figure 30 (a-e). Total algae content and the concentration of turbidity, TN, and TP indicate medium to strong positive linear relationship between Landsat predicted and measured data except TSS. Total algae content (r^2 = 0.851, P <0.01), level of turbidity (r^2 = 0.767, P <0.05), TN (r^2 = 0.798, P <0.05), TP (r^2 = 0.907, P <0.01) and TSS (r^2 0.284, P >0.05). Total suspended solid showed a low coefficient than all other parameters. Looking at R^2 values, it can be concluded that prediction models are best fit to derive the four water quality parameters except TSS.

The Landsat predicted data at specific sampling points were also compared to water quality standards for the different uses. These use includes livestock watering, recreational, agriculture and maintenance of aquatic life (see Table 7). Turbidity is found to be above the NamWater (1998) of 5 NTU but below the Canadian (2012) guidelines for recreational water quality (50NTU). On the other hand, TN and TP are below ECE (1994) standards for maintenance of the aquatic life which is <300 mg/L and <10 mg/L respectively.

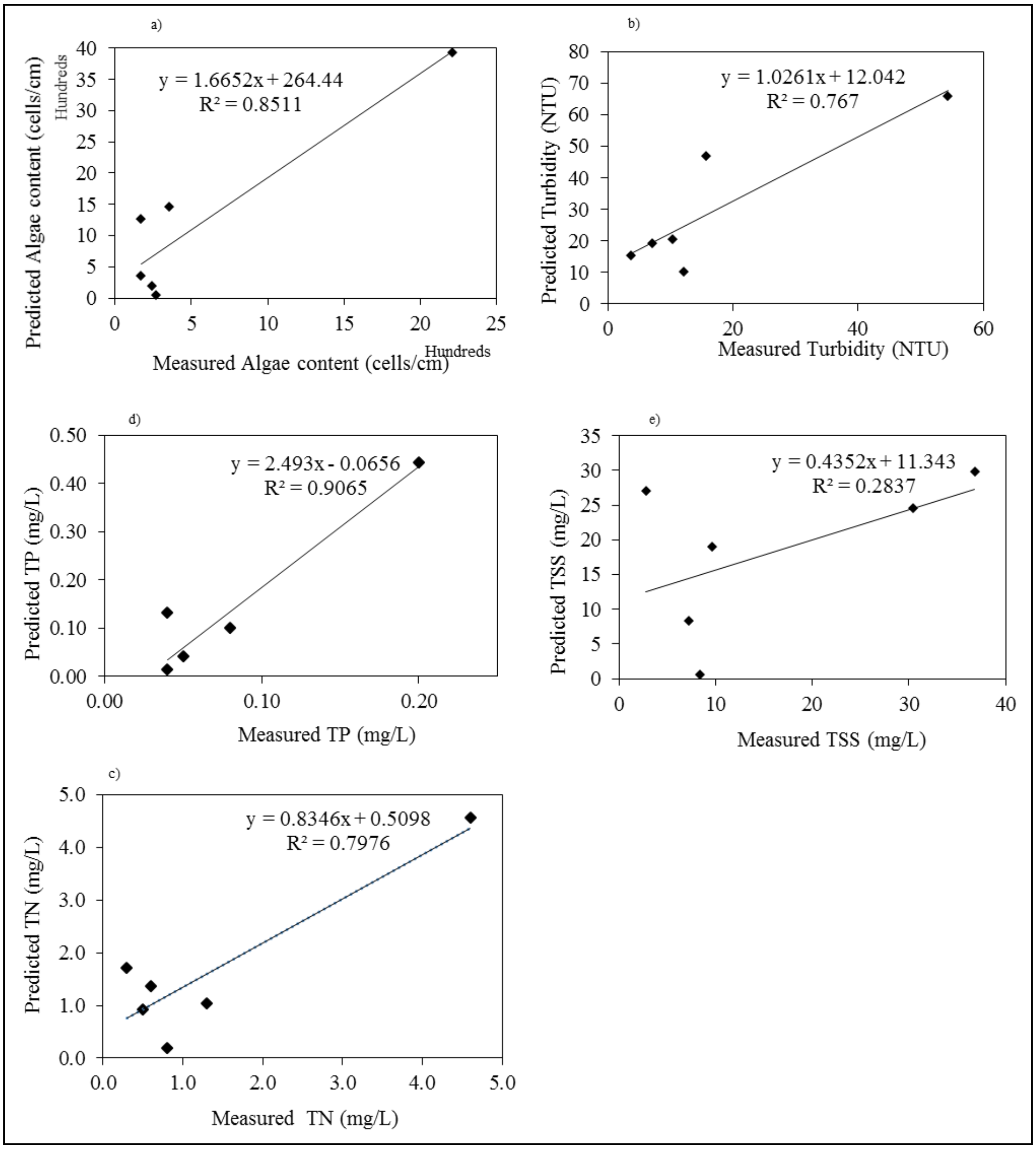

Figure 30 (a-e): Relationship between Landsat predicted versus field measured data.

Note: *(a) Total algae content, b) Turbidity level, (c) Total nitrogen (TN), (d) Total phosphorus (TP) and (e) Total suspended solids (TSS).*

Figure 30 (a-e) confirms the strength of the regression models by showing correlation with high coefficient of determination (R^2) between predicted values and measured data. It has been found that TP tended to have higher R^2 followed by total algae counts, TN and turbidity respectively. TSS had a low coefficient. This study proves that Landsat is able to predict water quality parameters as Alparslan (2007), He *et al*. (2008), Hellweger *et al*. Li (2009), Chen and Quan (2012), and Concha and Schott (2014), , however, used different Landsat missions imagery. The study also showed that Landsat 8 has capabilities in modelling water quality of relatively clean water body which has a low spectral radiation just like Landsat TM as recommended by He *et al.