A COMPARATIVE STUDY OF THE LIMNOLOGY OF TWO SMALL DAMS IN CAPRICORN DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA

by

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RESEARCH DISSERTATION

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DEDICATION

To my loving parents (Maselelo Salminah Mphalo and Motlhatlego Simon Mphalo), my inspiration.

DECLARATION

I declare that **A COMPARATIVE STUDY OF THE LIMNOLOGY OF TWO SMALL DAMS IN CAPRICORN DISTRICT, LIMPOPO PROVINCE, SOUTH AFRICA** hereby submitted to the University of Limpopo, for the degree of **Master of Science (Aquaculture)** has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been duly acknowledged.

Mphalo S.J (Ms) **Date**

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"For I know the plans I have for you, declares the Lord, plans to prosper you and not harm you, plans to give you hope and a future."

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ABSTRACT

The aim of this study was to provide baseline limnology data that can be used in the management of small dams, Molepo Dam and Hout River Dam. Physico-chemical parameters were assessed to determine the water quality and the effect of water level fluctuations on water quality. Water temperature, pH, dissolved oxygen, turbidity, electrical conductivity, nitrate, total phosphorus, total nitrogen and chlorophyll-a were assessed during the dry season (May-Oct) and wet season (Nov-Apr). Physico-chemical parameters showed seasonal variations with the exception of pH. The mean total phosphorus (1.06 and 0.98 mg/L), total nitrogen (1.27 and 1.56 mg/L) and chlorophyll-a (2.97 and 3.32 μg/L) were higher in the dry season than wet season in Molepo Dam and Hout River Dam respectively. Water level fluctuations had a significant effect on total nitrogen, total phosphorus and turbidity in Molepo Dam and total nitrogen in Hout River Dam.

Plankton were used as indicators of water quality. Phytoplankton and zooplankton were sampled using nets of 71 μm and 132 μm mesh respectively and identified to genus and species at both Molepo Dam and Hout River Dam. Individual species, number per litre for phytoplankton groups that contributed significantly in terms of abundance were *Microcystis aeruginosa* and *Oscillatoria sp*. in both Molepo Dam and Hout River Dam during the dry season months. The Shannon-Wiener diversity index was high during the wet season in these small dams. The abundance of Cyanophyta was greatest during the dry season followed by Desmids in Molepo Dam and Hout River Dam. During the wet season, Bacillariophyta were not recorded for Hout River Dam. The highest composition for Chlorophyta (15.4%) in Molepo Dam was recorded during the wet season months. Phytoplankton abundance was highest in Molepo Dam as compared to Hout River Dam throughout the sampling period. Zooplankton was dominated by Cladocerans (*Bosmina longirostris*) in both small dams. This study showed that plankton can be used as indicators of water quality. Zooplankton communities were dominated by *Bosmina longirostris* which was present throughout the sampling period possibly indicating clear water in Molepo Dam and Hout River Dam. Copepoda were sub-dominant phyla mainly represented by *Cycloid sp.* which are also indicators of clean water.

The study determined the abundance and composition of fish species and growth parameters of the most abundant fish species (*Oreochromis mossambicus*) in the two small dams. Scales were successfully used for the age determination of *O. mossambicus*. The rings on the scales were validated as being true annuli by marginal increment analysis which indicated that the distance between the last annuli and the scale edge was shortest in the wet season months in Molepo Dam and Hout River Dam. This is the time in which annulus formed. Annulus formation of *O. mossambicus* at these small dams coincided with the onset of increased water temperature and rainfall (increased water levels and increased water inflow into the dams) in this region. Furthermore, the growth performance index (ϕ) of male *O. mossambicus* was higher than that of female *O. mossambicus* in both Molepo Dam and Hout River Dam. The study provides the first record of limnology baseline data of Molepo Dam and Hout River Dam.

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CHAPTER 1: GENERAL INTRODUCTION

1.1 General introduction

A small dam in South African context is defined as a waterbody barrier that stops the flow of water or underground stream whose total storage capacity is less than seven million cubic metres with a maximum dam wall height of less than twelve metres (DWS, 2015). In South Africa, the total number of small farm dams is approximately 500 000 (DWAF, 1986; Mantel, 2010), which are primarily associated with agriculture and livestock farming as well as recreation. However, despite the large number of small dams and their importance, baseline limnological information is available for relatively few (Hart, 1999; Janse Van Vuuren and Pieterse, 2005). Limnology is the study of physical, chemical and biological characteristics in an aquatic ecosystem, these characteristics are influenced by seasonal water level fluctuations which are significantly associated with anthropogenic utilization (Wetzel, 1990; Geraldes and Boavida, 2005). Limnological investigations that exist on small dams are often based on short-term or once-off studies, whilst medium and large dams, lakes and rivers are being studied extensively (Hart, 2001; Riato *et al*., 2014; Harding, 2015). Small dams play a critical role in the livelihoods of rural communities in South Africa particularly during the dry season.

Water level fluctuation is one of the major challenges faced by small dams worldwide. Most of the small dams in South Africa, including the two small dams studied during this investigation, Molepo Dam and Hout River Dam are experiencing wide water level fluctuations from one year to another. The Molepo Dam which is situated at Ga-Ramphere Village, a large rural community approximately 35 km South East of Polokwane in the Capricorn District was constructed in 1987 for irrigation purposes. The small dam catchment area is approximately 125.43 km^2 and comprises of 54% built-up area, 27% arable land (crops), 10% forest and 9% livestock activity (FAO, 2016). Hout River Dam, also known as Matlala Dam is situated at Ga-Mamadila Village, 30 km North West of Polokwane in the Capricorn District. This small dam was constructed in 1988 for irrigation and water supply purposes. Hout River Dam is situated 1 257 m above sea level and has a 130 km^2 catchment area that forms part of the Limpopo River System (DWAF, 2015).

The catchment comprises of 13% built-up area, 8% arable land (crops), 75% forest and 4% livestock activity (FAO, 2016). Molepo Dam and Hout River Dam were chosen in this study based on the difference in magnitude and catchment land use. However, both small dams are subjected to water level fluctuations due to annual rainfall variations, non-seasonal water abstraction and anthropogenic activities.

The water level fluctuations in Molepo Dam and Hout River Dam will affect the water quality, plankton and fish. These changes will most likely affect communities that use these two small dams. Poor water quality and fish kills are a common occurrence in reservoirs and shallow small water bodies experiencing wide water level fluctuations (Sayer *et al.*, 2016). Some organisms inhabiting water bodies subjected to water level fluctuations have developed mechanisms for dealing with periodic droughts such as emigration or aestivation but plankton have low mobility and are therefore unable to avoid environmental changes imposed by fluctuating water levels which cause variations in physical and chemical variables (Nhiwatiwa, 2004; Dalu, 2012).

Furthermore, water level fluctuations in regulated and unregulated small water bodies such as Molepo Dam and Hout River Dam, may promote cyanobacterial blooms through changes in nutrient concentrations and by modifying water column light availability (No˜ges *et al*., 2010; Bakker and Hilt, 2016; Havens and Ji, 2018). Physico-chemical parameters particularly nitrogen and phosphorus are primary nutrients that are of major concern in aquatic ecosystems. Although they are essential elements in aquatic ecosystems, when one or both nutrients are in excess, they fuel overgrowth of algae which leads to eutrophication. Eutrophication has been regarded as one of the major serious threat facing freshwater ecosystems worldwide (Wetzel, 2001; Lemley and Adams, 2019). Eutrophication can occur naturally in the normal succession of some freshwater ecosystems. However, when the nutrient enrichment is due to anthropogenic activities and wide water level fluctuations, the rate of this natural process is greatly intensified. During the dry season, nitrogen and phosphorus are more concentrated due to the reduction of water volume and as a result stimulates phytoplankton growth (Welch, 1981; Lee *et al*., 2019).

The dominance of cyanobacteria (*Microcystis aeruginosa*) in small dams is a good indicator in assessing water quality (Nhiwatiwa and Marshall, 2007; Mhlanga *et al*., 2020). Cyanobacteria (*Microcystis aeruginosa*) is sensitive to water level fluctuations, flow rates, water quality deterioration and habitat alterations. The specific effects of water level fluctuations on cyanobacterial blooms and water quality can vary depending on the trophic status, depth, morphometry, sediment composition and external nutrient loading of small dams (Bakker and Hilt, 2016).

However, the dominance of *Microcystis spp* may be a challenge to communities using the water from these dams because some strains of *Microcystis* are toxic to cattle (Orr *et al*., 2001; Butler *et al*., 2009; Menezes *et al*., 2019). A number of cattle deaths have been reported in South Africa due to microcystin poisoning (Halderen *et al*., 1996; Oberholster *et al*., 2005; Kellerman and Naude, 2005; van Ginkel, 2011). Microcystins are also toxic to fish primarily affecting the liver, causing minor to widespread damage depending on the amount of toxin absorbed. It is thus important to determine the prevalence of *Microcystis* in the small dams.

The water level fluctuations also alter habitat availability, complexity and quality. Depending on the dam morphology, relatively minor changes in water level can lead to large variations in littoral zone and impair the breeding habitat of fish (Kolding and van Zwieten, 2006; Gownaris *et al*., 2017). Tilapia and many other fish species use the littoral zone during spawning and as juveniles, but the pelagic zone as adults (Winfried, 2004; Zohary and Ostrovsky, 2011). However, due to the loss of habitat complexity through shifts from stony to sandy substrates as a result of water level fluctuations and decline in macrophytes species diversity, the abundance of fish species inhabiting the ecosystem declines and in extreme cases they are even lost (Zohary and Osrovsky, 2011).

Prolonged water level fluctuations in Molepo Dam and Hout River Dam may expose fish communities to predators. Regardless, water level fluctuations promote high species diversity in littoral zones and increase productivity of the small dams (Kolding and van Zwieten, 2006; Utete *et al*., 2018; Kann and Walker, 2020). Water level fluctuations constantly influence internal nutrient mixing between wet and dry seasons, leading to the accumulation and resuspension of nutrient-rich organic matter and subsequently enhance productivity (Lu *et al*., 2018). This increases species diversity in response to high nutrient loads in shallow small water bodies.

Molepo Dam and Hout River Dam also experience water level fluctuations naturally as a result of seasonal or long-term imbalance between inflows and outflows. The magnitude of those fluctuations depends on factors such as dam morphology and its catchment areas, intensity of rainfall events as well as factors determining water losses such as wind speed and air temperature that impact evaporation (Zohary and Ostrovsky, 2011). Tilapia species may be stunted due to poor water quality and stress arising from water level fluctuations.

Despite the importance of Molepo Dam and Hout River Dam in the livelihoods of the rural communities, their limnology has not been investigated. Sustainable utilisation of the water resources in these two small dams can only be achieved if water quality parameters and population dynamics of the biota is understood. Therefore, the aim of this study is to provide baseline limnology data that can be used in the management of these small dams.

1.2 Dissertation layout

The assessment of physico-chemical parameters and the use of plankton as indicators of water quality to provide baseline limnology data in Molepo Dam and Hout River Dam. This dissertation has been divided into five chapters.

Chapter 1

The chapter introduced the problem statement and also highlighted the aim of the study.

Chapter 2

The literature on the effects of water level fluctuations on water quality, plankton dynamics and fish species of aquatic ecosystems was reviewed in this chapter.

Chapter 3

Physico-chemical parameters were used to determine the water quality status of Molepo Dam and Hout River Dam. The effect of water level fluctuations on water quality was determined in both small dams. Seasonal variation in physico-chemical parameters were also assessed.

Chapter 4

This chapter assesses the use of plankton as bio-indicators of water quality and further determined the composition, abundance and diversity of phytoplankton and zooplankton in Molepo Dam and Hout River Dam.

Chapter 5

This chapter determined the composition and abundance of fish species in Molepo Dam and Hout River Dam. The chapter further determined fish age and growth of *Oreochromis mossambicus* in both small dams.

CHAPTER 2: LITERATURE REVIEW

2.1 Effects of water level fluctuations on water quality

The effects of water level fluctuations on water quality have been widely studied in aquatic ecosystems (Wantzen *et al*., 2008; Zohary and Ostrovsky, 2011; Keitel *et al*., 2016; Utete *et al*., 2018; Kann and Walker, 2020). South Africa's shallow water bodies experience wide water level fluctuations due to annual rainfall variations and anthropogenic activities. Water level fluctuations affects water quality parameters such as pH, alkalinity, conductivity, total dissolved solids, total suspended solids, total nitrogen, total phosphorus and transparency. In two small dams on the Munwahuku River, Zimbabwe, Nhiwatiwa and Marshall (2007) reported that conductivity was high during the dry season when water levels were low. Transparency increased with increasing water level due to effects of the first rain, while increases in biological oxygen demand and chemical oxygen demand suggested increased organic matter at low water levels. Total nitrogen concentrations also increased at low water levels. A similar study in Malilangwe, Zimbabwe, where nutrient concentrations varied throughout the season due to water level fluctuations showed that total nitrogen and total phosphorus concentrations were considerably high when water levels were low (Dalu, 2012). However, a different study in selected small dams of the upper Vaal catchment in South Africa showed that water level fluctuations and high rainfall had very little effect in changing total nitrogen and total phosphorus concentrations to cause a change in water quality status. The study further reported that only water quality parameters such as fluoride and sulphate in selected sampling sites showed an increase in concentration during water level fluctuations (Merolla, 2011). This contradictory results make it imperative to carry out further investigation on small dams in South Africa.

Thermal stratification also plays a major role in the limnology of small dams. The effect of water level fluctuation on thermal stratification of a small dam (Kouris Dam) in Cyprus has been assessed (Ma *et al*., 2008). Thermal stratification and water temperature profiles were noticeably affected by water withdrawal schemes. The study found that deep-water withdrawals tend to facilitate heat transfer in the water column and deepen the water mixing layer (epilimnion). A similar study in Three Gorges Reservoir, China, reported that high water level fluctuations deepened the thermocline depth (Jin *et al*., 2019). The hypoxia and anoxia initial depths increased during high water level due to rainfall events in Qiandaohu Reservoir, China, which were well related to the changes of mixing layer depths (Liu *et al*., 2020). There is no baseline information on the effect of thermal stratification on oxygen levels in Molepo Dam and Hout River Dam. This study will determine if thermal stratification occurs in Molepo Dam and Hout River Dam.

2.2 Effects of water level fluctuations on plankton

Planktonic communities have been used widely as biological indicators in assessing water quality and pollution status of aquatic ecosystems (Chellappa *et al*., 2009; Singh *et al*., 2013; Dorche *et al*., 2018). In three shallow wetlands in Aguhas Plain, KwaZulu-Natal, South Africa, Gordon *et al*., (2010) reported that Voëlvlei showed signs of eutrophication mainly due to the presence of cyanobacteria such as *Anabaena sp*. and *Trichomes species*. The study further reported that the dominance of cyanobacteria within Voëlvlei indicated poor water quality which was most likely due to a prolonged water retention time. A different study in a small man-made reservoir in Mzingwane catchment, Limpopo basin, Zimbabwe reported that the abundance of *Anabaena sp.* was not high enough to create an algal bloom (Basima, 2005). This supports observations made by Cander-Lund and Lund (1995) who reported that *Anabaena sp*. can be found in non-polluted waters.

In South Africa, studies on plankton ecology have concentrated on the plankton of larger dams such as Hartbeespoort Dam (Jarvis, 1986; Jarvis, 1987), Wagendrift Dam (Hart, 2001) and South African coasts (Lebourges-Dhaussy *et al*., 2009). Relatively little is known about plankton in the country’s small dams, with notable study being carried out by Thomas *et al*. (2005) in two eutrophic estuaries in KwaZulu-Natal. The plankton profile of both Molepo Dam and Hout River Dam have not been investigated before.

The effects of water level fluctuations on plankton dynamics have been studied in aquatic ecosystems worldwide (Ogbuagu and Ayoade, 2012; Bakker and Hilt, 2016; Alfonso *et al*., 2017). Wang *et al*. (2011) assessed the effect of water level fluctuations on phytoplankton dynamics in Three Gorges Reservoir, China. The study reported that under high water level fluctuations, *Microcystis aeruginosa* was the most dominant phytoplankton. Diatoms (*Aulacoseira granulate*) dominated the phytoplankton community followed by Cryptophyta (Cryptomonas spp.) in periods of low water levels and in periods of high water levels, the community was dominated by cyanobacteria (*Microcystis spp.*) in a Changjiang Dam, China (Liu *et al*., 2015). The effect of water level fluctuations on zooplankton was also assesses in Serra Serrada Reservoir, a small waterbody in Montesinho National Park, Portugal (Geraldes and Boavida, 2007). The study reported that Cladocera and Copepoda were dominant during high water level fluctuations with *Ceriodaphnia pulchella, Daphnia longispina, Diaphanosoma brachyurum, Bosmina longirostris* and *Copidodiaptomus numidicus* being the most abundant taxa. Among the Rotifers, *Keratella cochlearis, Conochilus sp.* and *Asplanchna priodonta* were also dominant when water levels were high. A similar study reported that zooplankton (rotifers and copepods) increased during the high water column, confirming that these groups as resilient and less sensitive to the variation in hydrological regime (Špoljar *et al*., 2018). However, such important limnological data lacks for Molepo Dam and Hout River Dam. It is thus important to investigate the effects of water level fluctuations on plankton.

2.3 Effect of season/water level fluctuations on fish composition

Water level fluctuations impair ecosystem functioning ultimately leading to shifts between the fish population (Zohary and Ostrovsky, 2011). The effects of water level fluctuations on the fish species communities has been studied in rivers, lakes and reservoirs (Fernandes *et al*., 2009; deLima *et al*., 2017). Excessive water level fluctuations are often considered as the main hydrological stressor for fish communities inhabiting the littoral area of small water bodies (Sutela and Vehanen, 2008). The effect of water level fluctuations on six fish species (*Clarias gariepinus, Oreochromis mossambicus, Tilapia sparrmanii, Enteromius paludinosus and Enteromius lineomaculatus*) were assessed in two small reservoirs in Zimbabwe (Nhiwatiwa *et al*., 2017). *Clarias gariepinus* has the ability to survive extreme water conditions and tolerate wide water level fluctuations. *Enteromius lineomaculatus* and *Enteromius trimaculatus* occurred in small numbers, as well as *Oreochromis mossambicus* and *Tilapia sparrmanii* during low water level. A different study reported that *Tilapia rendalli* species was severely affected by water level fluctuations, being the least dominant fish species during low water levels (Dalu, 2012). Cott *et al*. (2008) noted a change in movement of largemouth bass (*Micropterus salmoides*) during water level fluctuations and normal conditions in a small reservoir. Micropterus salmoides was the most abundant fish species during the wet season when water levels were high. Despite the importance of Molepo Dam and Hout River Dam in the livelihoods of rural communities, there is no baseline information on the effects of water level fluctuation on fish.

CHAPTER 3: SEASONAL VARIATION OF PHYSICO-CHEMICAL PARAMETERS OF MOLEPO DAM AND HOUT RIVER DAM

3.1 Introduction

Physico-chemical analysis has been the prime consideration in assessing the water quality status in aquatic ecosystems (Jordaan and Bezuidenhout, 2012; Hamid *et al*., 2020). Physical and chemical parameters in an aquatic ecosystem are influenced by changes in water volume and depth during the wet and dry seasons due to water level fluctuations (Gownaris *et al*., 2018; Kann and Walker, 2020). The water level fluctuations in Molepo Dam and Hout River Dam can affect water quality both directly by altering the physical and chemical processes as well as indirectly by making conditions more conducive to cyanobacteria growth leading to poorer water quality. Water level fluctuations can also affect patterns of water column stability and mixing leading to modification of water temperature and dissolved oxygen dynamics in Molepo Dam and Hout River Dam. In addition, water level fluctuations altering cyanobacterial bloom dynamics may result in high pH during the growth process and hypoxia during the bloom decline periods (Kann and Walker, 2020).

Physical and chemical parameters in aquatic ecosystems are also affected by anthropogenic activities such as the use of fertilizers in agriculture, industrialization and sewage and mining effluent (Dalu *et al*., 2017). Any activities within a dam catchment has the potential to cause environmental changes. Excessive nutrient inputs from the catchment area can cause eutrophication. Small dams are more prone to eutrophication than large water bodies due to low flushing rates. Their small volume and changes in water level may influence the concentrations of total nitrogen and total phosphorus (Zohary and Ostrovsky, 2011).

Molepo Dam and Hout River Dam are relatively small shallow dams subjected to natural processes such as wide water level fluctuations. Though the main purpose of these dam’s construction was to supply irrigation water (DWS, 2016), other multiple designated uses comprising domestic water abstraction and fishing practices have evolved subsequently. Molepo Dam and Hout River Dam are built across seasonal rivers which dry up during the dry season and flood during the wet season. When this is integrated with loses of water due to abstraction for domestic uses and high evapotranspiration rates, pronounced water level fluctuations results in reduction of the dam’s storage capacity which has an effect on limnology. Wide water level fluctuations impair ecosystem functioning, ultimately leading to shifts between clear water and turbid states which is a threat to water quality (Utete *et al.,* 2018).

Nhiwatiwa (2004) reported that there is a historical bias in limnological investigations towards large water bodies that resulted in small water bodies not being studied. Water level fluctuations can cause seasonal variations in physical and chemical parameters in large water bodies and these are almost inevitably more extreme in small dams such as Molepo Dam and Hout River Dam. Although physico-chemical parameters of Hout River Dam were assessed by previous studies, the effects of water level fluctuations were ignored (Sara *et al*., 2013). Therefore, this study will assess seasonal variation of physico-chemical parameters and the effects of water level fluctuations on water quality of Molepo Dam and Hout River Dam.

3.2 Objectives and null hypothesis

3.2.1 *Objectives*

I. To determine seasonal variation of physico-chemical parameters in the Molepo and Hout River Dams
II. To determine the effects of water level fluctuations on water quality of Molepo and Hout River Dams.

3.2.2 *Null hypothesis*

I. There is no significant difference in seasonal variation of physico-chemical parameters in the Molepo and Hout River Dams
II. There is no effect of water level fluctuations on water quality of Molepo Dam and Hout River Dam.

3.3 Methods and materials

3.3.1 *Study areas*

The study was conducted at Molepo Dam and Hout River Dam in Limpopo Province, South Africa. The study areas were visited monthly from May 2018 to April 2019.