* (2008). However, the traditional methods remain critical in the process of monitoring water quality using remote sensing technique (Ritchie *et al.*, 2003).

5.3.3 Spatial distribution of predicted water quality parameter levels

Spatial distribution maps of the water qualities over the entire dam were obtained. The resultant quantitative maps for the five water quality variables (total algae content, turbidity, and concentration of total nitrogen, total phosphorus and total suspended solids) are presented in Figure 32-36. The resultant maps clearly show that different water quality parameters had several distribution patterns spatially over the reservoir over time.

Some parameters show very low predicted values, especially in areas with dense vegetation in the inner and along the edge of the dam closer to the land and some show the opposite. This can be due to reflectance ability of specific bands, especially band 5 (near-infra red) that reflect high on vegetation and interaction of water and land than in water (USGS, 2013). Figure 31 depict the presence of vegetation in and on the edge of the dam in January and February 2015.

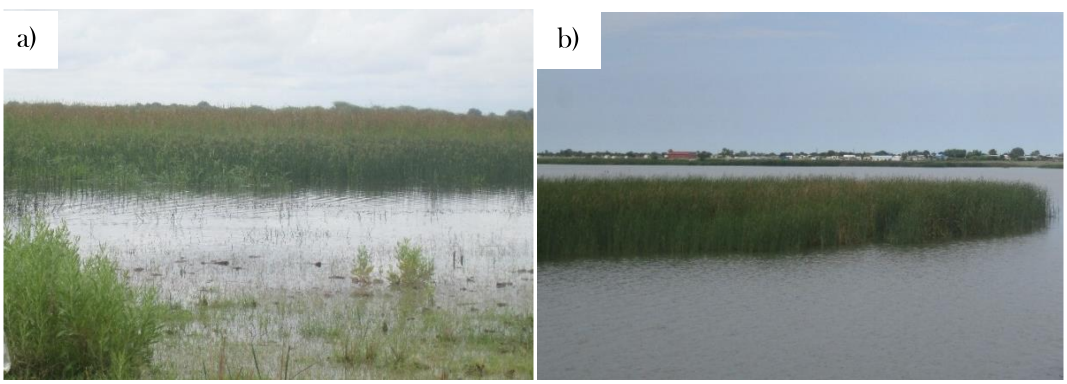

Figure 31 (a-b): a) Vegetation on the edge b) a patch of vegetation in inner part.

With spatial distributions of water quality variables, it is feasible to determine water qualities anywhere in the dam than only few sampling points. The summary statistics of the five water quality parameters are presented in Table 12. The statistics include the minimum, maximum, average, standard deviation and the local and international standards and guidelines (by local and international organizations) on water quality for different uses.

Table 12: Summary statistics of predicted water qualities over the entire Olushandja Dam

Statistics	Concentrations				
	Algae (cells/ml)	**Turbidity (NTU)**	**TN (mg/L)**	**TP (mg/L)**	**TSS (mg/L)**
Minimum	0	4.7	0.00	0.00	0.0
Maximum	21204	356.0	13.20	2.60	42.0
Average	1650	83.2	1.39	0.43	8.8
Standard deviation	3143	63.2	2.18	0.40	16.3
NamWater	-	5	-	-	-
Canadian	-	50	-	-	-
FAO	-	-	-	-	-
ECE	-	-	<300	<10	-

Spatial distribution of total algae contents in the dam: The distribution of total algae as retrieved from satellite data on each sampling campaign date is shown in Figure 32. Based on the statistics, the counts of total algae ranged from 0 to 21204 cells/ml (refer to Table 12). The high standard deviation to the average of ±3143 demonstrated that total algae contents have high spatial variance. Using the Olushandja Dam maps, it shows that total algae counts has a high up to 21204 cells/ml. High algae content contribute significantly to poor water quality. In the Central Area of Namibia (CAN), due to high nutrient load in Swakoppoort Dam, algae bloom has contributed to poor quality of water (Lehmann, 2010; NamWater, 2012).

The spatial distribution maps clearly show that, the total algae content was lower in the inner upper part and increased as you move to areas closer to the land and to the end part of the dam. This distribution corresponds to the trend of field measurements (see Figure 6). This could be due to input of nutrients through runoff from agricultural lands and area around the dam which has a potential of increasing algae growth. It could also be associated to dead matters that release nutrients which can be favourable for algae growth as they decompose. In addition, water in the end part of the dam remains stagnant for a long time thus encouraging accumulation of nutrients which are required for algae production.

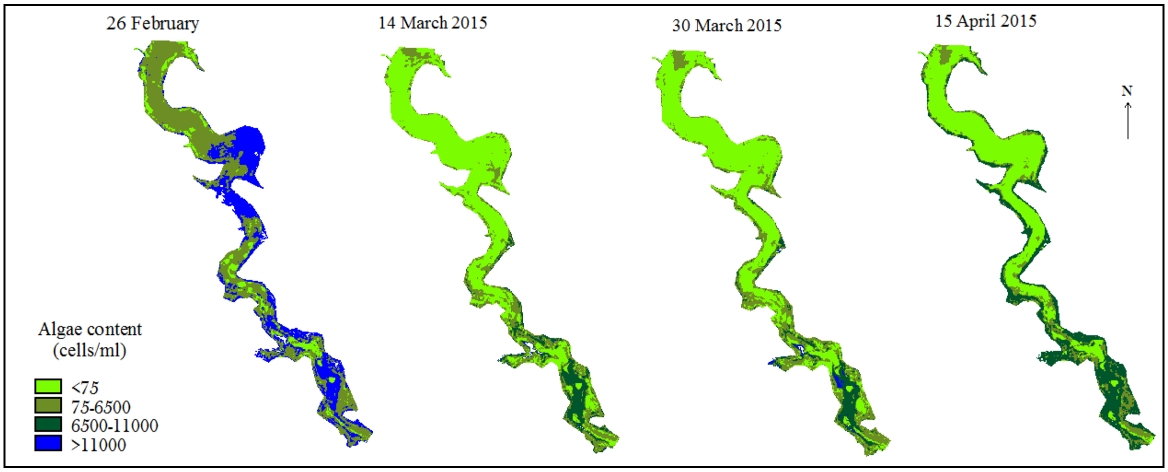

Figure 32: Spatial distribution of Landsat 8 predicted total algae content in Olushandja Dam.

Spatial distribution of turbidity levels: The predicted concentrations of turbidity ranged from 4.7 NTU to 356 NTU over the sampling period (see Table 12). The upper part of the dam shows the lower levels of turbidity as compared to the downstream. This could be due to the fact that such part of the dam is deeper compared to the middle and end parts of the dam. Figure 33 reveals that turbidity levels are highest (88 NTU to above 300 NTU) toward the end part and areas closer to the land suggesting increasing trend of pollution. This can also be attributed to human activities such as local fishing and water abstraction for horticultural production which occur in the dam lake and increase as one goes downstream. Both predicted and measured turbidity levels show high spatial variations. Overall, turbidity is found to be above recommended limits of drinking water standards by NamWater as well as for recreational purpose of the Canadian (50 NTU). Other studies (He *et al.*, 2008; Li, 2009; Lehmann, 2010) also found high turbidity levels in different water bodies.