Molepo Dam is located in the large rural area of Ga-Ramphere, Capricorn District, approximately 35 km South East of Polokwane (24°0.56.0’ S, 29°46.30.1’ E) (Figure 1). The dam is accessible from Polokwane-Tzaneen tar road (R71). It was designed by the Department of Water Affairs and was constructed in 1987. The maximum dam wall height is 6.5 metres with a mean depth of 10.8 metres. At full supply level, the storage capacity was 4.52 million cubic metres and the surface area of 10 867.5 m^2 (DWS, 2016) fed by the Mphogodima River. Molepo Dam has a catchment area of approximately 125.43 km^2 and comprises of 54% built-up area, 27% arable land (crops), 10% forest and 9% livestock activity (FAO, 2016).

Hout River Dam is located near Ga-Mamadila Village, Capricorn District, 30 km North West of Polokwane (23°47'32.0'' S, 29°13'39.21'' E) (Figure 2). The dam is accessible from the Seshego-Moletji road. It was also designed by the Department of Water Affairs and was constructed in 1988. The maximum dam wall height is 10 metres with a mean depth of 18.2 metres. At full supply level, the storage capacity was 6.92 million cubic metres and the surface area of 11 250 m^2 (DWS, 2016) fed by the Hout River. Hout River Dam is situated 1 257 metres above sea level and has a catchment area of approximately 130 km^2 that forms part of the Limpopo River System (DWAF, 2015) and comprises of 13% built-up area, 8% arable land (crops), 75% forest and 4% livestock activity (FAO, 2016).

Four sampling sites were selected along each dam. Site 1 is located in the river. Site 2 is where the river enters the dam (inlet), Site 3 is located in the middle of the dam next to the dam wall and Site 4 is where the dam ends (outlet) (Figure 3.1; Figure 3.2).

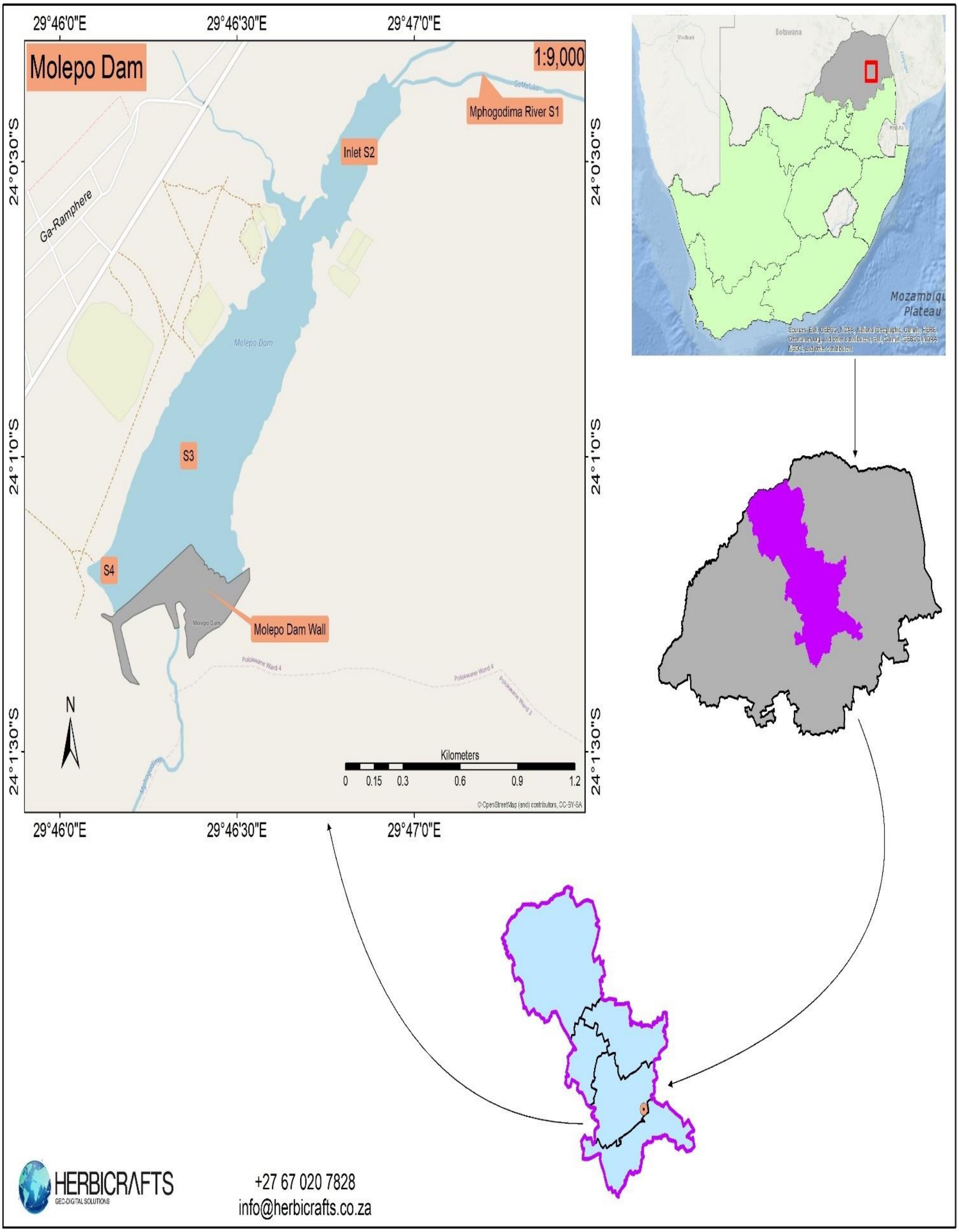


Figure 3.1: Map of the Molepo Dam showing sampling sites, Site 1 (S1), Site 2 (S2), Site 3 (S3) and Site 4 (S4).

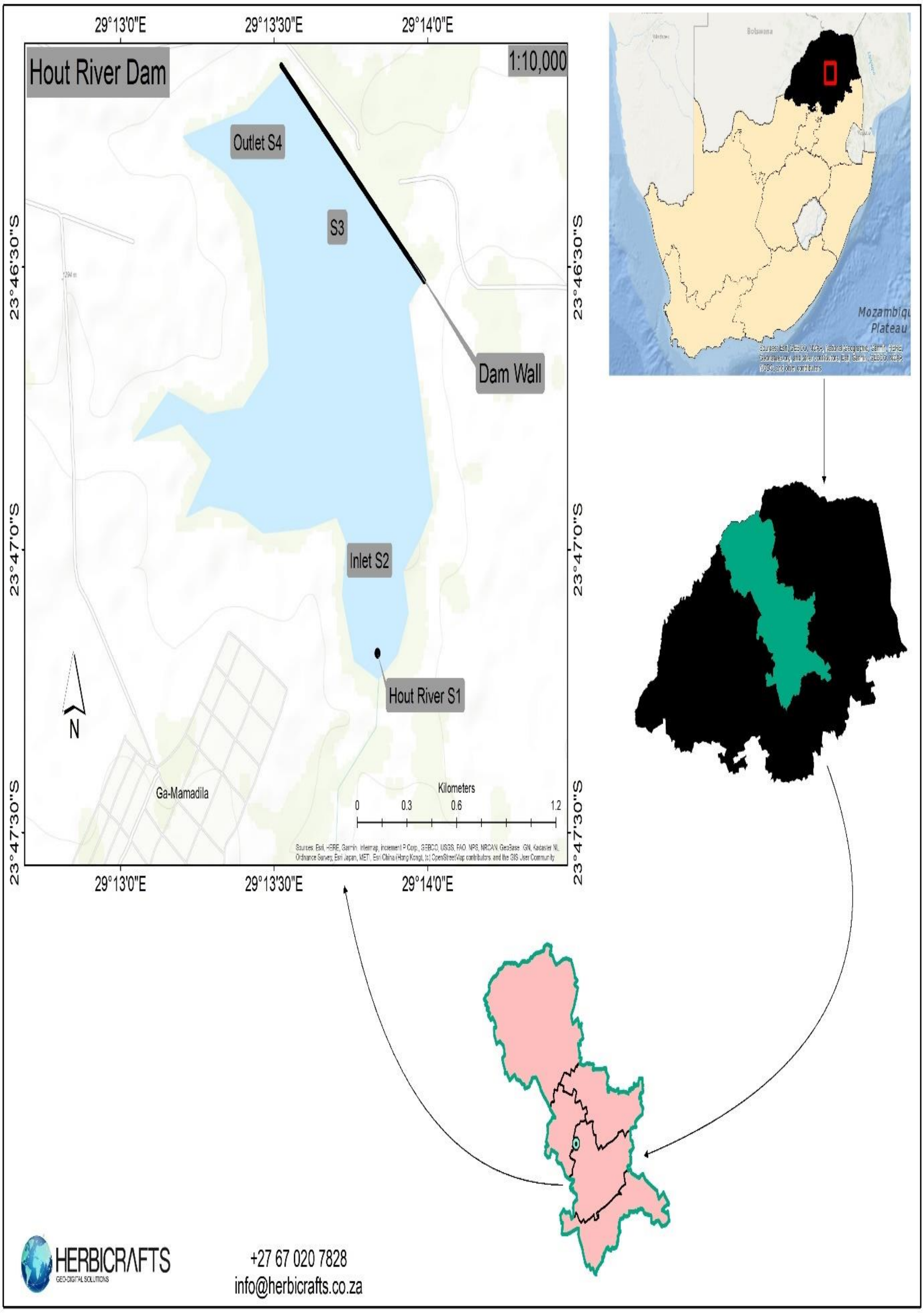


Figure 3.2: Map of the Hout River Dam showing sampling sites, Site 1 (S1), Site 2 (S2), Site 3 (S3) and Site 4 (S4).

3.3.2 *Physico-chemical parameters*

Water sampling was conducted once a month in Molepo Dam and Hout River Dam for a period of twelve months during the dry season (May to October 2018) and wet season (November- April 2019). Four sampling sites were selected at each dam. Water temperature (°C), pH, dissolved oxygen (mg/L) and electrical conductivity (mS/cm) were measured *in situ* using a multi-probe YSI meter (MPS 556). Turbidity (NTU) was measured using a Horiba U23 multi-probe meter (Horiba, Osaka, Japan) and the water flow rate was quantified using a flow rate meter (Xplorer PASpont PS-2000). Water transparency was measured *in situ* using a secchi disk (cm) according to standard methods (Wetzel, 1983). The disk was slowly lowered into the water to the point where the four quadrants on the secchi disk could no longer be distinguished. This point would be the secchi disk depth. Polyethylene sampling bottles (1L) washed with distilled water were used to collected water samples at each site in both dams. The water samples were collected just below the surface at a depth of 10 cm and stored in ice during transportation from the sampling site to the University of Limpopo, Aquaculture Research Unit (ARU) Laboratory. These water samples were to analyse for nitrate according to American Public Health Association (APHA, 2005), total nitrogen, total phosphorus and total alkalinity as $CaCO_3$ and chlorophyll-a.

Total Nitrogen as N

Total nitrogen was determined according to spectroquant nitrogen test 1.14537.0001. In this method, organic and inorganic nitrogen compounds are transformed into nitrate according to Koroleff's method by treatment with an oxidizing agent in a thermoreactor. In concentrated sulfuric acid, this nitrate reacts with a benzoic acid derivative to form a red nitro compound that is determined photometrically.

Total Phosphorus as P

Total phosphorus was determined according to spectroquant 1.14848.0001. In this method, phosphorus in solution is acidified with sulfuric acid, reacts with molybdate ions to form molibdofosforic acid, was reduced by ascorbic acid phosphomolybdic blue

(PMB) which was determined photometrically. This method is analogous to ISO 6878/1-2005 method and is used to determine orthophosphates and phosphate.

Total alkalinity

Total alkalinity was determined according to the US Standard Methods 2320 B. This method is based on the principle that hydroxyl ions present in a sample as a result of dissociation or hydrolysis of solutes react with additions of standard acid. Alkalinity thus depends on the end point pH used, 0. 02 N sulfuric acid is titrated to an end point of pH 4.5 using methyl red as an indicator.

Chlorophyll-a

The polyethylene sampling bottles (1L) were used to collect water samples at a 0.5 m depth at different sites in both dams. The water sample bottles were then wrapped in foil immediately after sampling and were kept in ice during transportation from the sampling sites to Aquaculture Research Unit (ARU) Laboratory. Upon arrival at the lab, each sample was passed through an aspirator connected filter. The filter was then transferred into glass containers filled with 5 ml of 90% methanol. Samples were then placed in a bath of water maintained at 75°C for 4 minutes to destroy the cell integrity and free the chlorophyll molecules. Containers were then wrapped in aluminium foil and placed in the refrigerator for 18 hours. The extract was then transferred into centrifuge tubes and centrifuged at 4 000 rpm for 10 minutes to remove any remnants of the filter. The supernatant was removed and absorbencies were read using a HACH DR/200 spectrophotometer at 650 and 665 nm, methanol was used as a blank. Chlorophyll-a was then calculated according to the formula:

$C_a = 15.65\ A_{650}-7.340\ A_{665}$

Where: C_a = chlorophyll-a

3.3.3 *Water level fluctuations*

Water level fluctuations were measured once a month using a measuring tape and fish finder (NAK18850B). The measurements were captured from the dam wall which was the reference location in both Molepo Dam and Hout River Dam. The maximum dam wall height of Molepo Dam and Hout River Dam is 6.5 and 10 meters respectively.

3.3.4 *Data analysis*

One-way analysis of Variance (ANOVA) on the Statistical Package and Service Solutions (SPSS version 20.5) was used to determine the significant difference of physico-chemical parameters between sampling sites in Molepo Dam and Hout River Dam. Normality and homogeneity of variance of all water quality parameters was tested using the Shapiro-Wilk normality test. A linear regression analysis was used to ascertain the effect of water level fluctuations on nitrogen, phosphorus, turbidity and chlorophyll-a in Molepo Dam and Hout River Dam. Carlson Trophic State index was used to determine the trophic status of Molepo Dam and Hout River Dam. The Carlson Trophic State index (Carlson, 1977):

$$\mathbf{TSI = 10(6 - \log 2\ SD)}$$

Therefore,

$$CTSI = [TSI\ (TP) + TSI\ (CA) + TSI\ (SD)] / 3\ TP$$

Where: TP = Total phosphorus in mg/L, CA = Chlorophyll-a in mg/L, SD = Secchi disk transparency in meters. The table below represents the Carlson trophic state index values and classification:

TSI	**Trophic status**	**Attributes**
<30	Oligotrophic	Clear water, oxygen throughout the year in the hypolimnion
30-40		Hypolimnia of shallow lakes may become anoxic
40-50	Mesotrophic	Water moderately clear, increasing probability of hypolimnetic anoxia during summer
50-60	Eutrophic	Anoxia hypolimnia, macrophytes problems possible
60-70		Blue-green algae dominate, algal scum and macrophytes problems
70-80	Hypereutrophic	Light limited production, dense algae and macrophytes
>80		Algal scum, few macrophytes

3.4. Results

3.4.1 *Physico-chemical parameters used to assess the water quality status of Molepo Dam and Hout River Dam.*

Total phosphorus and total nitrogen concentrations were lower at all sampling sites in the wet season (Table 3.1) than in the dry season (Table 3.2) in Molepo Dam and Hout River Dam. There was a significant difference ($P<0.05$, ANOVA) in total phosphorus and total nitrogen concentrations in both dams (Table 3.1). Sampling sites had no significant difference ($P>0.05$, ANOVA) in pH, dissolved oxygen (DO), electrical conductivity (EC) and alkalinity as $CaCO_3$ levels in Molepo Dam during the wet season. In Hout River Dam, sampling sites also had no significant difference ($P>0.05$, ANOVA) in pH, electrical conductivity and Alkalinity as $CaCO_3$ levels during the wet and dry seasons (Table 3.1 and 3.2).

Secchi disk transparency fluctuated across the different sampling sites. Secchi disk mean readings were lowest (26 cm) at Site 2 followed by Site 1 with a mean reading of 36.5 cm; Site 3 had the highest mean reading (95.5 cm) in Hout River Dam during the wet season (Table 3.1). These values corresponded with the turbidity levels which were highest at Site 2 with an average of 33.9 Nephelometric Turbidity Units (NTU) and Site 1 had an average of 28 NTU, and the lowest turbidity levels were recorded at Site 3 with 25.1 NTU. There was no significant difference ($P>0.05$, ANOVA) in turbidity between the sampling sites in Hout River Dam during the wet season (Table 3.1). However, there was a significant difference ($P<0.05$, ANOVA) in secchi disk levels between the sampling sites in Molepo Dam and Hout River Dam during the wet and dry seasons (Table 3.1 and 3.2).

Table 3.1: Physico-chemical parameters measured at four (4) sampling sites in Molepo and Hout River Dams during the wet season (Nov 2018-Apr 2019) indicated as the mean ± SD. Means with different superscripts are significantly different (ANOVA, P<0.05)

	Molepo Dam				**Hout River Dam**				**TWQR***
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	
Parameters									
Temp (°C)	$21.28±0.35^a$	$22.57±0.33^a$	$25.00±0.53^b$	$24.35±0.53^b$	$20.30±0.34^a$	$22.50±0.71^a$	$23.32±0.91^b$	$24.20±0.36^b$	5-30
Ph	$7.49±0.34^a$	$7.61±0.23^a$	$7.66±0.22^a$	$7.71±0.19^a$	$7.75±0.41^a$	$7.71±0.41^a$	$7.80±0.15^a$	$7.67±0.22^a$	6-8
DO (mg/L)	$4.82±0.07^a$	$3.72±0.05^a$	$5.00±0.15^a$	$4.29±0.06^a$	$4.53±0.11^a$	$1.32±0.02^b$	$4.63±0.33^a$	$4.43±0.07^a$	4-5
Turbidity (NTU)	$29.2±0.70^a$	$10.5±0.30^b$	$5.71±0.05^c$	$8.72±0.07^c$	$28.0±16.9^a$	$33.9±0.12^a$	$25.1±0.12^a$	$26.4±0.91^a$	-
EC (mS/cm)	$0.753±0.14^a$	$0.748±0.14^a$	$0.744±0.13^a$	$0.744±0.13^a$	$0.380±0.05^a$	$0.355±0.08^a$	$0.352±0.03^a$	$0.352±0.03^a$	-
Secchi disk (cm)	$89.0±1.05^a$	$32.0±0.12^b$	$114±1.08^c$	$77.0±1.06^a$	$36.5±1.09^a$	$26.0±1.60^b$	$95.5±2.20^c$	$37.5±1.02^a$	-
Nitrate (mg/L)	$1.10±0.04^a$	$0.06±0.02^b$	$0.13±0.05^b$	$0.11±0.04^b$	$0.61±0.03^a$	$0.10±0.02^b$	$0.13±0.03^b$	$0.05±0.01^c$	-
Total Phosphorus (mg/L)	$1.00±0.08^a$	$0.80±0.02^a$	$0.20±0.02^b$	$0.30±0.04^b$	$1.40±0.03^a$	$1.20±0.02^a$	$0.16±0.04^b$	$0.28±0.06^b$	<0.005
Total Nitrogen (mg/L)	$1.68±0.05^a$	$1.30±0.08^a$	$0.53±0.32^b$	$1.20±0.08^a$	$1.73±0.29^a$	$1.20±0.07^a$	$0.65±0.20^b$	$0.76±0.47^b$	<0.5
Chlorophyll-a (µg/L)	$1.25±0.63^a$	$2.50±2.42^b$	$3.00±0.40^b$	$1.00±0.02^a$	$1.51±1.08^a$	$2.61±2.59^b$	$4.30±4.27^c$	$4.02±3.46^c$	-
Alkalinity ($CaCO_3$)	$135.6±3.57^a$	$126.3±2.69^a$	$123.6±2.37^a$	$134.6±4.26^a$	$115.6±1.56^a$	$118.4±1.84^a$	$119.5±1.95^a$	$119.1±1.92^a$	-

*Target Water Quality Range (TWQR) for aquatic ecosystems (DWAF, 1996).

Table 3.2: Physico-chemical parameters measured at four (4) sampling sites in Molepo and Hout River Dams during the dry season (May-Oct 2018) indicated as the mean ± SD. Means with different superscripts are significantly different (ANOVA, P<0.05)

	Molepo Dam				**Hout River Dam**				**TWQR***
	Site 1	**Site 2**	**Site 3**	**Site 4**	**Site 1**	**Site 2**	**Site 3**	**Site 4**	
Parameters									
Temp (°C)	20.10±2.61^{a}	20.0±2.06^{a}	20.50±0.51^{a}	20.80±1.26^{a}	19.40±3.25^{a}	19.0±0.71^{a}	19.41±2.87^{a}	19.62±1.20^{a}	5-30
Ph	7.41±0.04^{a}	7.48±0.02^{a}	7.60±0.05^{a}	7.58±0.10^{a}	7.51±0.22^{a}	7.48±0.04^{a}	7.68±0.15^{a}	7.59±0.32^{a}	6-8
DO (mg/L)	1.42±0.07^{a}	2.41±0.05^{b}	4.45±1.95^{b}	3.25±0.06^{b}	1.75±1.32^{a}	1.95±0.06^{a}	3.87±0.03^{b}	1.32±0.01^{a}	4-5
Turbidity (NTU)	22.5±0.10^{a}	10.8±0.18^{b}	8.37±0.05^{b}	6.75±0.05^{b}	34.8±11.6^{a}	22.0±0.16^{b}	25.0±10.2^{b}	45.5±0.09^{a}	-
EC (mS/cm)	0.768±0.10^{a}	0.762±0.08^{a}	0.752±0.05^{a}	0.749±0.05^{a}	0.404±0.05^{a}	0.403±0.02^{a}	0.403±0.02^{a}	0.402±0.02^{a}	-
Secchi disk (cm)	45.0±0.32^{a}	10.0±0.05^{b}	70.0±1.03^{c}	50.0±0.06^{a}	25.0±0.09^{a}	26.0±1.04^{a}	65.0±0.02^{b}	27.5±0.12^{a}	-
Nitrate (mg/L)	1.15±0.02^{a}	0.11±0.04^{b}	0.20±0.05^{b}	0.14±0.04^{b}	0.19±0.02^{a}	0.30±0.03^{a}	0.22±0.04^{a}	0.10±0.02^{a}	-
Total Phosphorus (mg/L)	1.38±0.02^{a}	1.20±0.10^{a}	0.60±0.08^{a}	1.02±0.06^{a}	1.70±1.02^{a}	1.20±0.20^{a}	0.20±0.06^{b}	0.80±0.04^{a}	<0.005
Total Nitrogen (mg/L)	1.80±0.33^{a}	1.30±0.32^{a}	0.76±0.08^{a}	0.80±0.04^{a}	2.00±0.61^{a}	1.80±1.27^{a}	0.86±0.09^{b}	1.56±0.17^{a}	<0.5
Chlorophyll-a (µg/L)	1.67±0.10^{a}	2.84±0.08^{b}	4.72±0.31^{c}	2.61±0.12^{b}	1.73±0.09^{a}	2.91±0.17^{b}	4.53±0.57^{c}	4.11±0.91^{c}	-
Alkalinity ($CaCO_{3}$)	130.4±1.43^{a}	122.1±1.52^{a}	120.2±2.10^{a}	131.6±3.16^{a}	110.2±1.05^{a}	119.3±1.43^{a}	110.1±1.15^{a}	110.0±1.27^{a}	-

*Target Water Quality Range (TWQR) for aquatic ecosystems (DWAF, 1996)

Dissolved oxygen and temperature profiles were recorded for Site 3, which is the deepest point of the dam in both Molepo Dam and Hout River Dam. The dissolved oxygen concentrations decreased with increasing depth in the wet and dry seasons (Figure 3.3 and 3.4). The dissolved oxygen concentrations were lowest at 4.5 m in Molepo Dam and Hout River Dam during the wet season (Figure 3.3). The dissolved oxygen concentrations were higher at the surface layer and well distributed throughout the water column, however, they slightly dropped at 3.5 m in Molepo Dam and at 2.0 m in Hout River Dam during the dry season (Figure 3.4).