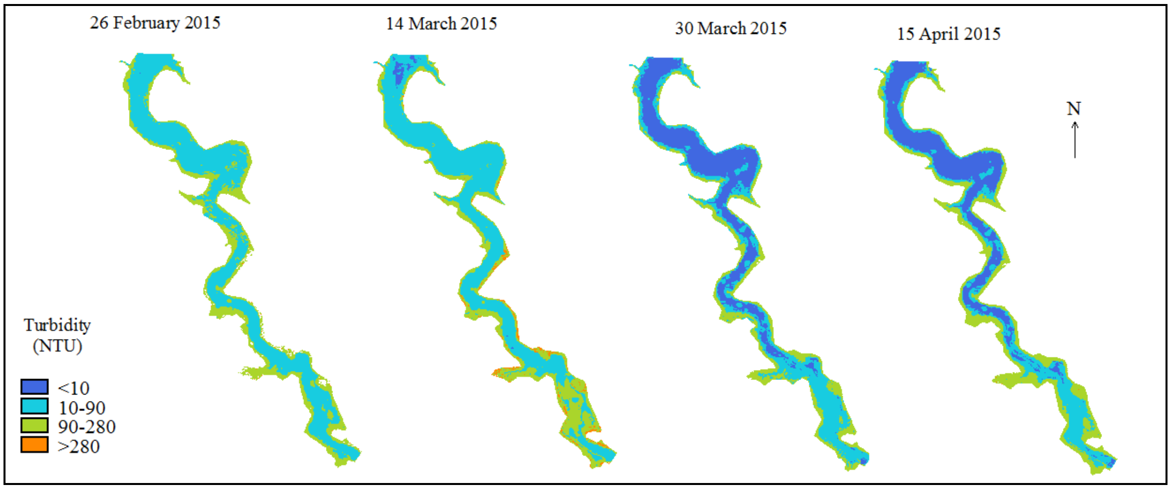

Figure 33: Spatial distribution of Landsat 8 predicted turbidity level in Olushandja Dam.

Spatial distribution of total nitrogen concentrations: The spatial distribution of total nitrogen concentration in the dam for the dates indicated ranged from 0 mg/L to 13.2 mg/L. The summary statistics shows that TN had high spatial variance (see Table 12). Total nitrogen was the highest range of 5.0 mg/L to 13.2 mg/L mostly at the lower end part of the dam on the 14 and 30 March as well as 15 April 2015 as shown in Figure 34. Spatially, there is an increase in the concentrations as one move from the end to the beginning of the dam and from the inner part to the area closer to the land. High concentrations in the lower end of the dam could be attributed to nutrient accumulation, water plants in some area and low or no significant flow for longer time as water remain stagnant. This trend of variation corresponds to field measurements that also increase from the beginning to end of the dam. The predicted TN is below the ECE (1994) recommended limits which <300 mg/L maintenance of aquatic life.

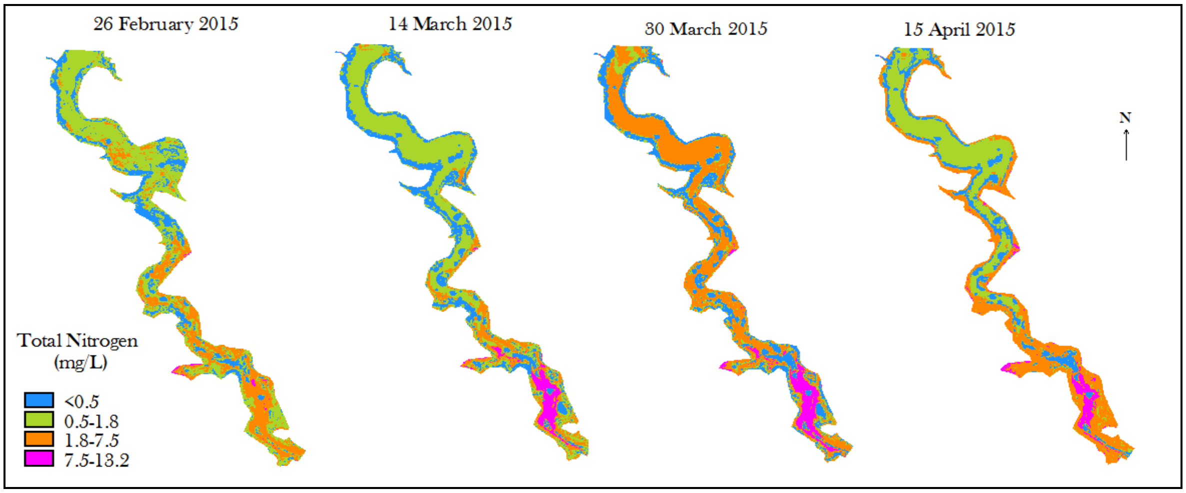

Figure 34: Spatial distribution of Landsat 8 predicted TN levels in Olushandja Dam.

Spatial distribution of total phosphorus concentrations: The distribution of total phosphorus as predicted from Landsat 8 image is shown by figure 35. The concentrations of TP ranged from 0 mg/L to 2.60 mg/L over the dam and show less spatial variation. The concentrations in most part of the dam are low but with a trend of increasing from upstream to downstream and as one move from the inner part of the dam to the areas closer to the land. The highest concentrations (0.9 mg/L to 2.60 mg/L) were noted in the area closer to the edge, mostly at the very lower part of the dam. This could be also attributed to nutrient accumulation along the edge of water and lower end of the dam. TP concentrations are found to be within the UNECE (1994) standards for maintaining the aquatic life.

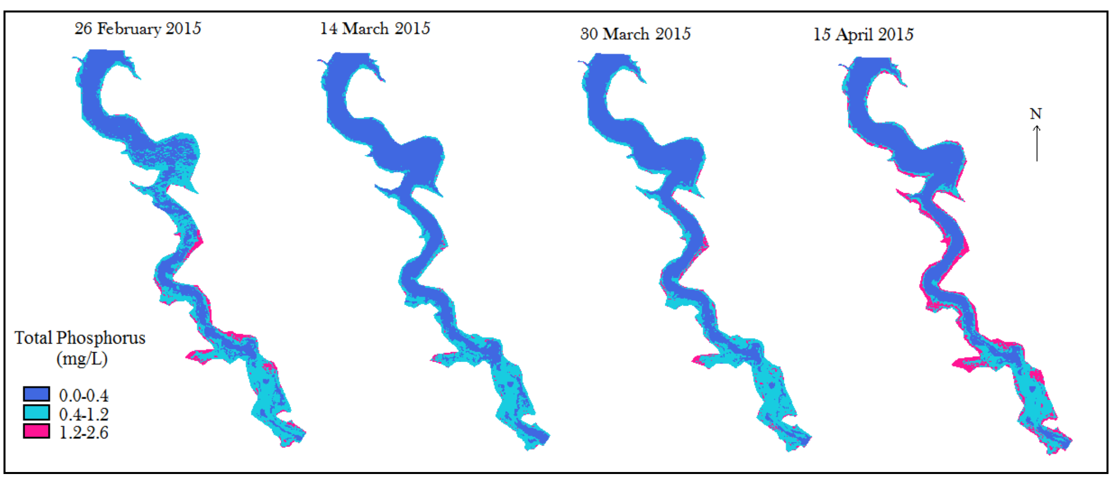

Figure 35: Spatial distribution of Landsat 8 predicted TP levels in Olushandja Dam.

Spatial distribution of total suspended solids concentrations: The concentrations of TSS ranged from 0 mg/L to 42.0 mg/L over the dam. Figure 36 depict the spatial distributions of predicted levels of suspended solid matters from satellite in Olushandja Dam. The results shows that the concentration was highest (19 mg/L to 42 mg/L) in most parts of the upper then decrease toward the edge and lower part of the dam for 14 and 30 March as well as 15April 2015. The distribution at the lower end of the dam on these days, as well as for 26 February (whole dam), was not uniform. TSS in water indicates the presence of productivity in the inner and deeper part of the dam, thus it is considered as a natural component of freshwater ecosystem (Swietlik *et al.*, 2003). Suspended solid in water increases due to runoff and mixing of nutrients in the dam. The distribution of TSS is highly varied and similar to that of total algae content both predicted and measured data.