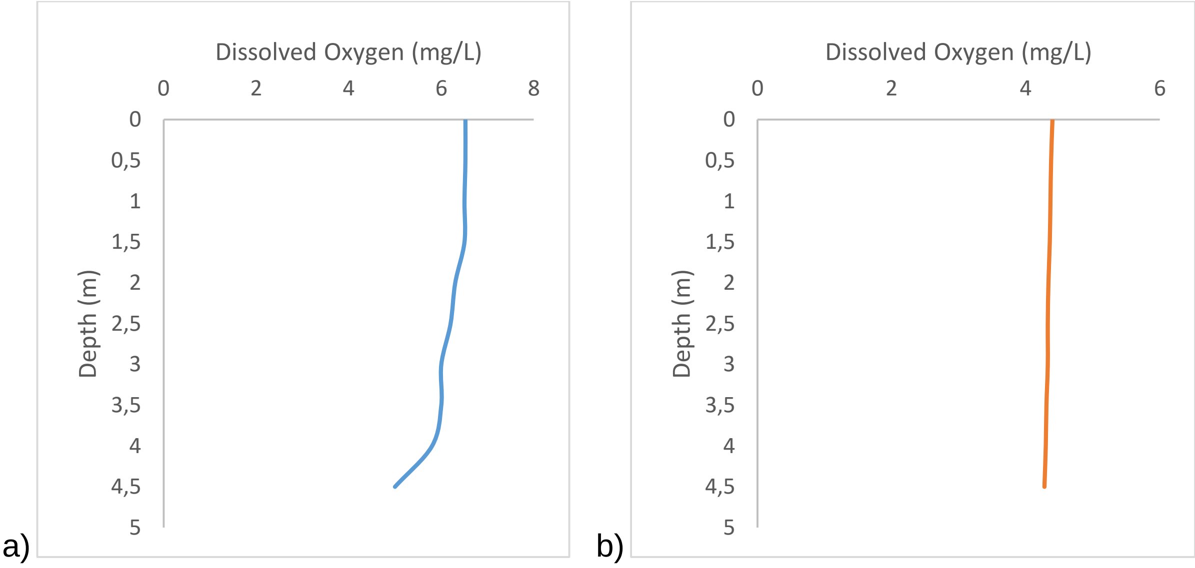


Figure 3.3: Dissolved Oxygen profiles at Site 3 in a) Molepo Dam and b) Hout River Dam during the wet season (Nov 2018-Apr 2019).

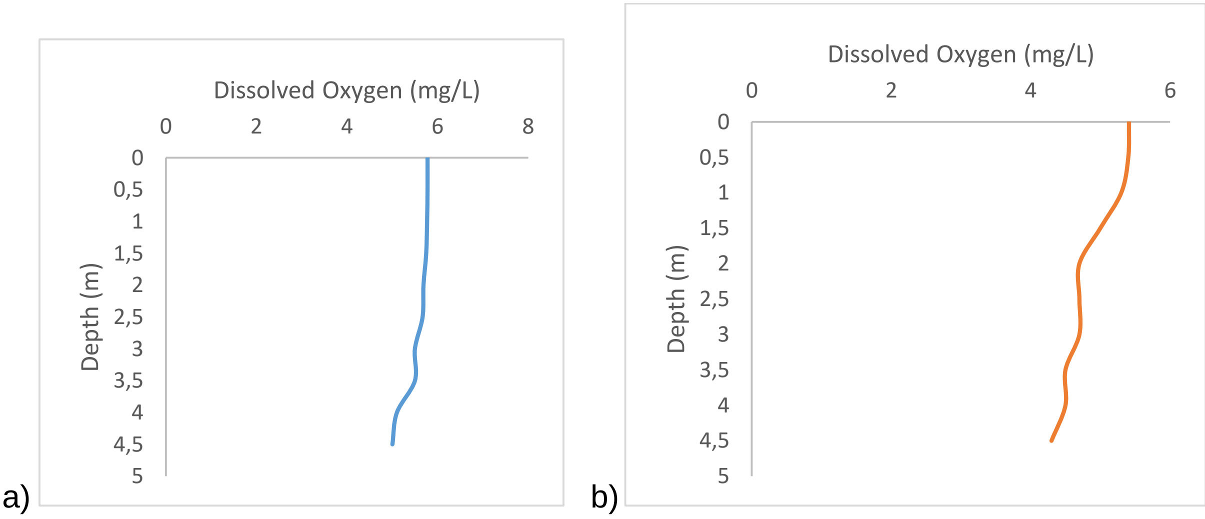


Figure 3.4: Dissolved Oxygen profiles at Site 3 in a) Molepo Dam and b) Hout River Dam during the dry season (May-Oct 2018).

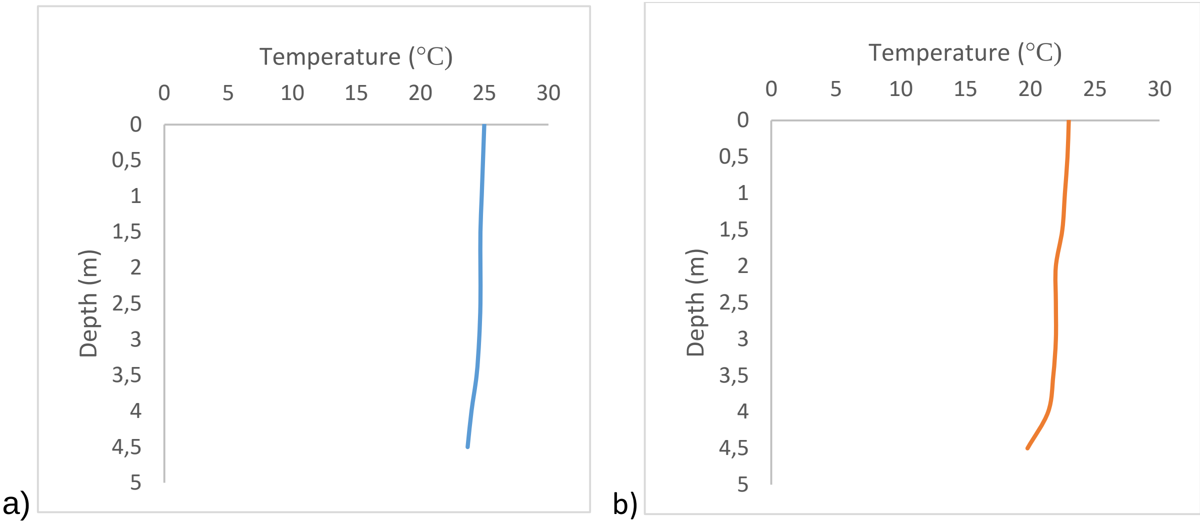


Figure 3.5: Temperature profiles at Site 3 in a) Molepo Dam and b) Hout River Dam during the wet season (Nov 2018-Apr 2019).

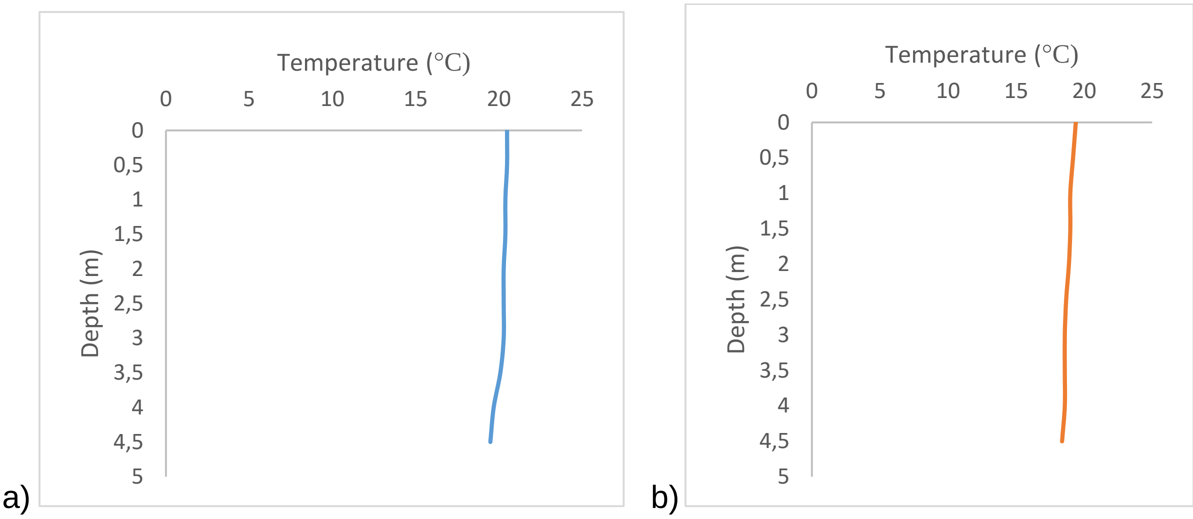


Figure 3.6: Temperature profiles at Site 3 in a) Molepo Dam and b) Hout River Dam during the dry season (May-Oct 2018)

The average temperature at Site 3 was relatively uniform throughout the water column during the wet and dry seasons in both Molepo Dam and Hout River Dam (Figure 3.5 and 3.6). The surface layer temperature was higher (25 and 23 °C) in the wet season (Figure 3.5), 20.5 and 19.4 °C in the dry season (Figure 3.6) for Molepo Dam and Hout River Dam respectively. However, a slight drop in temperature was observed at 4.5 m depth in Hout River Dam (Figure 3.5b). At the beginning of sampling period in May 2018, water temperature was 19 and 18.4 °C in Molepo Dam and Hout River Dam respectively (Figure 3.7) but for Molepo Dam, there was a peak increase (27 °C) in March during the wet season.

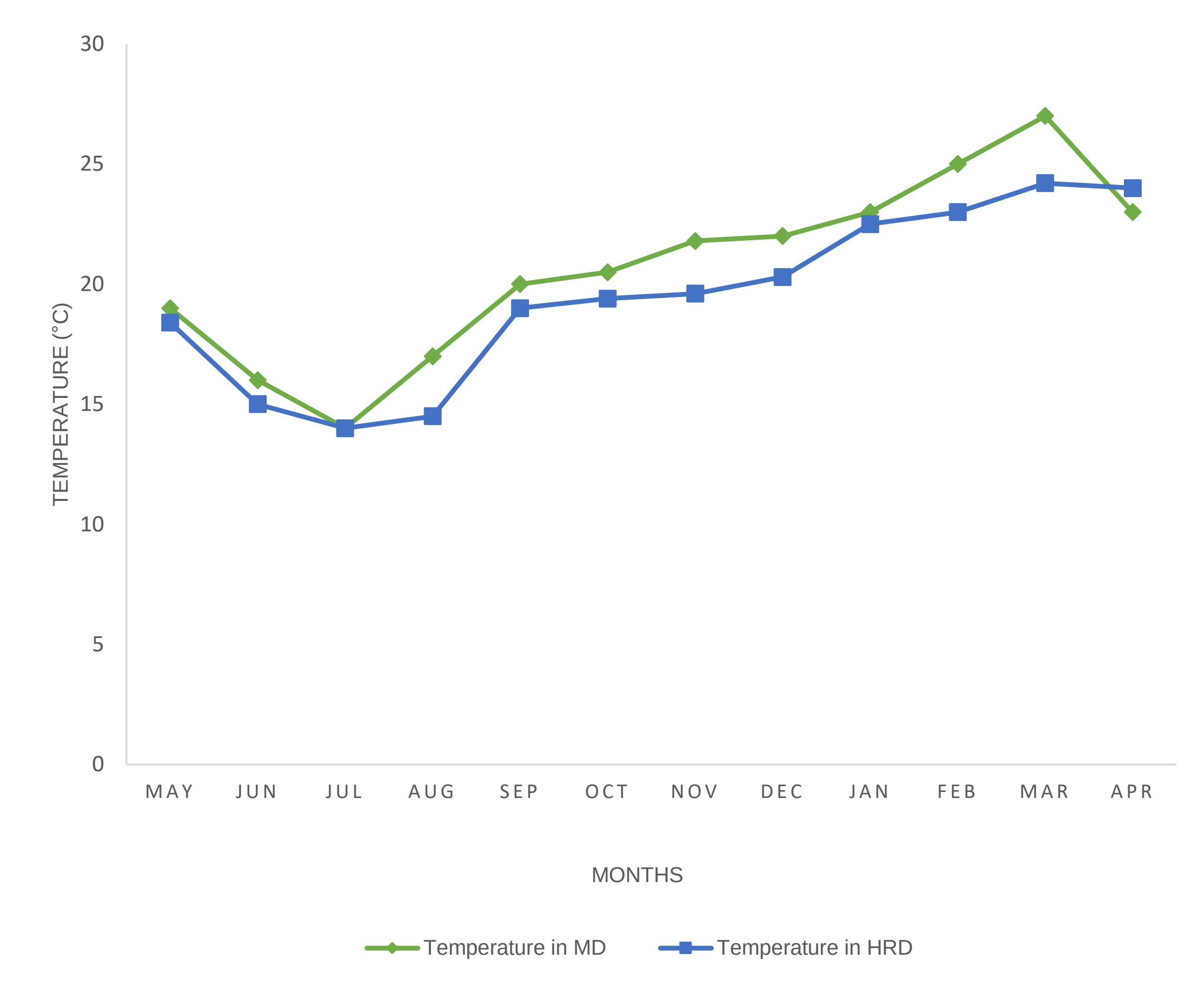
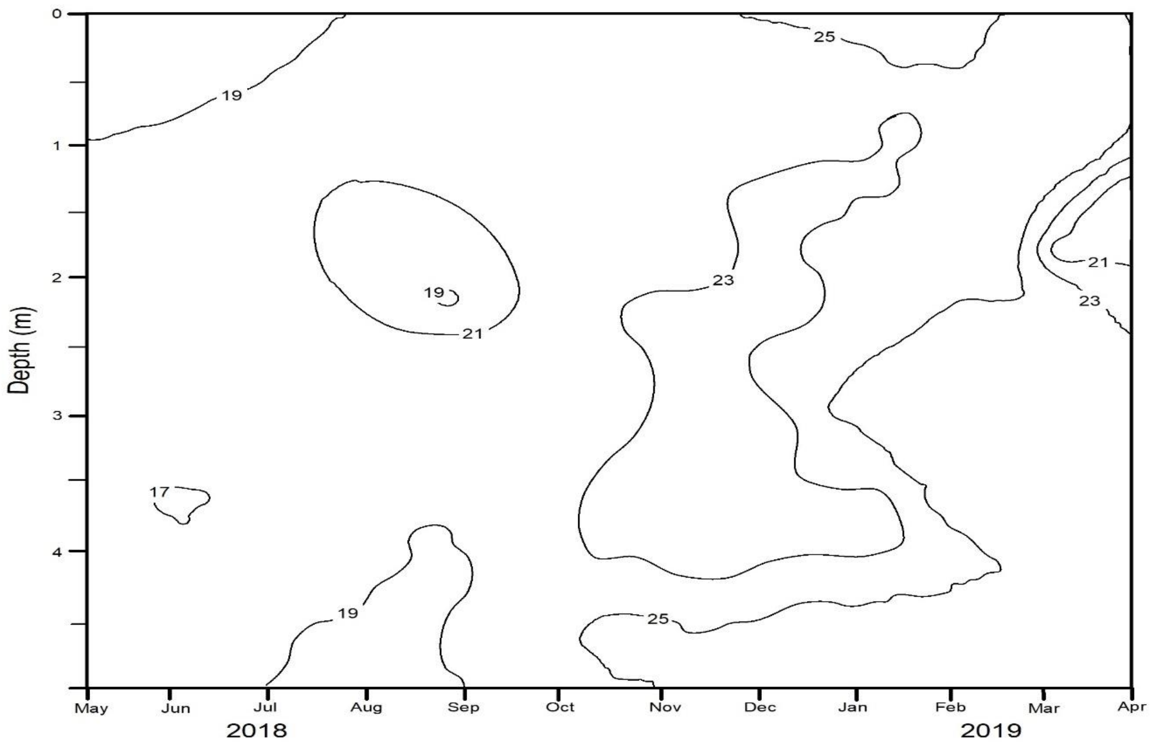


Figure 3.7: Monthly results for water temperature (°C) in Molepo Dam (MD) and Hout River Dam (HRD) from May 2018-April 2019

The thermocline was not well developed in both Molepo Dam (Figure 3.8a) and Hout River Dam (Figure 3.9a). During the wet season months (Nov to Apr), the water column remained slightly stable. Molepo Dam and Hout River Dam experienced little to no turnover whereby the water temperature at the surface of the dam and the bottom were roughly the same. Thermal stratification was not observed in these small dams (Figure 3.8a and 3.9a). Dissolved Oxygen concentration patterns followed the temperature distribution in the water column for both Molepo Dam and Hout River Dam (Figure 3.8b and 3.9b). Dissolved oxygen stratification was not established in both dams. The surface water recorded higher water temperature values and dissolved oxygen concentrations, steadily decreasing with increasing depth recording slightly lower water temperature values and dissolved oxygen concentrations at the bottom in both Molepo Dam and Hour River Dam (Figure 3.8 and 3.9).

a)



b)

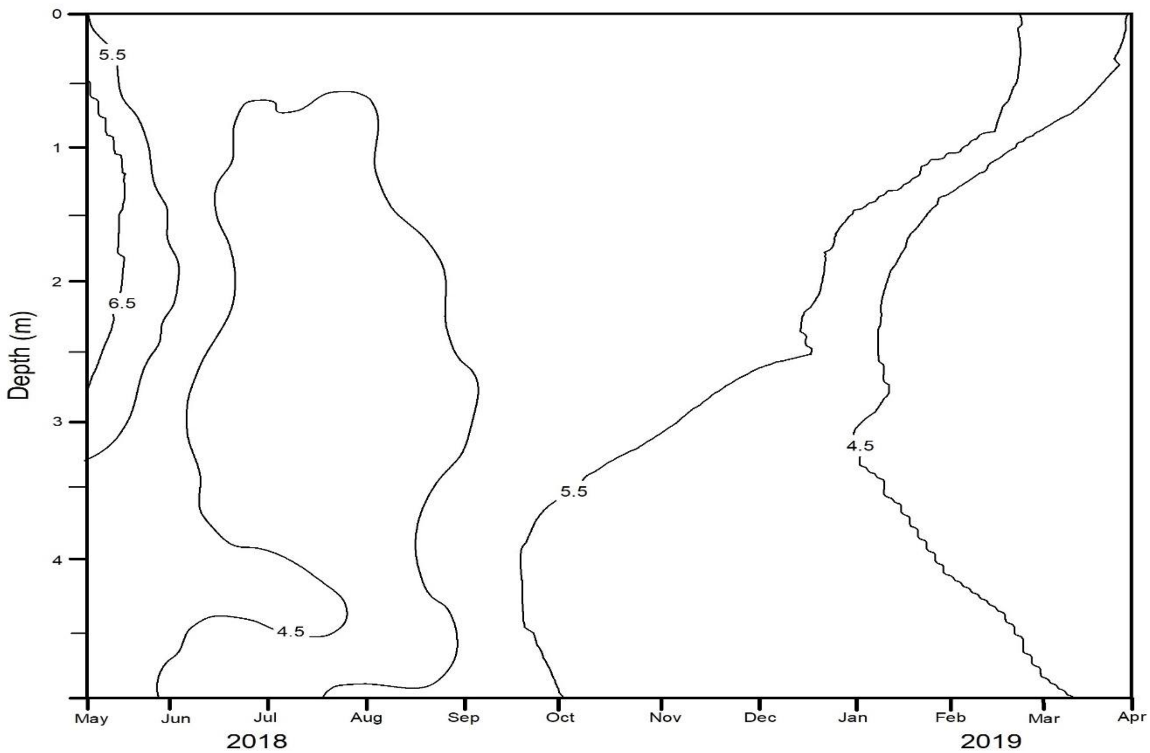


Figure 3.8: Contour plot of a) temperature (°C) and b) dissolved oxygen concentration (mg/L) with depth in Molepo Dam from May 2018 to April 2019.