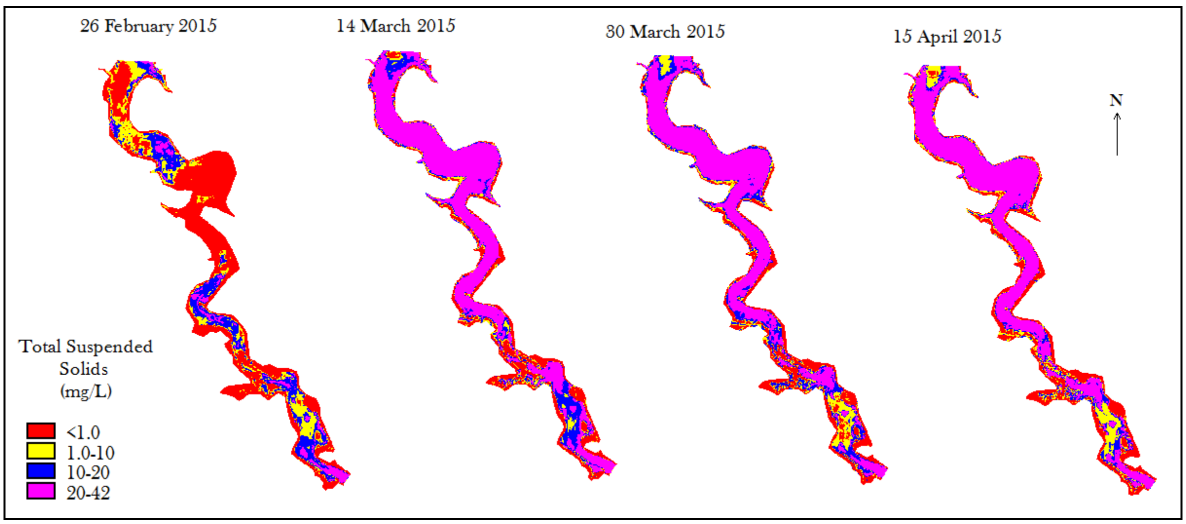

Figure 36: Spatial distribution of Landsat 8 predicted TSS levels in Olushandja Dam.

In *summary*, the spatial maps show apparent variations of the five selected variables and inform decision makers of the water quality distributions over Olushandja Dam. The resultant maps demonstrated that total algae contents and concentrations TN, and TSS were highly varied over the dam while turbidity and TP had less spatial variance. The spatial distribution of water quality parameter retrieved from satellite data demonstrate a similar patterns as the field measurement data discussed in section 5.1.

The result shows that there was variation in the concentration of water quality parameters both longitudinal and latitudinal due to several factors. These include rainfall runoff (Bonansea *et al.*, 2015), nutrient accumulation due to decomposition of plants and animals as well as low or no flow especially at end part of the dam. In addition, it could be due human activities such as fishing, abstraction of water and swimming which would encourage mixing of water constituents. All these factors affect water quality. Therefore, this study demonstrated that Landsat 8 is a great instrument that can provide frequent and continuous information of water quality parameters in Olushandja Dam. However monitoring using satellite data in combination with field measured data is necessary to ensure accuracy.

5.3.4 Framework for monitoring

Based on the result of this study, Landsat data has proven its ability to derive water quality parameters, data that are comparable to the field measurements. Therefore, a proposed framework for predicting water qualities for Olushandja Dam is presented in Figure 37. A Remote sensing based framework clearly show processes, sub-process, in-put data and outputs involved in integrating satellite data and field measurements.

The framework will help responsible institutions and interested members of the community to implement a continuous monitoring of water quality. This will provide valuable information that will support decision-making with regard the management of the water source, Olushandja Dam.

Firstly, the framework would benefit the Namibia Water Corporations company (NamWater) and Department of Water Affair under Directorate of Resources Management in the Ministry of Agriculture, Water and Forestry. NamWater as a water utility company, supplying bulk water to industries, municipalities and Directorate of Rural Water Supply in Namibia and the Department of Water Affairs as responsible for utilization and management of scarce resources.

Secondly, this framework or its end products can be useful to the Ministry of Fisheries as there are fishery resources, the Ministry of Health and Social Services, students, community members, water resources managers, planners, developers and any other interested parties.

The application of this framework would require among others:

1. Human resources (someone with some knowledge of GIS and Remote Sensing, statistics, data interpretation and management to acquire process and interpret the data).

2. Financial resources (for transportation to the field site, laboratory analysis of water samples, and equipment. In addition, for purchasing software in case it is required).