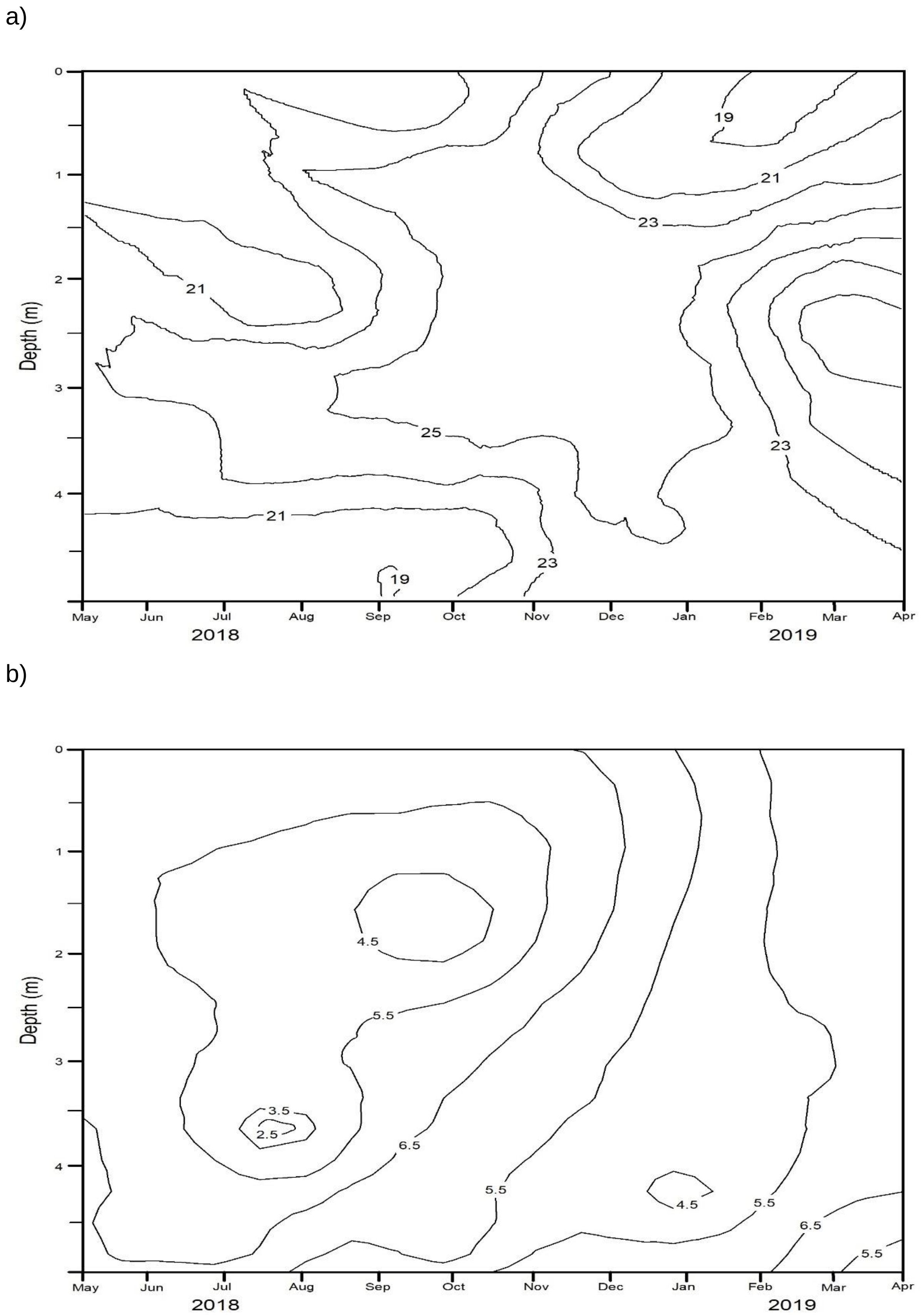
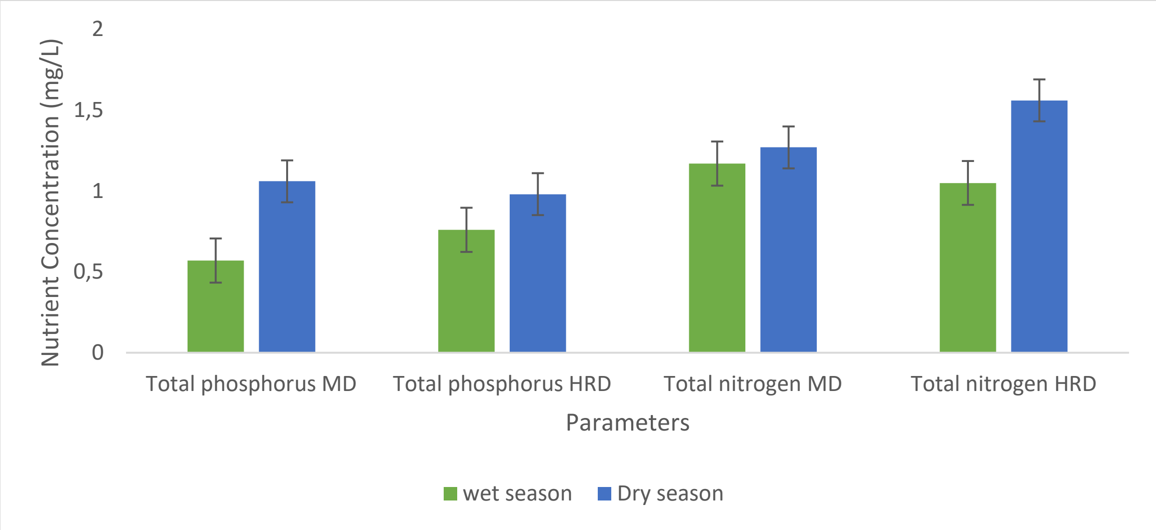
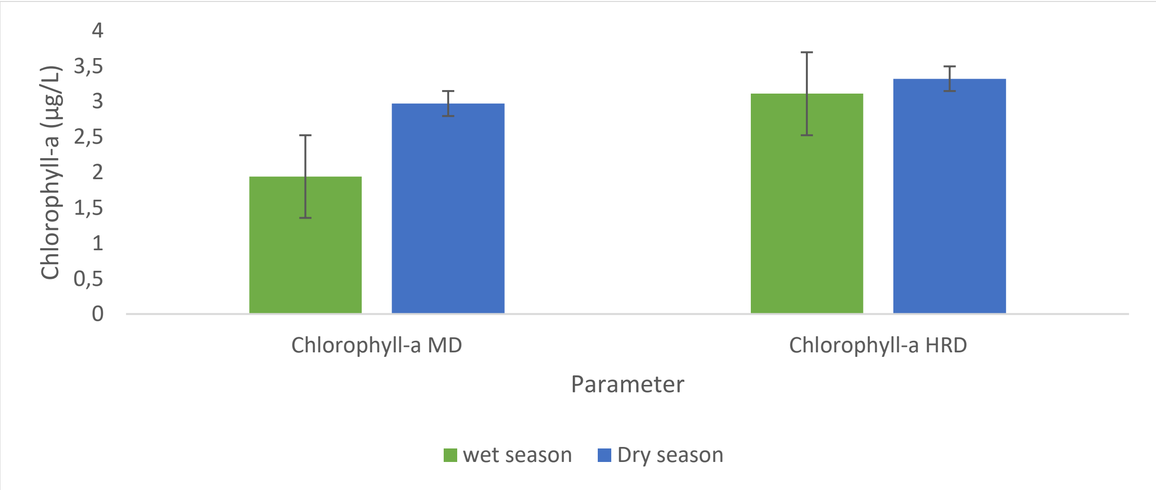


Figure 3.9: Contour plot of a) temperature (°C) and b) dissolved oxygen concentration (mg/L) with depth in Hout River Dam from May 2018 to April 2019.



a)



b)

Figure 3.10: Seasonal variation in a) total phosphorus, total nitrogen and b) chlorophyll-a concentrations in Molepo Dam and Hout River Dam between the wet and dry season

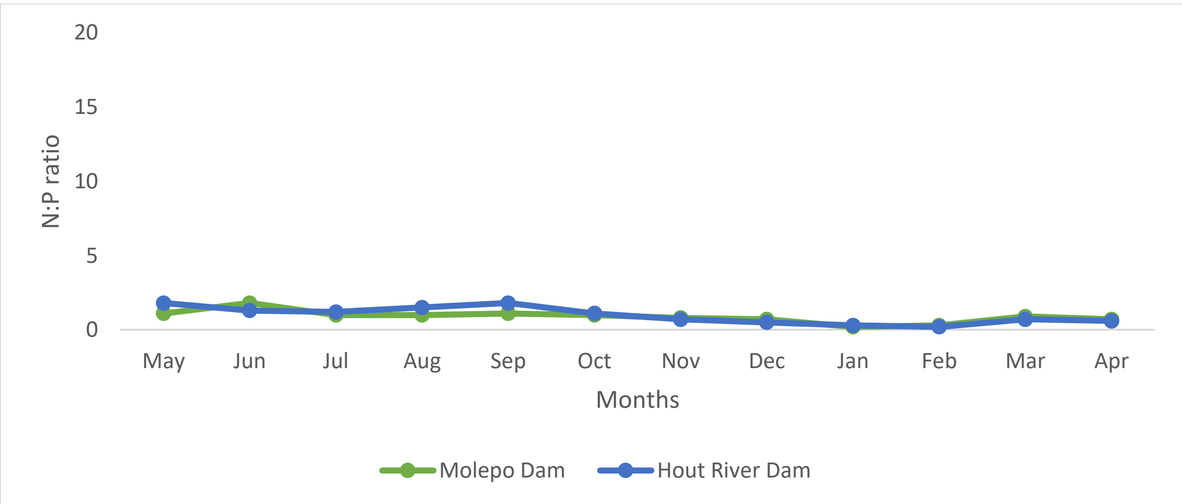


Figure 3.11: N: P ratio in Molepo Dam and Hout River Dam from May 2018 to April 2019

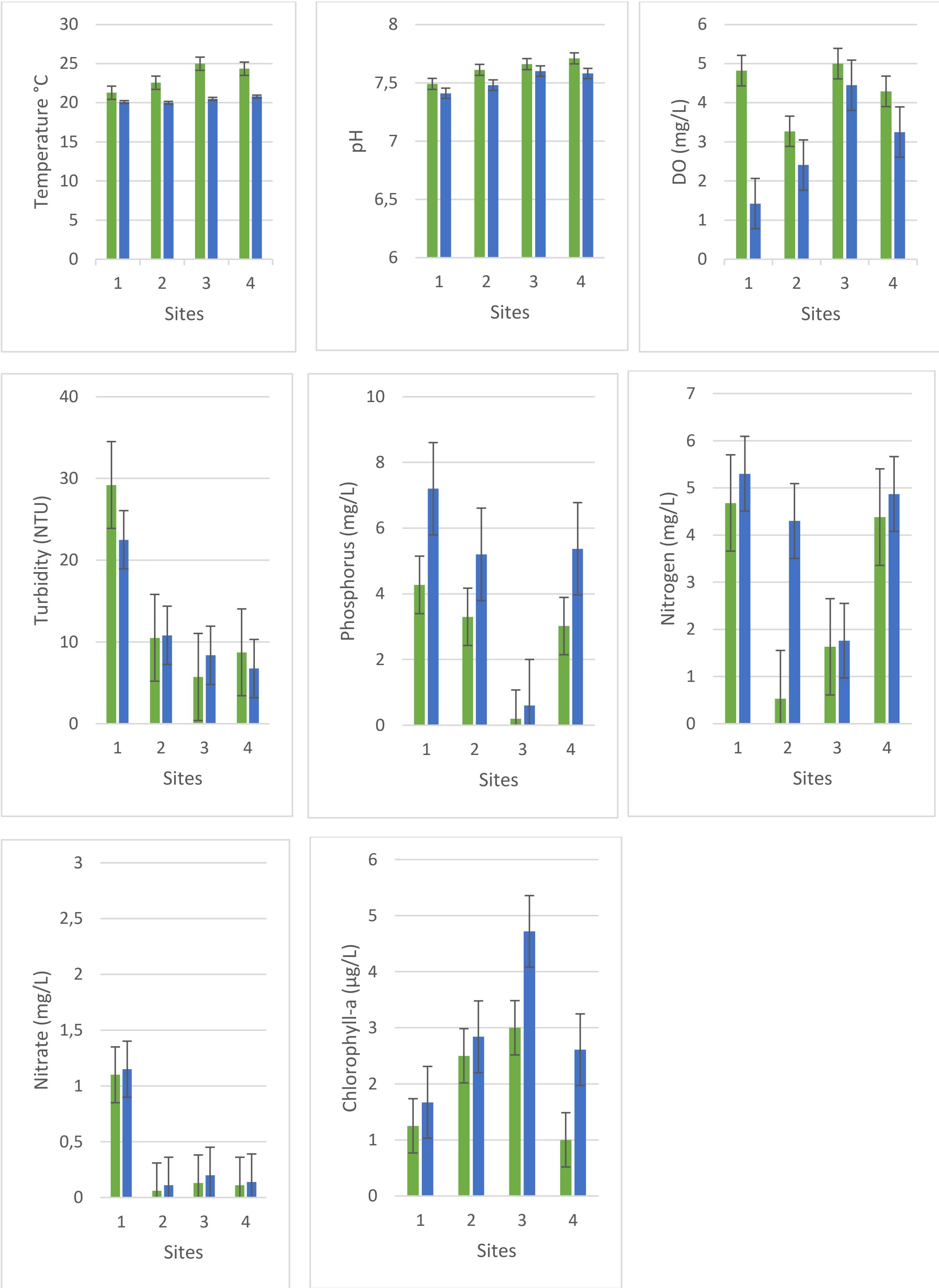


Figure 3.12: Physico-chemical parameters indicating seasonal variation between the wet season (green bars) and dry season (blue bars) at different sampling sites in Molepo Dam.

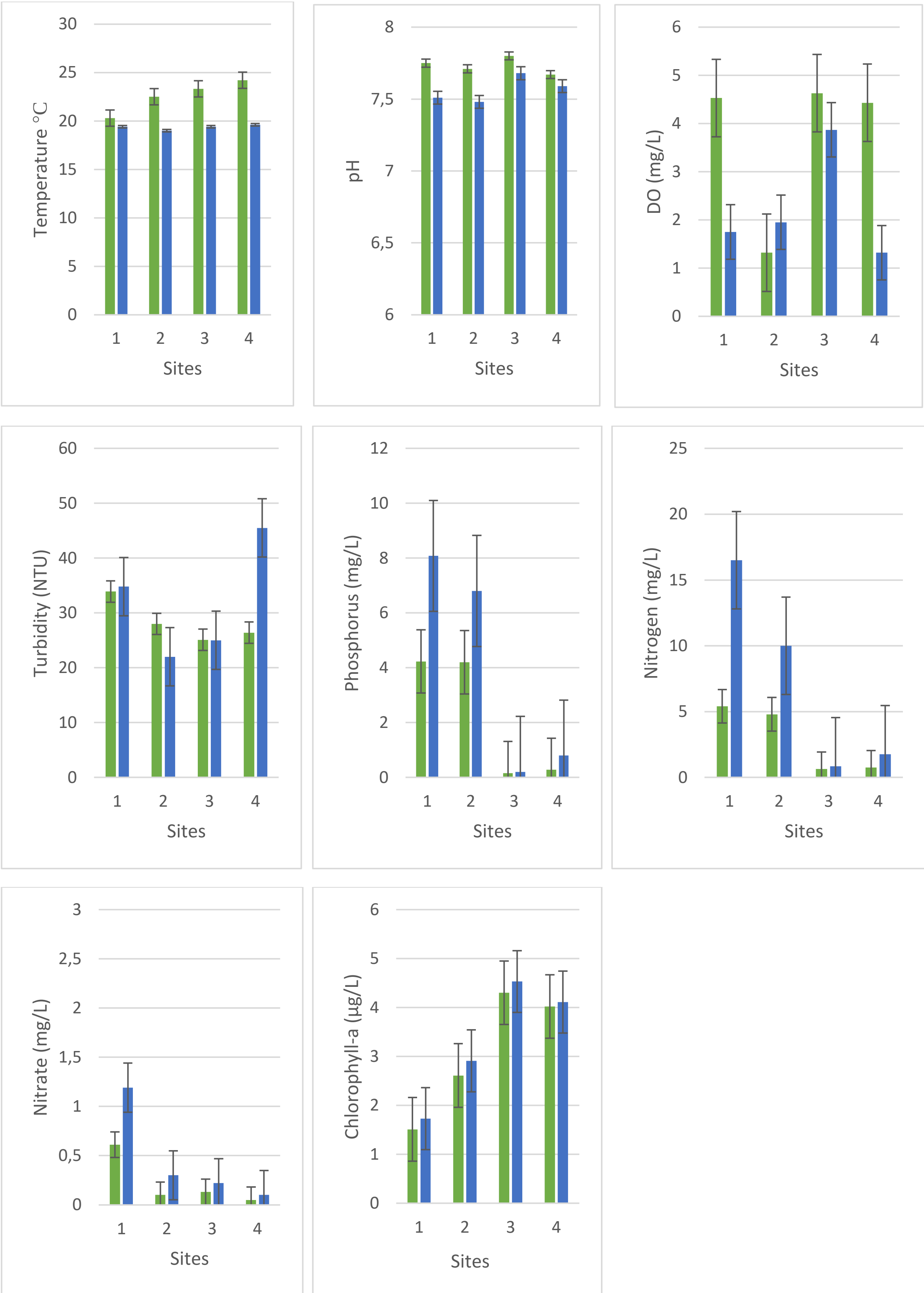


Figure 3.13: Physico-chemical parameters indicating seasonal variation between the wet season (green bars) and dry season (blue bars) at different sampling sites in Hout River Dam.

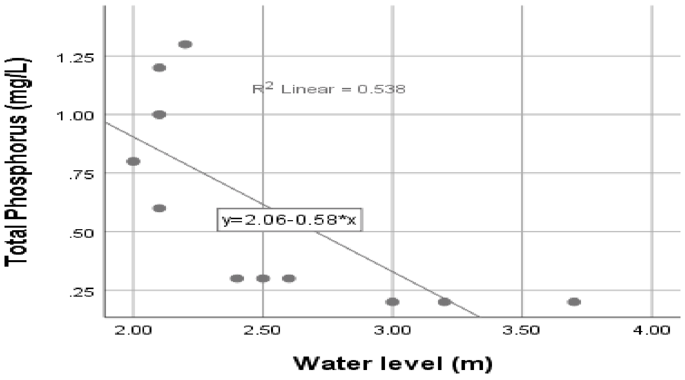
All assessed physico-chemical parameters showed seasonal variation between the wet season and the dry season with the exception of pH. The mean total phosphorus (1.06 and 0.98 mg/L), total nitrogen (1.27 and 1.56 mg/L) and chlorophyll-a (2.97 and 3.32 µg/L) were higher in the dry season than wet season in Molepo Dam and Hout River Dam respectively (Figure 3.10). The N: P ratios were below 1 during the wet season months (Nov – Apr) in both Molepo Dam and Hout River Dam (Figure 3.11). The mean water temperature (25 and 23 °C), pH (7.6 and 7.8) and dissolved oxygen (5.0 and 4.6 mg/L) values at all sampling sites for the wet season were higher than the dry season values in Molepo Dam and Hout River Dam respectively (Figure 3.12 and 3.13).

3.4.2 *The effects of water level fluctuations on water quality parameters of Molepo Dam and Hout River Dam*

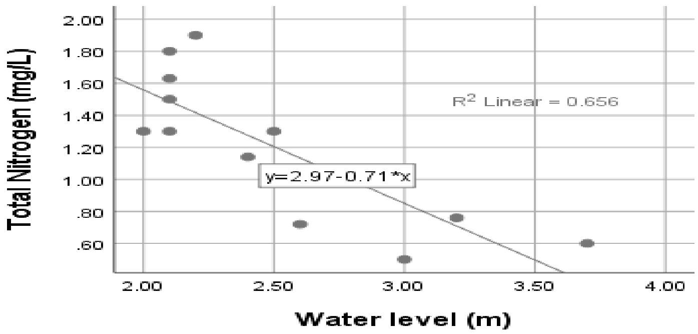
As the water level increased, total phosphorus concentration decreased in Molepo Dam (Figure 3.14a). There is a significant effect of water level on total phosphorus. Equally as water level increased, total nitrogen concentration decreased (Figure 3.14b) and there is a significant effect of water level on total nitrogen in Molepo Dam. As the water level increased, chlorophyll-a concentration decreased (Figure 3.14c). However, there is no significant effect of water level on chlorophyll-a in Molepo Dam. As the water level increased, turbidity also increased (Figure 3.14d). There is a significant effect of water level on turbidity in Molepo Dam.

In Hout River Dam, as the water level increased, total phosphorus concentration decreased (Figure 3.15a). However, there is no significant effect of water level on total phosphorus. As the water level increased, total nitrogen concentration decreased (Figure 3.15b) and there is a significant effect of water level on total nitrogen in Hout River Dam. As the water level increased, chlorophyll-a concentration (Figure 3.15c) and turbidity (Figure 3.15d) decreased. However, there is no significant effect of water level on chlorophyll-a and turbidity in Hout River Dam.

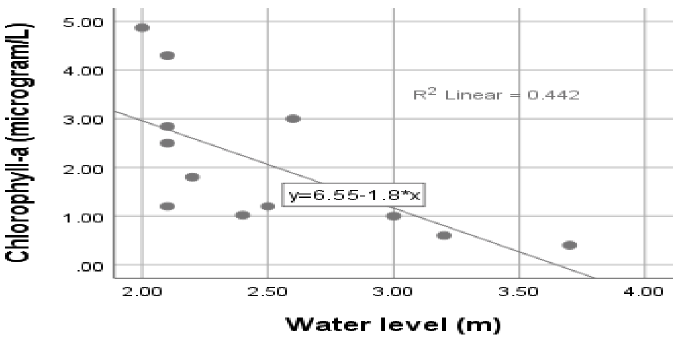
a)



b)



c)



d)

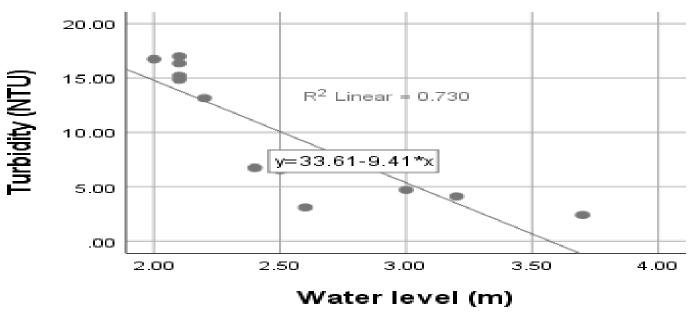


Figure 3.14: Linear regression analysis between water level fluctuations and a) Total phosphorus, b) Total nitrogen, c) Chlorophyll-a and d) Turbidity in Molepo Dam from May 2018- April 2019.

a)

b)

c)

d)

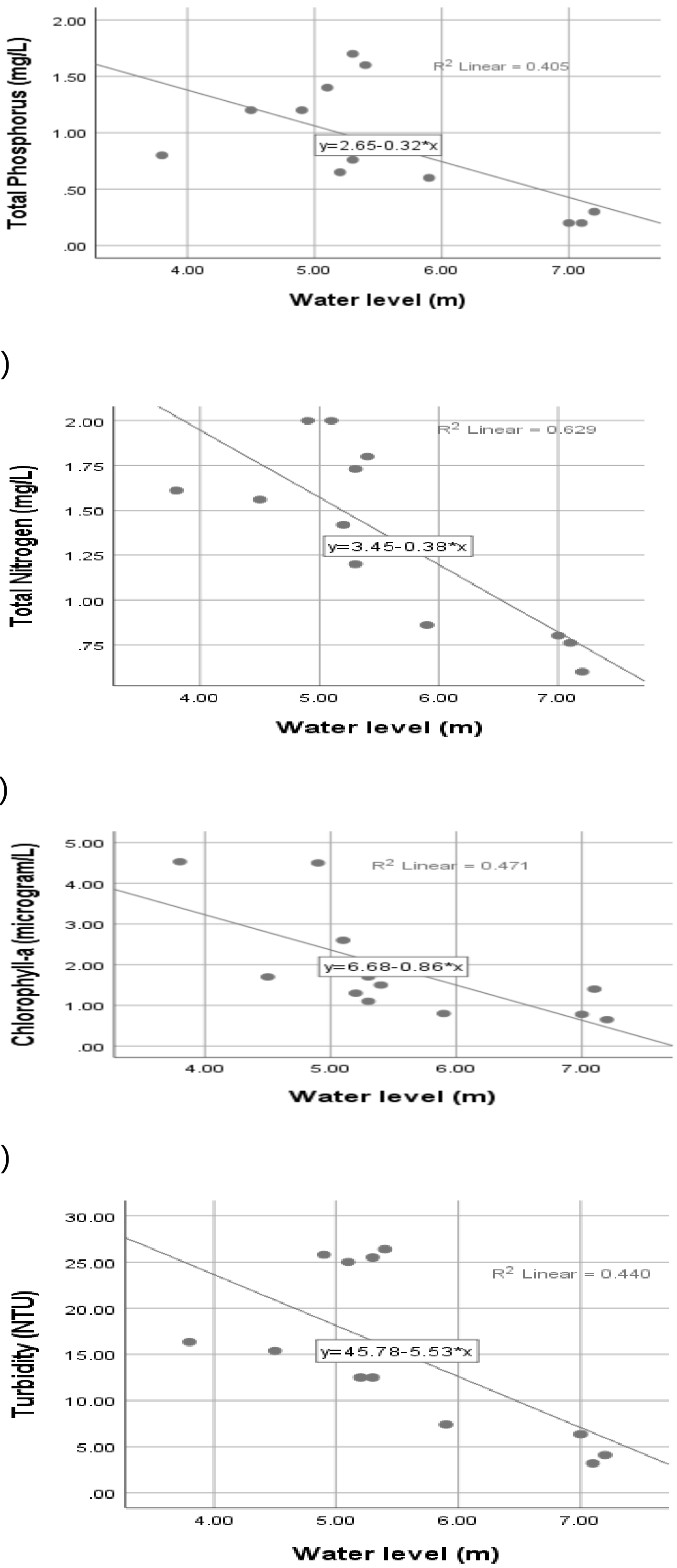


Figure 3.15: Linear regression analysis between water level fluctuations and a) Total phosphorus, b) Total nitrogen, c) Chlorophyll-a and d) Turbidity in Hout River Dam from May 2018- April 2019.

3.5 Discussion

Molepo Dam and Hout River Dam are situated in a semiarid region where rainfall is seasonal. This climatic condition affects water levels in small dams resulting in large decreases in the dry season (May-Oct) through high temperatures and drawdown. Seasonal variation in water quality parameters was observed in Molepo Dam and Hout River Dam. Total phosphorus, total nitrogen, chlorophyll-a, dissolved oxygen and nitrate recorded higher levels during the dry season than wet season. In Limpopo province, dry season is associated with low or lack of rainfall events which results to low water levels. This often results in high nutrients in small dams during the dry season. When nutrients are in excess, they stimulate the overgrowth of algae which leads to eutrophication. Van Ginkel (2011) reported that eutrophication has become an increasing threat to South African freshwater resources. Small dams are more prone to eutrophication than large water bodies. Their small volume and low flushing rates make them more susceptible to rapid eutrophication. Sara *et al*. (2013) reported that high levels of nitrate, nitrogen and phosphorus recorded during summer indicated eutrophication in Hout River Dam, caused by the introduction of organic matter in tributaries further upstream. However, high nutrients in Molepo Dam and Hout River Dam during did not result in eutrophication. The trophic status of Molepo Dam and Hout River Dam according to the Carlson Trophic State Index classification indicates that these small dams are oligotrophic. Seasonal variation in water quality parameters was also observed in other aquatic ecosystems worldwide (Edokpayi *et al*., 2015; Eliku and Leta, 2018; Adedeji *et al*., 2019).

Secchi disk transparency was lowest in the dry season especially at site 2 in both Molepo Dam and Hout River Dam. This might indicate the disturbance caused by cattle grazing activity occurring at these small dams. High water transparency was observed during the wet season (Nov-Apr) when water levels were high and as a result suspended particles settled at the bottom. Conductivity was high during the dry season in both these dams. The lower concentrations during the wet season occurred due to rainfall events and this resulted in a high dilution factor. Similar results were observed by Nhiwatiwa and Marshall (2007) in Malilangwe Reservoir, whereby conductivity was high in the dry season when water level was low.

Dissolved oxygen was lowest in both Molepo Dam and Hout River Dam during the dry season and did not comply with the Target Water Quality Range (TWQR) for aquatic ecosystems in South Africa (DWAF, 1996). Dissolved oxygen depletion during the dry season could be a result of demand exceeding supply due to decaying organic matter and increase in aquatic organisms which consume dissolved oxygen. Phytoplankton are photosynthetic, they have the ability to use sunlight to convert carbon dioxide and water into energy. During the night there is no photosynthesis therefore dissolved oxygen tend to decline. Phytoplankton are responsible for much of the dissolved oxygen found in surface waters. As oxygen is required for fish and other aquatic organisms, a decrease in photosynthesis productivity is detrimental to aquatic populations. Without phytoplankton, the oxygen supply of the water would not be enough. Dissolved oxygen levels can be raised by increasing algal growth (Dhar and Baghel, 2016). Large fish population in small dams experience a fast metabolic rate as water temperature increase because of change of season increasing their oxygen requirements. As a result, more oxygen is needed by the fish during dry season especially when water levels are fluctuating (Neubauer and Andersen, 2019). Abd El- Monem (2008) reported that fish species and other aquatic animals usually avoid water layers containing less than 2-3 mg/L oxygen concentration.

Water temperature and oxygen concentrations at the surface of the dams and bottom were roughly the same throughout the study period in Molepo Dam and Hout River Dam. The isopleths of temperature and oxygen were not large enough to cause thermal and oxygen stratification. Hence, Molepo Dam and Hout River Dam experienced little to no thermal and oxygen stratification. Nitrogen and phosphorus (N: P) ratios observed in these small dams were relatively unchanged during the study period. According to Smith (1979) nitrogen is limiting when the N: P ratio is less than 10:1 and phosphorus is limiting when the ratio N: P is greater than 13:1. Thus, for the Molepo Dam and Hout River Dam, nitrogen was found to be the limiting factor.

Water level fluctuations could both directly and indirectly affect water quality in Molepo Dam and Hout River Dam. Total phosphorus and total nitrogen were more concentrated during the dry season at lower water levels than at higher water levels. Pan *et al*. (2018) showed that both total nitrogen and total phosphorus actually decreased after the water level increased, which may be due to the combination of relatively poor soil quality and the dilution factor. Nutrient increase as a result of water level decrease would lead to algal and macrophytes production, and in some cases algal blooms (Leira and Cantonati, 2008; Zohary and Ostrovsky, 2011). However, nutrient increase in Molepo Dam and Hout River Dam did not result to algal blooms. A negative linear regression described the relationship between water level and total phosphorus, total nitrogen, chlorophyll-a and turbidity in Molepo Dam and Hout River Dam. As the water level increased, these water quality parameters decreased. Similar results were observed by Rocha *et al*. (2018) whereby a negative linear regression described the relationship between water level and total phosphorus and total nitrogen. Increase in total nitrogen and total phosphorus may result in an increase in phytoplankton biomass (chlorophyll-a concentrations) producing phytoplankton populations dominated mostly by the blue-green algae (cyanobacteria).

CHAPTER 4: PLANKTON AS INDICATORS OF WATER QUALITY IN MOLEPO DAM AND HOUT RIVER DAM

4.1 Introduction

Bio-indicators have provided valuable information for water resource management in recent years (Singh *et al*., 2013). Among aquatic biota, plankton are generally highly sensitive and their dynamics can be affected by environmental alterations. Due to their short-life cycles, plankton inhabiting shallow small dams respond quickly to water quality deterioration (Munamati *et al*., 2007, Dembowska *et al*., 2018). Plankton have low mobility and are therefore unable to avoid habitat alterations imposed by environmental changes. These environmental changes may affect phytoplankton and zooplankton species composition, abundance, diversity and biomass through changes in both underwater light availability and nutrient dynamics (Leira and Cantonati, 2008; Costa *et al*., 2016).

In small dams, during low water levels, nutrient can stimulate the growth of harmful cyanobacterial and algal species and as a result reduce the water quality. The dominance of *Microcystis spp* and *Anabaena spp* may be a challenge to communities using the water from small dams as they produce bio toxins which affect the taste of water, cause high turbidity, impact bad taste on fish and harbour diseases causing massive fish kills (Dimowo, 2013; Dorche *et al*., 2018). Physico-chemical parameters such as water temperature, total nitrogen, total phosphorus, turbidity and the biomass of micro-algae which are largely influenced by environmental changes also play an important role in the succession of phytoplankton and zooplankton communities (Rajashekhar *et al.,* 2009). Plankton have fast growth rates thus they therefore can provide meaningful and quantifiable indicators of ecological change in short timescales (Munamati *et al*., 2007; Dalu, 2013).

Phytoplankton and zooplankton are important components of aquatic ecosystems, with zooplankton helping in regulating algal and microbial productivity through grazing and the transfer of primary production to fish and other consumers (Okogwu, 2010). Zooplankton grazing on phytoplankton and bacteria helps in improving water quality hence they are considered as important indicators of the structure and function of aquatic ecosystems and their ecological status (Jeppesen *et al*., 2011). However, the responses of zooplankton to water quality variations are ecosystem and species dependent and they vary within and between small waterbodies. Molepo Dam and Hout River Dam are small dams characterised by environmental alterations and as a result creates unpredictable aquatic environment for phytoplankton and zooplankton. Therefore, this study will determine the plankton abundance and composition as indicators of water quality in Molepo Dam and Hout River Dam.

4.2 Objectives and null hypothesis

4.2.1 *Objectives*

I. To determine the abundance and composition of phytoplankton and zooplankton in Molepo Dam and Hout River Dam

4.2.2 Null hypothesis

I. There is no difference in the abundance and composition of phytoplankton and zooplankton in Molepo and Hout River Dams.

4.3 Methods and materials

4.3.1 *Study areas*

The study was conducted at Molepo Dam and Hout River Dam in Limpopo province, South Africa. The study areas were visited monthly from May 2018 to April 2019. Four sampling sites were selected along each dam. Site 1 is located in the river. Site 2 is where the river feeds the dam (inlet), Site 3 is located in the middle of the dam next to the dam wall and Site 4 is where the dam ends (outlet) (Figure 4.1 and 4.2, Chapter 3).

4.3.2 Plankton sampling

Handheld plankton nets of 71 µm and 132 µm mesh were used to collect phytoplankton and zooplankton respectively. The water samples were preserved in 10% formalin. Enumeration of plankton was done for each dam using a Plexiglas petri dish with a polished bottom for best transparency. The water samples were well shaken and aliquots of 10mL were transferred onto the Plexiglas petri dish for microscopic study. The phytoplankton were identified to genus level with the aid of a compound light microscope (Zeiss Stereo Discovery v8) at a magnification of 400x using the manual by Botes (2003). The zooplanktons were identified to family level using the same microscope at a magnification of 50x or 400x. Identification was done using manuals published by the Water Research Commission (Day *et al.,* 1999; Day *et al.,* 2001; Day *et al.,* 2003; de Moor *et al.,* 2003a and b).

4.3.3 Data analysis

Shannon-Wiener diversity index was used to determine the phytoplankton and zooplankton species diversity between Molepo Dam and Hout River Dam. The Shannon-Wiener index (Shannon and Wiener, 1949):

$$H' = -\sum_{i=1}^{S}(p_i \ln p_i)$$

Where:

In = natural logarithm

i = the abundance of species

S = number of species

p*i* = the relative abundance of each species

4.4 Results

4.4.1 Abundance and composition of phytoplankton and zooplankton in Molepo Dam and Hout River Dam

A total of 4 phytoplankton phyla (Chlorophyta, Cyanophyta, Desmids and Bacillariophyta) were recorded in Molepo Dam and Hout River Dam (Table 4.1 and 4.2), with 11 phytoplankton species (*Chlorella sp., Pediastrum colony, Coelospharium sp, Microcystis aeruginosa, Oscillatoria sp., Spirulina sp., Diatom sp., Flagilaria sp., Closterium sp., Cosmarium sp., Spirogyra sp*.) observed in Molepo Dam (Table 4.1) and only 7 phytoplankton species (*Chlorella sp., Pediastrum colony, Microcystis aeruginosa, Oscillatoria sp., Flagilaria sp., Closterium sp., Spirogyra sp*.) observed in Hout River Dam (Table 4.2) between May 2018 and April 2019.

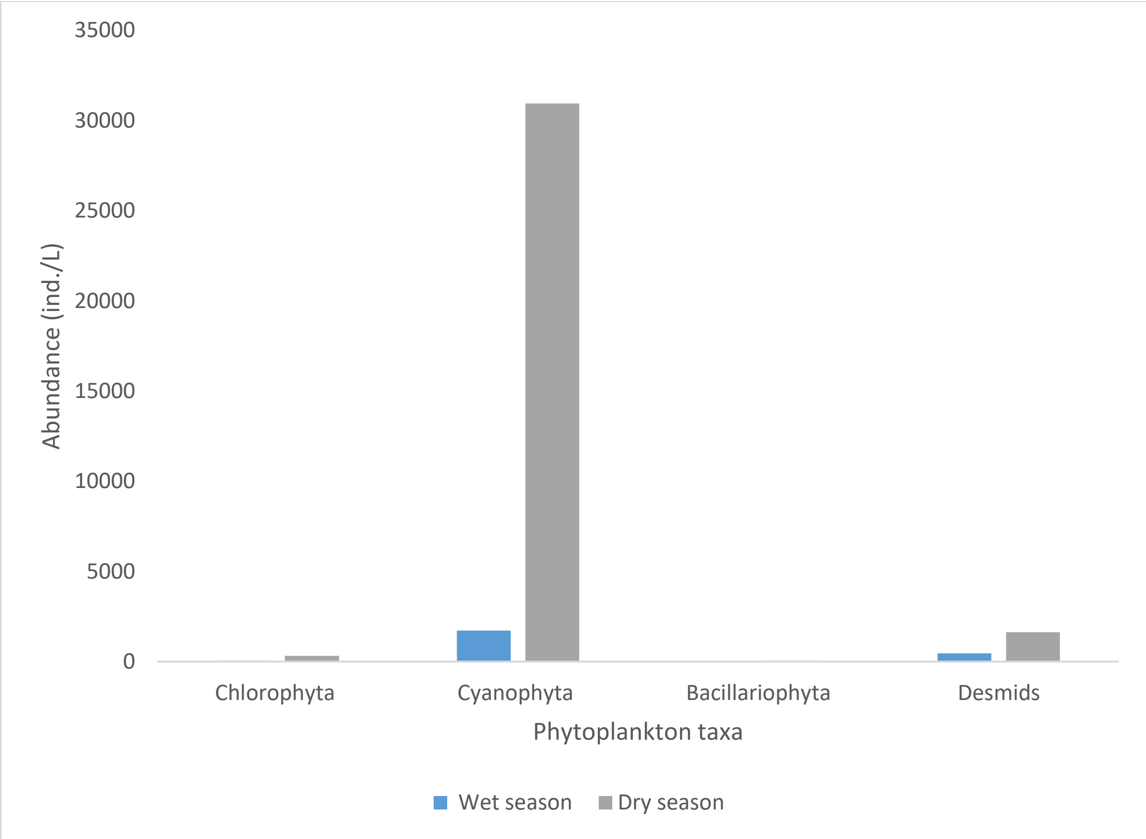
Species diversity was greatest during the dry season (May-Oct); August and September recording 11 species in Molepo Dam (Table 4.1), August, September and October recording 8 species in Hout River Dam (Table 4.2). The Shannon-Wiener diversity index was high for the wet season months with February recording (*H'*=0.529) in Molepo Dam and November recording (*H'*=0.325) in Hout River Dam (Table 1 and 2). Individual species, number per litre for phytoplankton groups that contributed significantly in terms of abundance were *Microcystis aeruginosa* and *Oscillatoria sp*. in both Molepo Dam and Hout River Dam during the dry season months, May to October (Table 4.1 and 4.2). *Microcystis aeruginosa* was the only species that occurred in all the sampling months in these small dams. The abundance of Cyanophyta was greatest during the dry season followed by Desmids in Molepo Dam and Hout River Dam (Figure 4.1a and b). During the wet season, Bacillariophyta were not recorded for Hout River Dam (Figure 4.1b). The highest composition for Chlorophyta (15.4%) in Molepo Dam was recorded during the wet season month of December (Figure 4.2a). Phytoplankton abundance was higher in Molepo Dam as compared to Hout River Dam throughout the sampling period.

Table 4.1: The abundance (individual per litre) of phytoplankton of Molepo Dam, May- April 2019

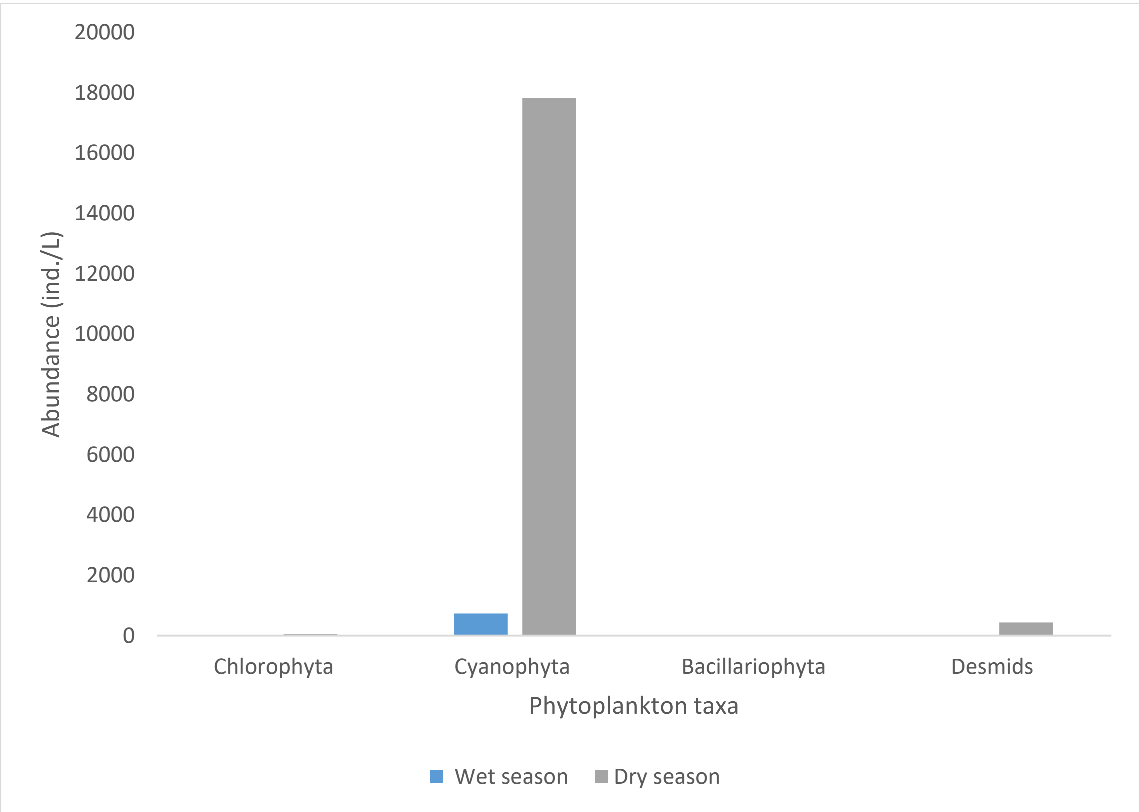
Phytoplankton Division	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Chlorophyta												
Chlorella sp.	-	-	17	10	13	-	-	3	4	2	3	6
Pediastrum colony	4	-	187	73	13	1	7	20	-	2	7	6
Cyanophyta												
Coelospharium sp		-	20	18	8	14	9	8	10	5	7	13
Microcystis aeruginosa	705	1108	2001	2621	11358	11468	103	94	68	110	469	581
Oscillatoria sp.	109	297	302	411	313	187	30	19	21	61	85	41
Spirulina sp.	-	-	-	2	4	-	-	1	-	-	1	-
Bacillariophyta												
Diatom sp.	-	-	13	5	19	-	-	-	-	-	-	9
Flagilaria sp.	-	-	-	16	3	11	4	-	-	-	3	-
Desmids												
Closterium sp.	3	3	7	6	3	9	2	2	-	-	3	6
Cosmarium sp.	-	4	-	-	-	-	3	2	-	-	-	-
Spirogyra sp.	331	340	311	287	221	119	-	-	-	81	67	302
Total number of taxa (*N*)	**7**	**6**	**9**	**11**	**11**	**8**	**8**	**9**	**5**	**7**	**10**	**9**
Shannon-weiner index (*H'*)	**0.422**	**0.405**	**0.439**	**0.367**	**0.111**	**0.070**	**0.486**	**0.523**	**0.413**	**0.529**	**0.398**	**0.434**