3. GIS software (e.g ILWIS, ENVI, QGIS, ArcGIS etc.). Softwares such as ILWIS, ENVI and QGIS are open source software that can be downloaded for internet. More information about ILWIS can be found at http://www.itc.nl/ilwis/downloads/ilwis33.asp and http://52north.org/communities/ilwis.

4. Cloud free Landsat 8 OLI images. These can be downloadable free of change and have advantages over the other satellite sensors. The calendar for Landsat imagery can be found at: http://landsat.usgs.gov/tools_L8_acquisition_calendar.php. However, this framework is not limited to Landsat data only but other sensors such as MODIS, SPOT can be explored.

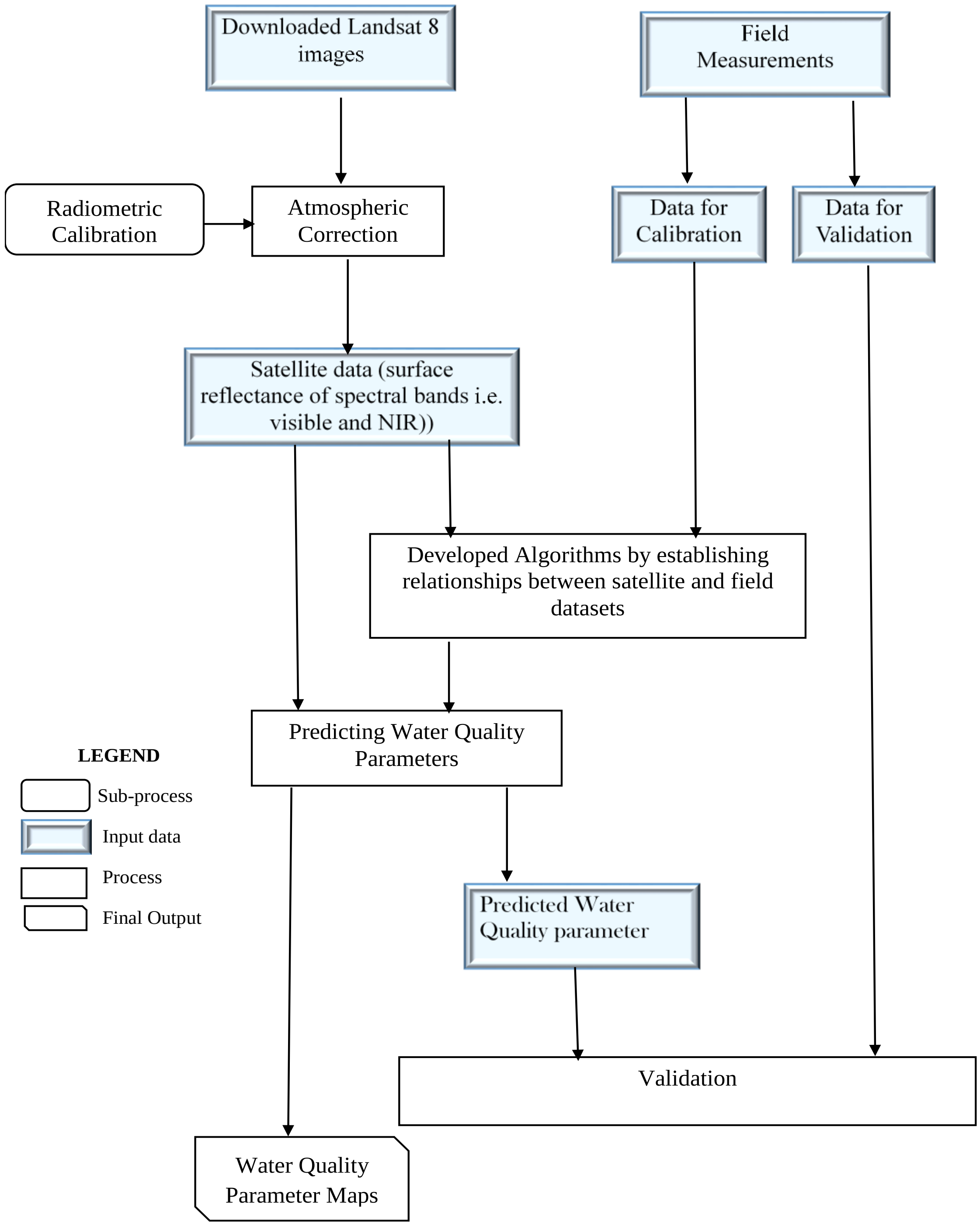

Figure 37: A proposed framework for predicting water quality parameters

Note: *More information on the methodological approach to each step is described in section 4 of this thesis.*

CHAPTER 6

6.1. CONCLUSION

In this research, the following conclusion can be drawn:

1. Based on the laboratory water quality results analysis, the study concludes that the status of water quality in Olushandja Dam and canal is of low health risk. Turbidity and total algae count are of major concern. Turbidity exceeded both NamWater Standards and the Canadian guidelines for recreational purposes.