Table 4.2: The abundance (individual per litre) of phytoplankton of Hout River Dam, May- April 2019

Phytoplankton Division	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Chlorophyta												
Chlorella sp.	-	-	-	1	1	1	-	-	-	-	2	-
Pediastrum colony	2	2	14	10	7	1	-	-	-	1	3	4
Cyanophyta												
Microcystis aeruginosa	603	110	1941	2101	3099	9498	36	28	17	10	163	445
Oscillatoria sp.	-	-	256	96	73	44	25	13	-	-	-	-
Bacillariophyta												
Flagilaria sp.	-	-	-	2	1	1	-	-	-	-	-	-
Desmids												
Closterium sp.	-	-	3	5	5	8	1	-	-	-	-	-
Spirogyra sp.	-	-	-	208	115	96	-	-	-	-	-	-
Total number of taxa (*N*)	**3**	**3**	**5**	**8**	**8**	**8**	**4**	**3**	**2**	**3**	**4**	**3**
Shannon-weiner index (*H'*)	**0.009**	**0.005**	**0.176**	**0.220**	**0.125**	**0.041**	**0.325**	**0.271**	**0.000**	**0.132**	**0.067**	**0.022**

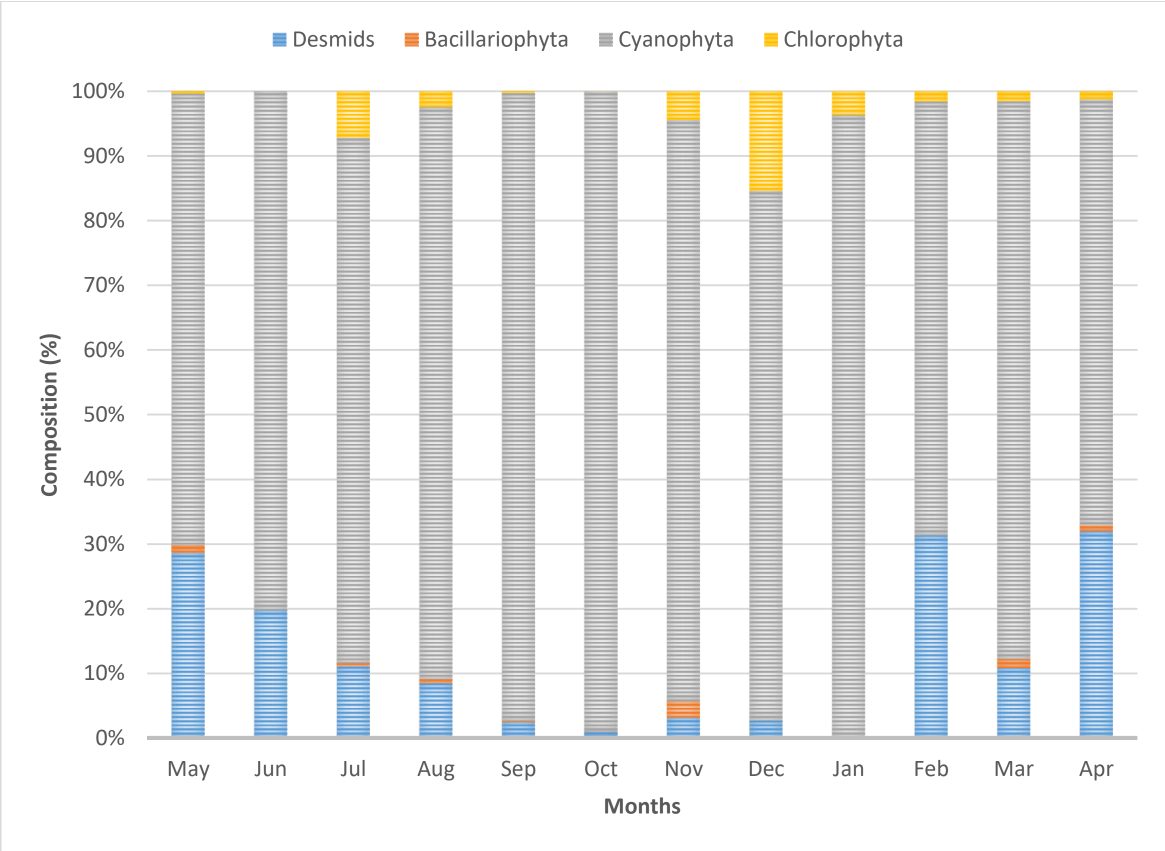


a)



b)

Figure 4.1: The abundance of phytoplankton taxa in the wet and dry seasons in a) Molepo Dam and b) Hout River Dam.



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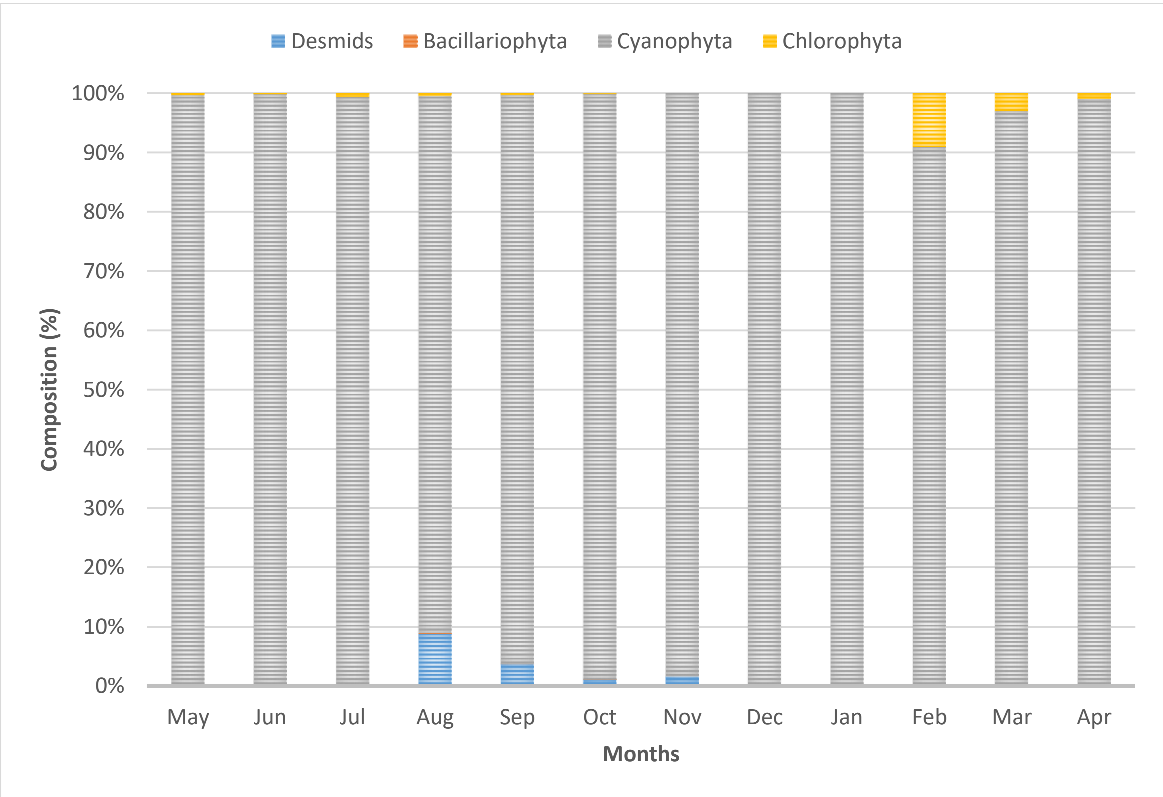


b)

Figure 4.2: Monthly changes in composition of phytoplankton taxa in a) Molepo Dam and b) Hout River Dam

A total of 3 zooplankton phyla, Cladoceran, Copepoda and Rotifera were observed in both Molepo Dam and Hout River Dam throughout the sampling period (Table 4.3 and 4.4). *Keratella cochlearis* was not observed in Molepo Dam during the wet season months (Dec-Feb) (Table 4.3). Individual species within the zooplankton groups that contribute significantly in terms of abundance were *Cycloid sp.* and *Bosmina longirostris* in both Molepo Dam and Hout River Dam during the dry season months (May-Oct) (Table 4.3 and 4.4).

The abundance of Cladocera, Copepoda and Rotifera was greatest during the dry season than in the wet season in both Molepo Dam and Hout River Dam (Figure 4.3a and b). Copepoda (*Cycloid sp*.) was highest during the dry season followed by Cladocera (*Bosmina longirostris)* in Molepo Dam (Figure 4.3a). In Hout River Dam, Cladocera (*Bosmina longirostris)* was highest during the dry season followed by Copepoda (*Cycloid sp*.). However, Copepoda dominated in the wet season (Figure 4.3b). The lowest zooplankton taxa in both the dry and wet seasons was recorded for Rotifera (*Keratella cochlearis).*

The highest Copepoda composition was observed during the wet season month of December (69.9%) in Molepo Dam and February (98.7%) in Hout River Dam. The lowest composition was recorded for Rotifera in these dams (Figure 4.4a and b). However, Molepo Dam recorded the highest abundance of zooplankton species as compared to Hout River Dam.

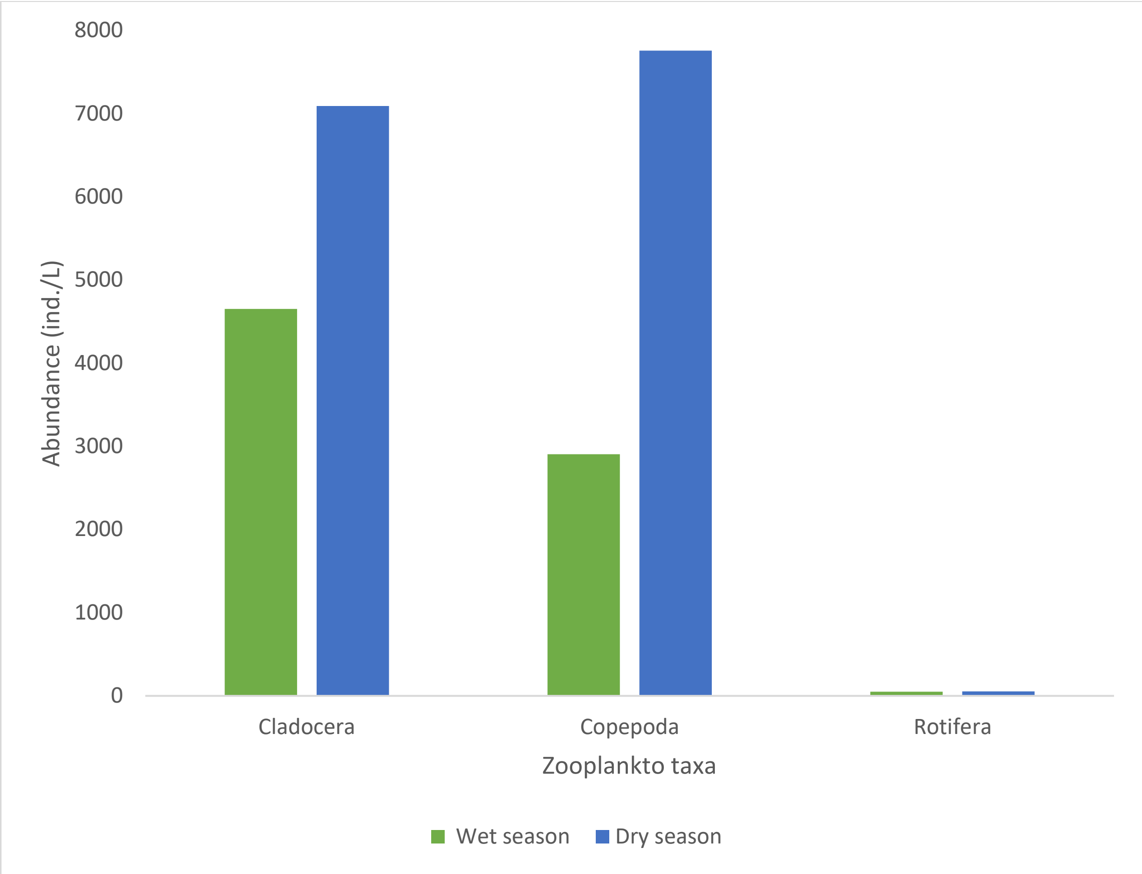
Table 4.3: The abundance (individual per litre) of zooplankton in Molepo Dam, May 2018- April 2019.

Zooplankton Division	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Cladocera												
Bosmina longirostris	1472	1563	949	1614	640	851	255	306	642	670	1359	1417
Copepoda												
Cycloid sp.	1362	1691	982	1719	948	1054	574	712	803	815	1361	1360
Rotifera												
Keratella cochlearis	10	6	4	1	14	18	21	-	-	-	20	9

Table 4.4: The abundance (individual per litre) of zooplankton in Hout River Dam, May 2018- April 2019.

Zooplankton Division	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Cladocera												
Bosmina longirostris	114	336	191	2818	1189	1128	12	8	83	13	172	261
Copepoda												
Cycloid sp.	782	671	1002	815	1272	649	471	361	615	1248	451	563
Rotifera												
Keratella cochlearis	9	2	12	15	15	8	8	5	4	3	1	14

a)



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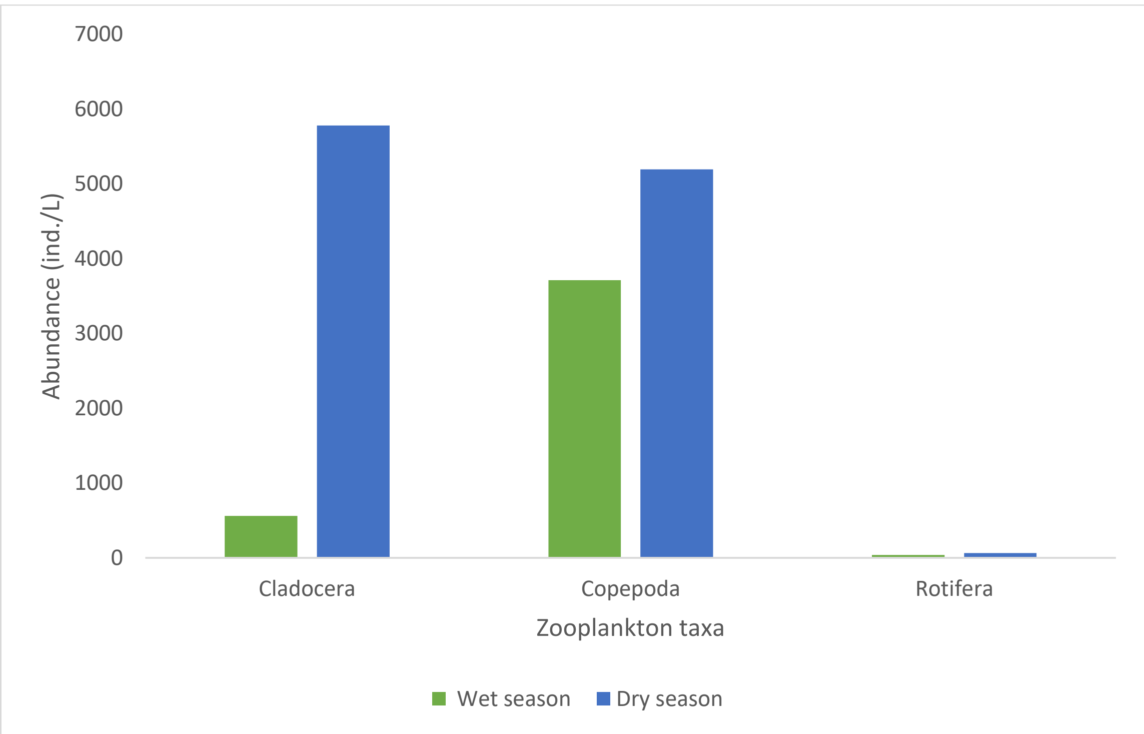
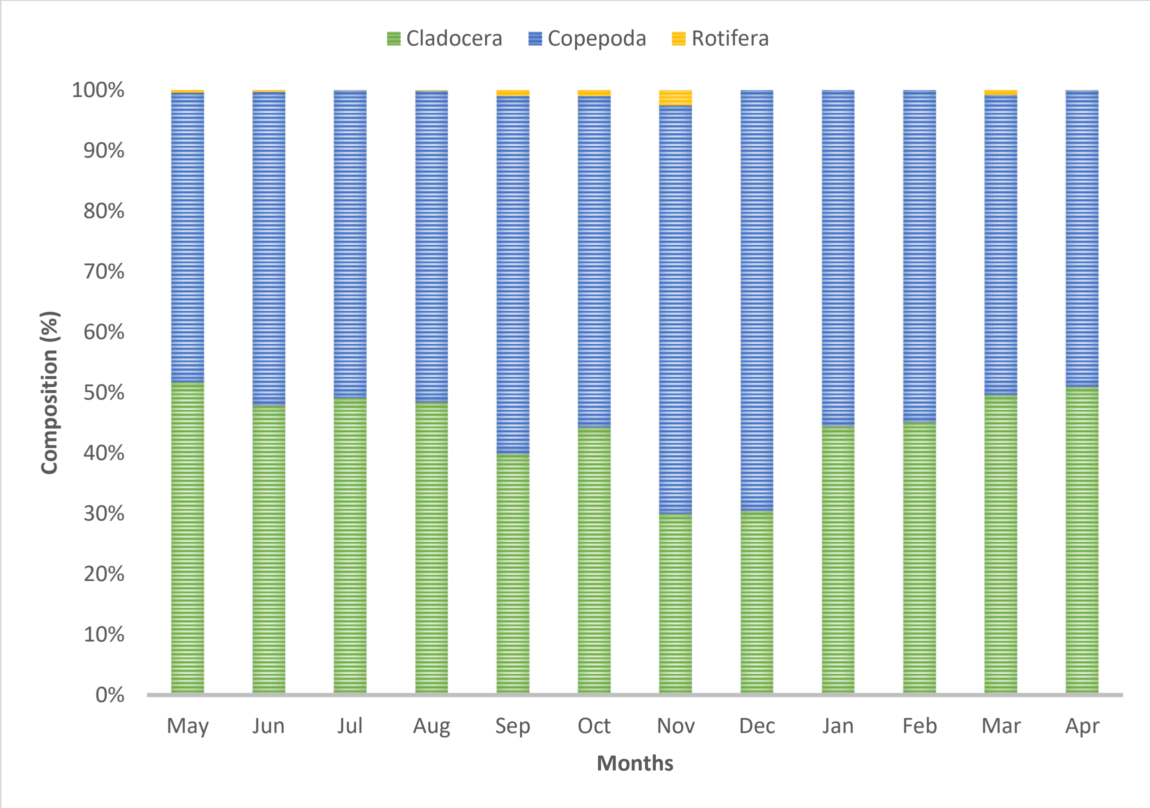
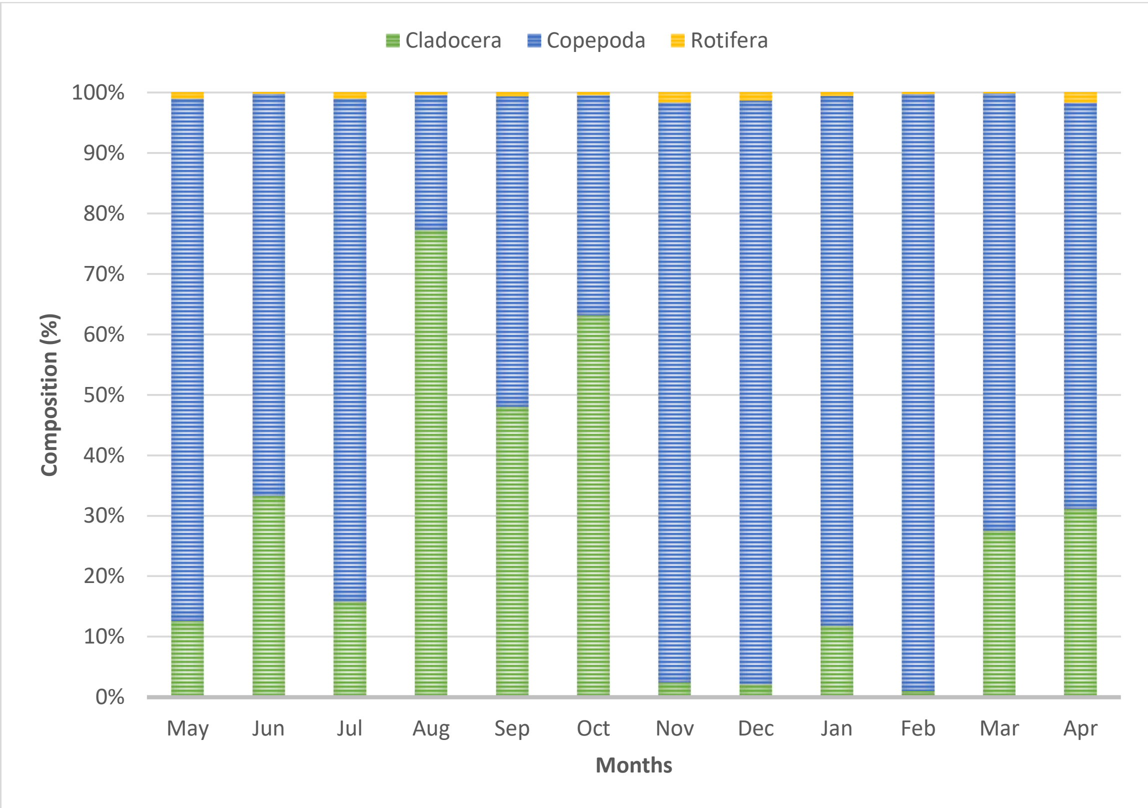


Figure 4.3: The abundance of zooplankton taxa in the wet and dry seasons in a) Molepo Dam and b) Hout River Dam



a)



b)

Figure 4.4: Monthly changes in composition of zooplankton taxa in a) Molepo Dam and b) Hout River Dam

4.5 Discussion

Seasonal variations in physico-chemical parameters such as total nitrogen, total phosphorus, chlorophyll-a, conductivity, dissolved oxygen and turbidity in Molepo Dam and Hout River Dam were important in structuring phytoplankton abundance and composition. The phytoplankton community in both small dams is characterised by four phyla, Cyanophyta, Chlorophyta, Bacillariophyta and Desmids. Highest phytoplankton abundance in both dams were recorded during the dry season when water levels were low with high nutrient concentrations and decreased during the wet season due to the dilution factor. Nhiwatiwa and Marshall (2007) observed similar trends in two small reservoirs where phytoplankton increased during periods of long water residency. High phytoplankton abundance could also be attributed to increased nutrient concentrations during the dry season which favours accelerated plankton growth decreasing water transparency due to algal blooms. A low turbidity measure indicates improved light attenuation and this can become an important factor influencing algal productivity.

The Cyanophyta were the most abundant phyla in Molepo Dam and Hout River Dam throughout the study period in both the dry and wet seasons. This species composition followed an increase in phosphorus and as a result increase of nitrogen-fixing species such as colonial cyanobacteria (*Microcystis aeruginosa)* was observed. This could reflect a nitrogen-limitation in the dams and this was confirmed by the very low N: P ratio for the study areas. The key attributes of Cyanophyta which enable them to out-compete other species is their superior light capturing capacity in low light situations and their high affinity to absorbing nitrogen and phosphorus at severe limiting levels (Harding, 1992; Munkes *et al*., 2020). The presence of bloom producing species such as *Microcystis aeruginosa* and *Oscillatoria sp*. were observed in these small dams. *Microcystis aeruginosa* and *Oscillatoria sp*. are cosmopolitan algae found in every waterbody. Although they are useful indicator species of eutrophic status, they are also found in oligotrophic waterbodies (Chellappa *et al*., 2009; Jindal *et al*., 2014).

This indicates that Molepo Dam and Hout River Dam are not eutrophic. The proliferation of these species could be due to increased nutrient concentrations and chlorophyll-a especially in the dry season when enhanced by reduced water volume and higher rate of evaporation. Molepo Dam and Hout River Dam may be undergoing gradual decrease in water quality during this season. Also, some stains of *Microcystis* are toxic to cattle and fish primarily affecting the liver. The low abundance recorded during the wet season could be attributed to further dilution of essential growth nutrients in the dams.

Thermal stratification is an important factor controlling nutrient cycling and phytoplankton production in the aquatic ecosystem (Zhao *et al*., 2011). According to Engel and Fischer (2017) some of the stratification events resulted in reduced concentrations of dissolved nutrients in the surface layer as a result of increased uptake by algae. Brookes *et al*. (2017) reported that the most abundant phytoplankton during thermal stratification is chlorophyte *Chlorella species*. However, Molepo Dam and Hout River Dam experienced little to no stratification or turnover and the *Chlorella species* is one of the least dominant in both dams.

The zooplankton assemblages in the Molepo Dam and Hout River Dam consisted of Cladocerans, Cyclopoids and Rotifers. Studies have shown small water bodies to be less diverse and comprising between 5 and 10 species, however, the present study observed 3 species (Basima *et al*. 2006, Nhiwatiwa and Marshall 2007). Increase of Cladoceran abundance has already been recognised as an indicator of eutrophication in lakes and reservoirs (Leitão *et al*. 2006, Gülle *et al*. 2010) with some species presenting different responses associated to trophic gradients. *Bosmina longirostris* is usually found more abundant in water bodies with low nutrient concentrations indicating clear water (Dorche *et al.,* 2018). In the present study, zooplankton communities were dominated by *Bosmina longirostris* which was present throughout the sampling period (May 2018 - Apr 2019) possibly indicating clear water in Molepo Dam and Hout River Dam.

Copepoda are another sub-dominant phyla of zooplankton which occur in almost all types of freshwater bodies and form an important component of fish food (Sukad and Chavan, 2013). In Molepo Dam and Hout River Dam, Copepoda were mainly represented by *Cycloid sp.* which are also indicators of clean water. This may be useful indicator species for waterbodies that are not eutrophic like these small dams.

Among zooplankton, rotifers respond quickly to environmental changes and can be used as bio-indicators of water quality (Rajashekhar *et al*. 2009; Dorche *et al*., 2018). Rotifers are opportunistic organisms and adapt to fast population growth during favourable seasons, whose abundance change with temperature in a short time (Dorche *et al*., 2018). According to Dirican *et al*. (2009), the presence of rotifers such as *Brachionus, Keratella* and *Lecane* are indicative of eutrophic conditions. In this study, *Brachionus* and *Lecane* were not obsereved however, *Keratella cochlearis* was reported only in low abundance, which could indicate that the Molepo Dam and Hout River Dam water has not reached eutrophic level.

Water level fluctuations affected total nitrogen, total phosphorus and chlorophyll-a in Molepo Dam and Hout River Dam which as a result influenced the phytoplankton and zooplankton species abundance and composition. The highest phytoplankton abundance and composition was observed when total nitrogen and total phosphorus concentrations were high. Zooplankton abundance greatly depend on the abundance and composition of phytoplankton in these dams. The seasonal distribution of plankton in Molepo Dam and Hout River Dam shows that they are sensitive to environmental changes. As such plankton can be good indicators of water quality.

CHAPTER 5: COMPOSITION AND ABUNDANCE OF FISH SPECIES IN MOLEPO DAM AND HOUT RIVER DAM.

5.1 Introduction

Natural water level variations are necessary for the survival of many biological species including fish, as a guarantee for both productivity and biodiversity (Wantzen *et al*., 2008; Yang *et al*., 2016). However, untimely and extreme water level fluctuations have adverse effects on fish populations in small dams. The abundance and composition of fish species changes primarily in response to changes in the quality and quantity of spawning habitats, as influenced by the long-term effects of water level changes (Leira and Cantonati, 2008; Kann and Walker, 2020). The frequency, duration and extend of water level fluctuations in small dams, rivers and lakes are dominant forces controlling the functioning of aquatic ecosystems.

Seasonal water level fluctuations may determine the presence and absence of any fish species in small dams (Fischer and Ohl, 2005; Logez *et al*., 2016) These seasonal fluctuations in the water level can become a factor in controlling the distribution of fish species. Molepo dam and Hout River Dam are small dams of different magnitude that are subject to water level fluctuations. Fish may be stunted due to stress arising from water level fluctuations leading to shifts in species diversity and partial or total loss of fish. Very little is known about fish communities in these two small dams. This present will determine the abundance and composition of fish species and growth parameters of the most abundant fish species in the two dams.

5.2 Objectives and null hypothesis

5.2.1 *Objectives*

I. To determine fish species composition, abundance and diversity in Molepo Dam and Hout River Dam
II. To determine fish age and growth of *Oreochromis mossambicus* in Molepo Dam and Hout River Dam

5.2.2 *Null hypothesis*

I. There is no difference in fish species composition, abundance and diversity in Molepo Dam and Hout River Dam

II. There is no difference in fish age and growth of *Oreochromis mossambicus* in Molepo Dam and Hout River Dam.

5.3 Methods and materials

5.3.1 *Fish sampling*

Fish sampling was done using gill nets with stretched mesh size of 150 mm and rod and reel. The gill nets were left overnight to catch all possible species in the dams. Rod and reel fishing method was conducted in the middle of the dams. This was to ensure that all size groups of fish are represented in the study. Fish caught were identified to genus and species level according to Skelton (2005). Fish abundance was expressed as Catch Per Unit Effort (catch per 100m of the gill nets) and was calculated as:

$$\mathrm{CPUE} = \sum \frac{\left(\frac{C_i}{E_i}\right)}{n}$$

where: C_i is the catch size (either in the number or mass of fish) per gear, E_i is the effort expended by gear and *n* is the number of gears used.

After capture, the total length (TL), standard length (SL) were measured to the nearest mm and were converted to centimetres and mass/weight (g) was determined using the three battery operated field balance (Mettler Toledo: JL6001 GLA00). This was done for all fish caught. The length-weight relationships were estimated from the allometric formula:

$$W = aL^b$$

This expression can be transformed logarithmically; log W = log a + b log L.

Where:
W is weight, L = total length, a = constant and parameter b is the exponent of the arithmetic form of the weight–length relationship and the slope of the regression line in the logarithmic form.

If b = 3 the fish grows isometrically, then small fish in the sample under consideration have the same form and condition as large fish. If b > 3, the fish shows positive allometric growth, then large fish have increased in height or width more than in length, either as the result of a notable ontogenetic change in body shape with size, which is rare or largest fish in the sample were thicker than small fish, which is common. Conversely, if b < 3 the fish shows negative allometric growth, then large fish have changed their body shape to become more elongated or small fish were in better nutritional condition at the time of sampling (Froese, 2006; Shakir *et al*., 2008).
The condition factor (K) of fish, based on the analysis of length-weight data, indicates the health of fish in a habitat. To determine the overall physical health of fish, the condition factor (K) was calculated as:

$$K = 100 \times W \times L^{-3}$$

5.3.2 Fish age and growth

5.3.2.1 Ageing *Oreochromis mossambicus*

Fish age was determined using scales. Scales were removed above the lateral line, anterior to the dorsal fin from each fish using tweezers. In the laboratory, the scales were soaked and cleaned in distilled water. Once dry, the scales were mounted on Bells and Howell ABR-IV microfiche reader to count the annuli (rings).

The criteria used in the identification of annuli was as follows:

- Areas where circuli fuse or form anastomoses (Payne, 1976; Barger, 1990).
- Clear zones that were devoid of circuli (Cohen, 1991).
- Areas where circuli crowded together.

The assumption used for identification of annuli was that a true annulus can be traced completely around the scale and generally exhibits crossing over in the posterior portion of the lateral fields. Age was assigned to each fish based on the number of complete annuli.

Age Validation

The distance on the scale in millimetres (mm) from the last annulus to the scale margin (marginal increment) was measured. Measurements on scale images were made to the nearest 1 mm. The distance on the scale from the most recent annuli to the anterior edge of the fish was measured in the scales of 1-3-year-old fish.

5.3.2.2 Determination of growth *(Oreochromis mossambicus).*

Past version 3.14 software was used to calculate parameters for the generalized von Bertalanffy growth function (Von Bertalanffy, 1938) for length (*L*) at age (*t*) and *K* (Pauly, 1982) of fish within the Molepo Dam and Hout River Dam will be calculated.

The Von Bertalanffy growth model is defined as:

$$L_t = L_\infty \, [1- e^{-K} \, (t-t_0)]$$

Where:

L_t = length at time t

K = growth coefficient

L_∞ = average size the stock of fish would reach if they were allowed to grow indefinitely

t_0 = hypothetical age of the fish at zero length

5.3.2.3 *Growth performance index*

Moreau *et al.,* (1986)'s index of growth performance (ϕ), was used to compare the growth of Oreochromis mossambicus in Molepo Dam and Hout River Dam.

$$\phi = \log K + 2 \log L_\infty$$

Where; K and L_∞ are parameters from the Von Bertalanffy growth equation

ϕ = index of growth performance

5.3.2.4 *Determination of natural mortality*

Gulland (1987) showed that for fish that grow according to the von Bertalanffy growth function, natural mortality (Z) can be expressed by:

$$Z = K \, (L_\infty - L_{mean}) \, / \, (L_{mean} - L_c)$$

Where; K and L_∞ are parameters from the Von Bertalanffy growth equation

L_{mean} = mean length of all fishes caught at sizes

L_c = the smallest size in the catch

Z = natural mortality

5.4 Results

5.4.1 *Fish species composition, abundance (CPUE) and diversity in Molepo Dam and Hout River Dam*

Gill nets captured a total of 197 individuals from Molepo Dam, representing five (5) species from four (4) families; Cichlidae (*Oreochromis mossambicus* and *Tilapia rendalli*), Cyprinidae (*Cyprinus carpio*), Clariidae (*Clarias gariepinus*) and Centrarchidae (*Micropterus salmoides*). Hout River Dam recorded a total of 202 individuals representing four (4) species from four (4) families. *Oreochromis mossambicus* was the most abundant in both Molepo Dam (138) and Hout River Dam (146) (Table 5.1). Four (4) species were most common throughout the study months with *Cyprinus carpio* and *Clarias gariepinus* being the least in Molepo Dam and Hout River Dam respectively (Table 5.1).

Table 5.1: Fish species sampled in Molepo Dam and Hout River Dam (May-April 2019).

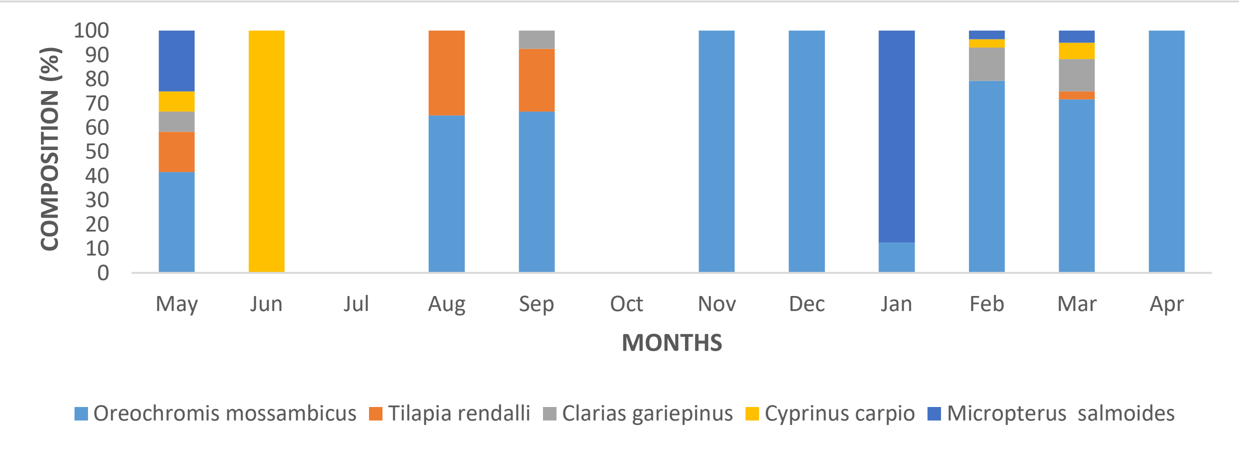
Species	**Molepo Dam**	**Hout River Dam**
Oreochromis mossambicus	138	146
Tilapia rendalli	18	0
Clarias gariepinus	15	10
Cyprinus carpio	12	28
Micropterus salmoides	14	18
Total individuals	**197**	**202**

Table 5.2: Fish species abundance (catch per 100m of the gillnets) in Molepo Dam and Hout River Dam in the dry season (May-Oct 2018) and wet season (Nov 2018-April 2019).

Species	**Molepo Dam**		**Hout River Dam**	
	Wet season	**Dry season**	**Wet season**	**Dry season**
O. mossambicus	0.66±0.05	1.15±0.09	1.12±0.07	0.83±0.09
T. rendalli	0.20±0.01	0.22±0.02	0.00±0.00	0.00±0.00
C. gariepinus	0.15±0.03	0.31±0.06	0.23±0.05	0.10±0.01
C. carpio	0.36±0.08	0.25±0.01	0.68±0.03	0.20±0.04
M. salmoides	0.30±0.03	0.36±0.05	0.55±0.08	0.18±0.02

The abundance (CPUE) was highest for *O. mossambicus* in the dry season (1.15 ± 0.09) and wet season (1.12 ± 0.07) in Molepo Dam and Hout River Dam respectively. *Tilapia rendalli* was not caught in Hout River Dam during wet and dry seasons (Table 5.2). *Oreochromis mossambicus* dominated the fish community with the highest composition throughout the sampling months followed by *Tilapia rendalli* (35%) in August (Aug) in Molepo Dam (Figure 5.1a). In Hout River Dam, *Oreochromis mossambicus* also dominated the fish community followed by *Cyprinus carpio* (65%) in May and *Clarias gariepinus* (33.3%) in the month of July (Figure 5.1b). Other fish species recorded was *Micropterus salmoides* which contributed 3.45 and 4% in February (Feb) and September (Sep) in Molepo Dam and Hout River Dam respectively (Figure 5.1a and b). Overall, there is a difference in fish species composition in Molepo Dam and Hout River Dam.

a)



b)

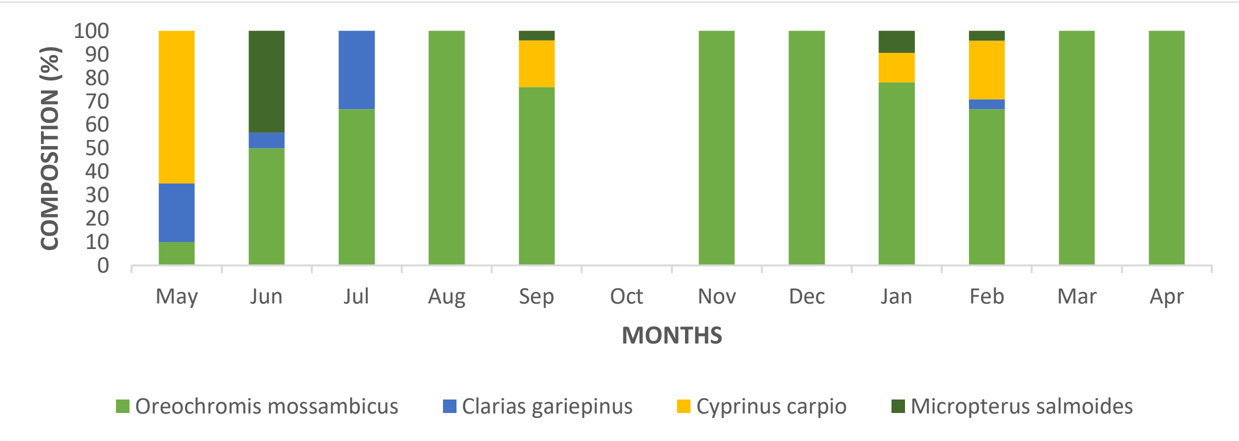


Figure 5.1: Percentage composition in a) Molepo Dam and b) Hout River Dam of fish species caught from May 2018-April 2019.

The monthly length frequency was recorded for the dominant fish species (*Oreochromis mossambicus*) in both small dams. *Oreochromis mossambicus* in Molepo Dam had high mean total length (TL) of 21.5 cm during April in the wet season. However, there was no *O. mossambicus* recorded for July and October 2018 sampling months in Molepo Dam (Figure 5.2). In Hout River Dam, *Oreochromis mossambicus* had high mean total length (TL) of 24.1 cm during September in the dry season. The lowest was in the wet season month of May (11.9 cm) (Figure 5.2). *Oreochromis mossambicus* was also not recorded for October 2018 sampling month in Hout River Dam.

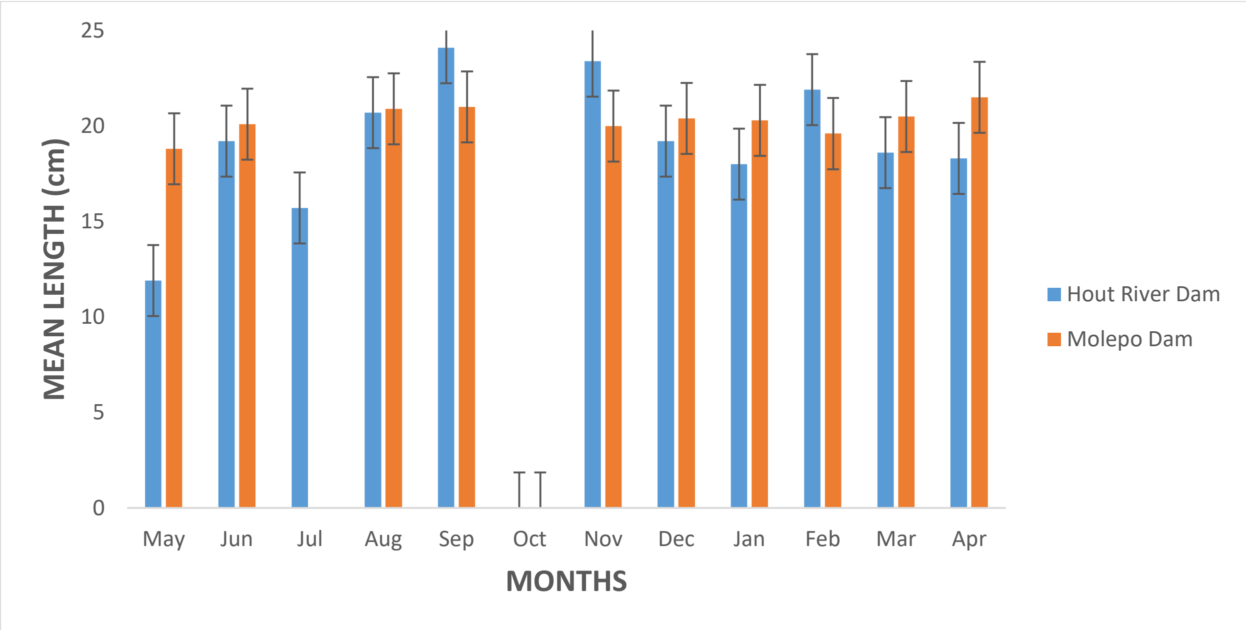


Figure 5.2: The mean length of *Oreochromis mossambicus* from samples taken monthly from May to April 2019 in Molepo Dam and Hout River Dam.

The condition factor value for *O. mossambicus* (K=4.56), *C. gariepinus* (K=4.40) and *T. rendalli* (K=4.38) indicate that these 3 fish species are in a slight better condition in Molepo Dam (Table 5.3). In Hout River Dam, *O. mossambicus* (K=1.75) and *M. salmoides* (1.57) condition factor values indicate that these 2 fish species are in a fair condition (Table 5.4). The condition factor of *O. mossambicus* was highest in summer months (Dec-Feb) and the lowest condition factor values (0.6 - 0.8) were recorded in winter months (May-Jul) in Molepo Dam and Hout River Dam (Figure 5.3).