2. The study also concluded that best fit algorithms for retrieving water quality parameters can be developed through regression analysis. The regression analysis produced algorithms with a high coefficient of determination (R^2) showing good fit.

3. Finally, the study has demonstrated that remote sensing, specifically Landsat 8 OLI, can be used to develop algorithms that can be used to predict water quality variables for the whole Olushandja Dam.

6.2. RECOMMENDATIONS

Based on the results and observations, this study recommends the following:

1. For frequent and continuous monitoring in Olushandja Dam, the application of remote sensing could be applied through the proposed framework using developed algorithms for predicting water quality variables. However, traditional methods of in-situ and laboratory analysis remain an important input in remote sensing technique.

2. The study also recommends that field sampling points may be increased in order to update the algorithms for them to be more robust. This study noted that more than ten sampling points over the dam are good for the regression models.

3. Furthermore, apart from the selected assessed parameters, other variables such as iron have been noted high by NamWater. Therefore, this study recommends further studies on algae and metallic components to explain their levels and effects on this water source.

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APPENDIXES

Appendix A:

Equations for converting DN to radiance then to TOA reflectance (Chander *et al.*, 2009; APHA, 2012; USGS, 2013).

The conversion of DNs to at-sensor Radiance follows equation
Equation : $L_\lambda = M_L Q_{cal} + A_L$

where:
L_λ = TOA spectral radiance (Watts/(m2 * srad * μm))
M_L = Band-specific multiplicative rescaling factor from the metadata (RADIANCE_MULT_BAND_x, where x is the band number)
A_L = Band-specific additive rescaling factor from the metadata (RADIANCE_ADD_BAND_x, where x is the band number)
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

The conversion of sensor radiance to TOA reflectance follows equation

Equation: $\rho\lambda' = M\rho Qcal + A\rho$

where:
$\rho\lambda'$ = TOA planetary reflectance, without correction for solar angle. Note that $\rho\lambda'$ does not contain a correction for the sun angle.
M_ρ = Band-specific multiplicative rescaling factor from the metadata (REFLECTANCE_MULT_BAND_x, where x is the band number)
A_ρ = Band-specific additive rescaling factor from the metadata (REFLECTANCE_ADD_BAND_x, where x is the band number)
Q_{cal} = Quantized and calibrated standard product pixel values (DN)

The TOA reflectance with a correction for the sun angle is then calculated using equation

Equation: $\rho\lambda = \rho\lambda' / \cos(\theta_{SZ}) = \rho\lambda' / \sin(\theta_{SE})$

where:
$\rho\lambda$ = TOA planetary reflectance
θ_{SE} = Local sun elevation angle. The scene center sun elevation angle in degrees is provided in the metadata (SUN_ELEVATION).
θ_{SZ} = Local solar zenith angle; $\theta_{SZ} = 90° - \theta_{SE}$

Appendix B:

NamWater Standards for determinants with aesthetic/physical implications and livestock watering (NAMWATER, 1998).

Determinants	**Units**	**Group A**	**Group B**	**Group C**	**Group D**	**Livestock watering**
p H	pH unit	6-9	5.5 - 9.5	4.0-11.0	4.0-11.0	<4.0 - >11.0
Electrical conductivity	mS/m at 25◦C	150	300	400	400	>895.5
Total dissolved solids (det.)	mg/L	-	-	-	-	>6000
Turbidity	NTU	1	5	10	10	
Colour	mg/L Pt	20	-	-	-	-
Nitrate as N	mg/L	10	20	40	40	>110
Iron as Fe	mg/L Fe	0.1	1	2	2	10

	Group A	Water with an excellent quality
	Group B	Water with good quality
	Group C	Water with low health risk
	Group D	Water with a higher health risk, or water unsuitable for human consumption