Table 5.3: Condition factor and length (cm) characteristics of 5 fish species from Molepo Dam

Species	Min	Max	K range	Average mean (K)
O. mossambicus	12.5	27.9	0.80-7.52	4.56
T. rendalli	16.3	21	3.92-4.83	4.38
C. gariepinus	35.1	44	2.31-4.18	4.40
C. carpio	27	45	1.52-3.29	3.17
M. salmoides	8.8	27.7	0.04-1.31	0.18

Table 5.4: Condition factor and length (cm) characteristics of 4 fish species from Hout River Dam

Species	Min	Max	K range	Average mean (K)
O. mossambicus	19.8	27.5	2.59-4.67	1.75
C. gariepinus	30.2	58.8	0.81-1.44	0.19
C. carpio	13.0	24.9	3.17-6.33	0.91
M. salmoides	22.6	27.9	2.41-2.96	1.57

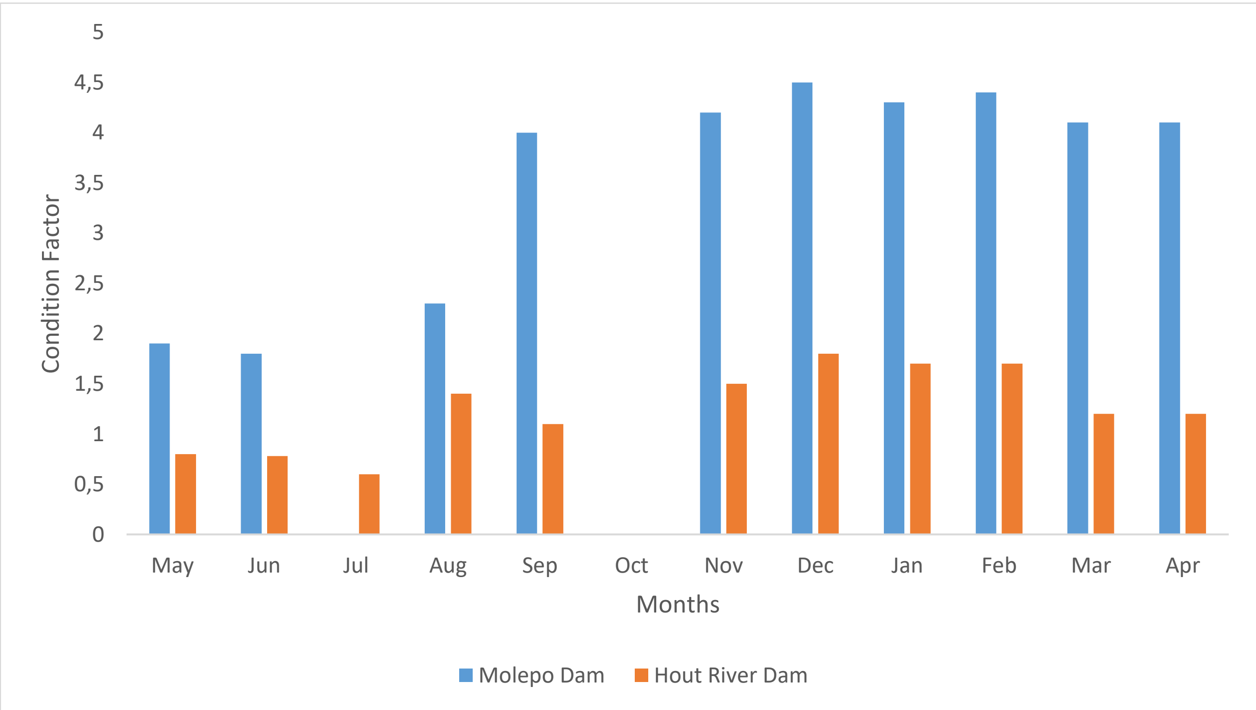
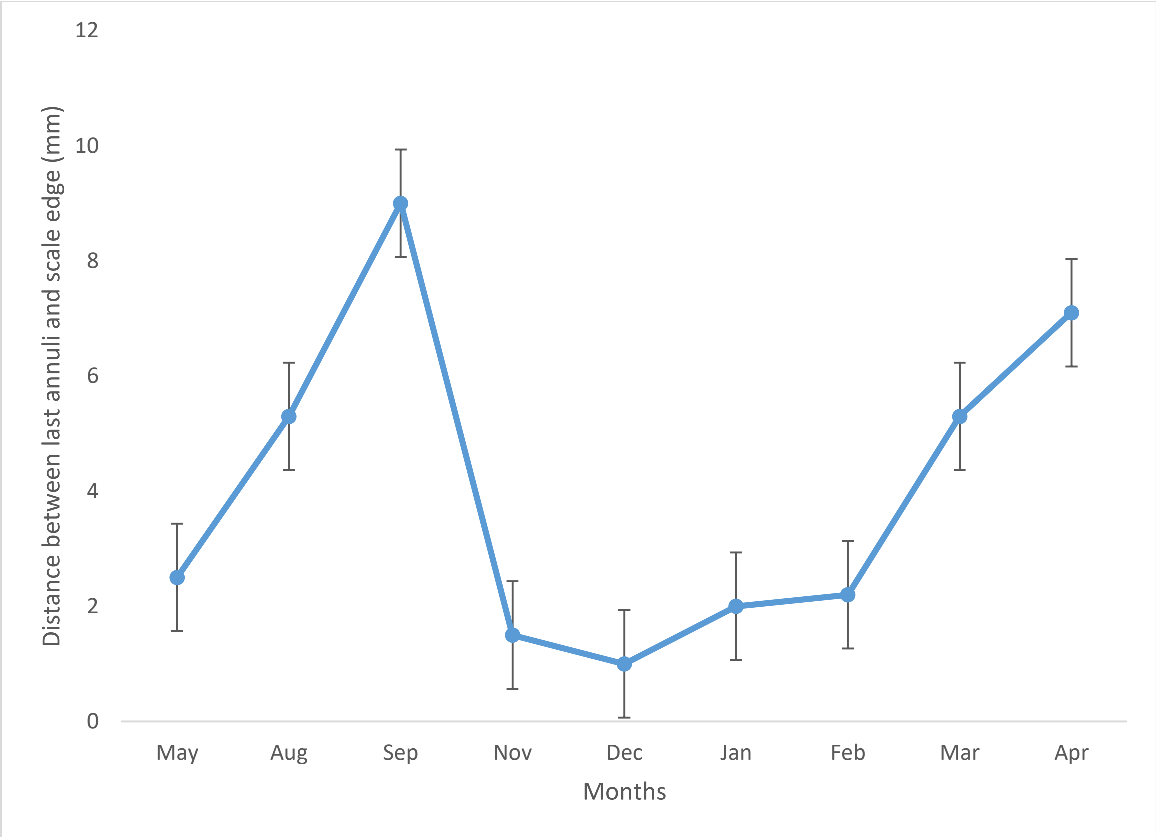


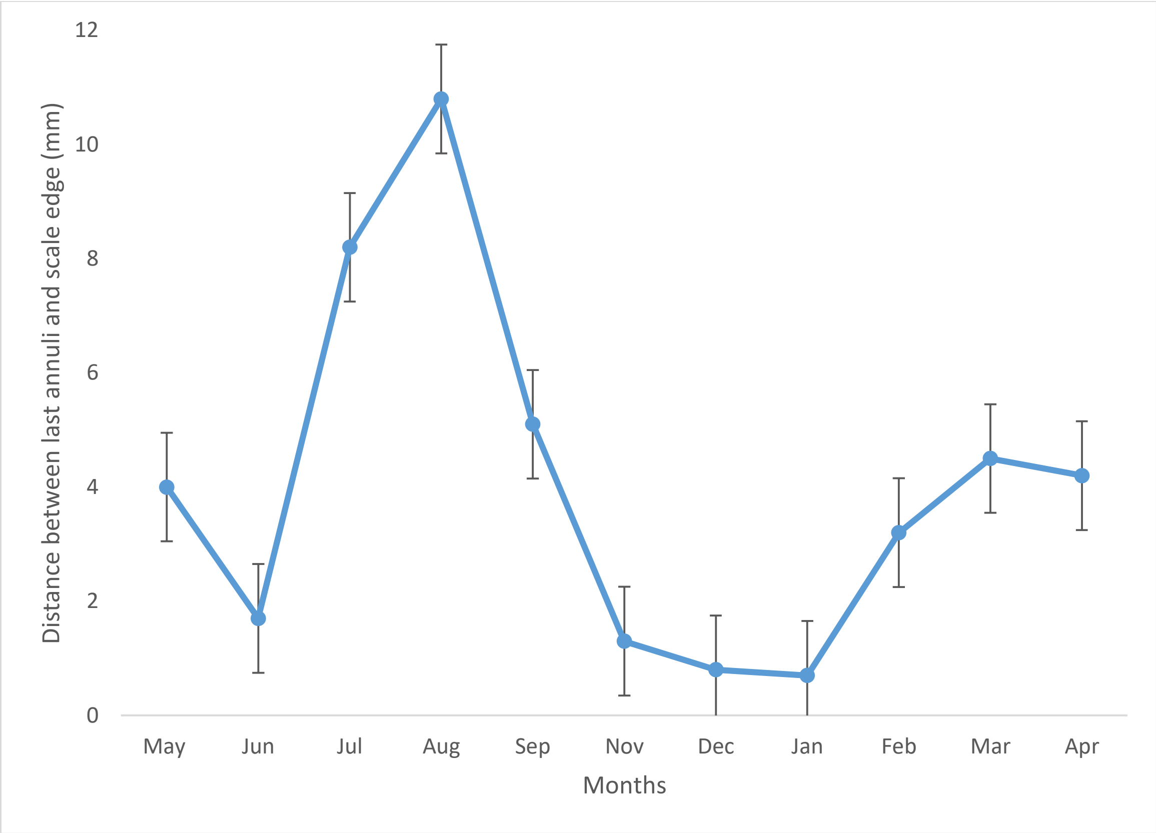
Figure 5.3: Monthly condition factor of *Oreochromis mossambicus* at Molepo Dam and Hout River Dam.

5.4.2 Age and growth determination of *Oreochromis mossambicus* in the Molepo Dam and Hout River Dam

Monthly measurements of the distance between the last annuli and the scale margin show that minimum scale growth occurred between November and December in Molepo Dam (Figure 5.4 a) and November, December and January in Hout River Dam (Figure 5.4b). During this periods, the distance between the last annuli and the scale margin were the shortest



a)



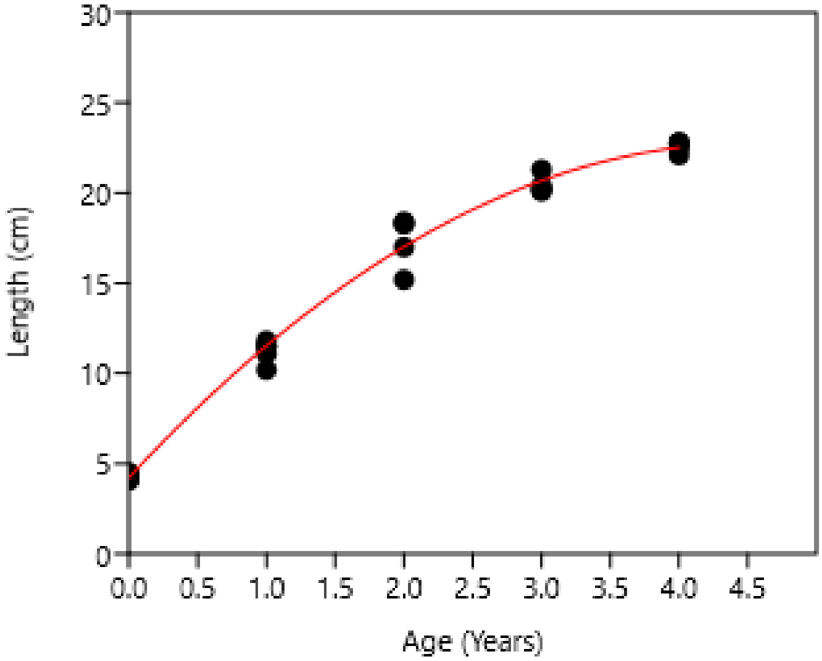
b)

Figure 5.4: Mean monthly distance beyond last annuli of 1-year-old *Oreochromis mossambicus* collected from a) Molepo Dam and b) Hout River Dam

The maximum observed length of *O. mossambicus* in Molepo Dam was 21.5 cm (female) and 22.1 cm (male) for a 4-year-old. The growth model for *O. mossambicus* was L_∞ = 22.8 cm, K = 0.914 and t_0 = -0.209 (female) and L_∞ = 23.7 cm, K = 0.918 and t_0 = -0.211 (male) (Figure 5.5). The maximum observed length of *O. mossambicus* in Hout River Dam was 24.1 cm (female) and 25.0 cm (male) for a 3-year-old. The growth model for *O. mossambicus* was L_∞ = 24.8 cm, K =0.948 and t_0 = - 0.251 (female) and L_∞ = 25.5 cm, K =0.951 and t_0 = - 0.253 (male) (Figure 5.6). There is a difference in fish age and growth of female *Oreochromis mossambicus* and male *Oreochromis mossambicus* in Molepo Dam and Hout River Dam.

The growth performance indices (ϕ) were 2.65 and 2.71 for female and male *O. mossambicus* at Molepo Dam, 2.77 and 2.79 for female and male *O. mossambicus* at Hout River Dam respectively. Natural mortality was found to be 0.440 for females and 0.489 for males in Molepo Dam and 0.542 for females and 0.569 for male *O. mossambicus* in Hout River Dam respectively.

a)



b)

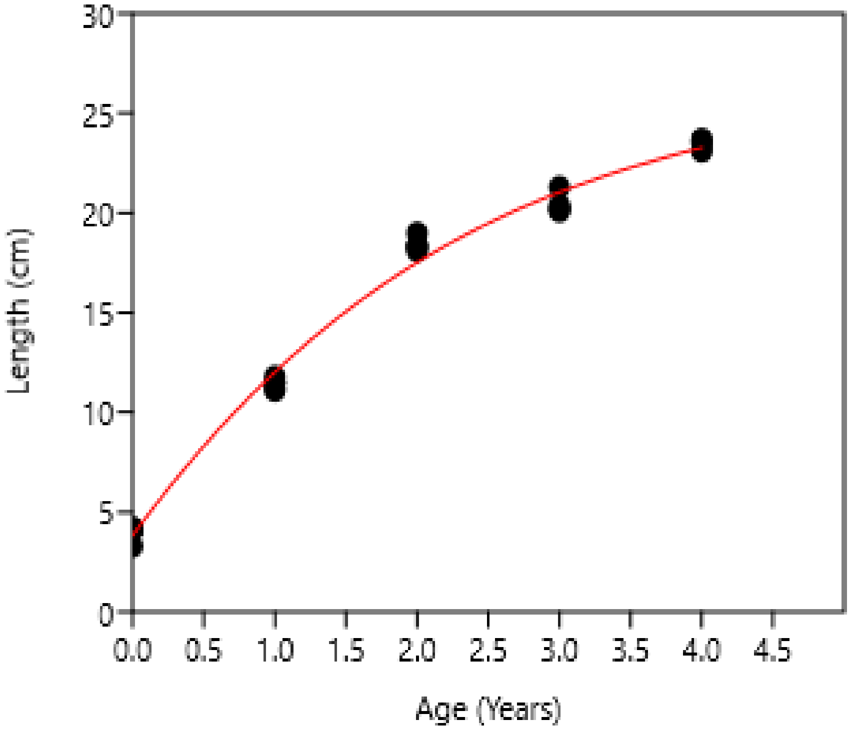
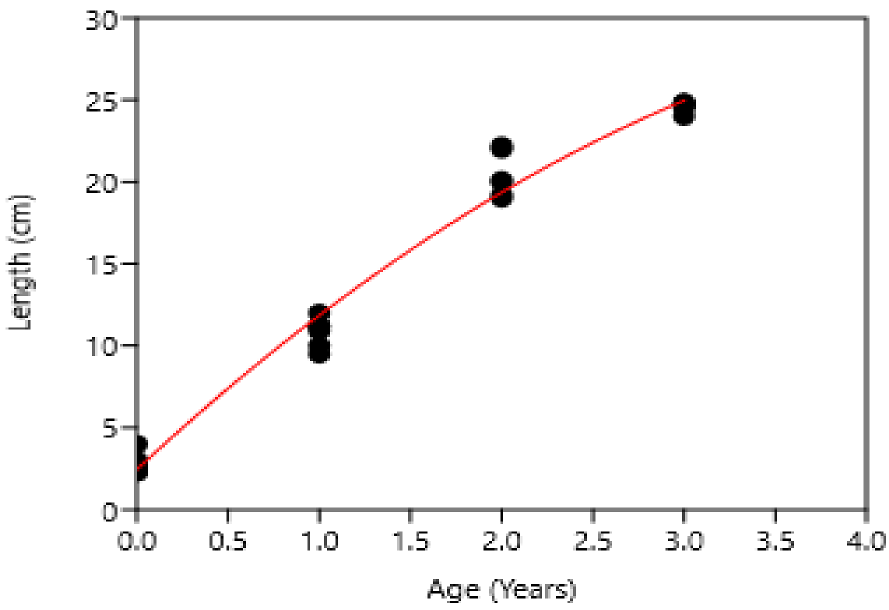


Figure 5.5: Length at age data for *Oreochromis mossambicus*, a) Female (L_t= 22.8 [1- $e^{-0.914}$ (t+0.209)]) and b) Male (L_t= 23.7 [1- $e^{-0.918}$ (t+0.212)]) in the Molepo Dam from May 2018 to April 2019.

a)



b)

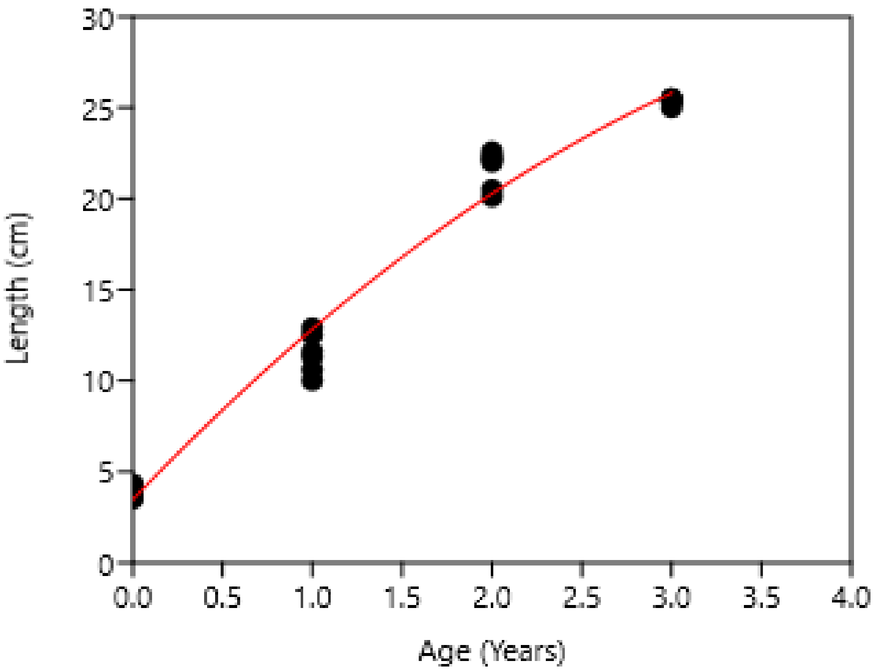


Figure 5.6: Length at age data for *Oreochromis mossambicus,* a) Female (L_t= 24.8 [1- $e^{-0.948}$ (t+0.251)]) and b) Male (L_t= 25.5 [1- $e^{-0.951}$ (t+0.253)]) in the Hout River Dam from May 2018 to April 2019.

5.5 Discussion

Fish species representing Cichlidae, Cyprinidae, Clariidae and Centrarchidae families were recorded in Molepo Dam and Hout River Dam. Water bodies in Limpopo Province are dominated by warm water fish such as Cichlids (Skeleton, 2001). *Oreochromis mossambicus* is one of the most widely distributed fish species in Limpopo Province because of the warm temperatures. Tilapia species are pre-adapted to live in lake-like conditions (Fernando *et al*., 1998). The fish species composition in Molepo Dam were numerically dominated by Cichlids, *Oreochromis mossambicus* followed by *Tilapia rendalli*. *Oreochromis mossambicus* also dominated in Hout River Dam followed by *Cyprinus carpio* belonging to the family Cyprinidae. It is important to note that *Cyprinus carpio* is exotic. The temperature regime at Hout River Dam seem to favour this fish species with a wide temperature tolerance range. However, *Cyprinus carpio* is the least dominant fish species in Molepo Dam. This may be due to environmental factors such as water level fluctuations as *Cyprinus carpio* tend to move into deeper water levels. The low number of fish caught may simply be a reflection of gill net selectivity. It may also be a result of overfishing as recreational activities occur at these small dams.

The presence and abundance of fish depends on many factors (Skelton, 2001). Fish may be stunted due to stress arising from water level fluctuations leading to shifts in species diversity and partial or total loss of fish. Dalu (2012) reported that *Tilapia rendalli* species was severely affected by water level fluctuations, being the least dominant fish species during low water levels. In this study, *Tilapia rendalli* was never caught in Hout River Dam and was one of the least dominant fish species in Molepo Dam. This may be attributed to water level fluctuations or avoidance of gill nets by *Tilapia rendalli*. *Tilapia rendalli* is characterised by strong territoriality, avoiding gill nets by swimming backwards (Starling *et al*., 2002). Gill nets were the main fish sampling gear in both Molepo Dam and Hout River Dam.

Factors influencing fish condition include season, degree of stomach fullness, growth phase, sex, health status, gonad maturity. The condition factor of *Oreochromis mossambicus* at Molepo Dam and Hout River Dam were highest during the dry season months when there was abundant food (phytoplankton) readily available to the fish. *Oreochromis mossambicus* stops feeding at temperatures below 20 °C and reproducing at 15 °C (El-Sayed, 2006). The minimum water temperature values observed was 14 and 14.5 °C in Molepo Dam and Hout River Dam respectively. In South Africa, the wet season period is usually long (3-6 months). As the water temperature decreased during the wet season months, *Oreochromis mossambicus* stopped feeding probably due to low metabolic rate. The condition factor of Oreochromis mossambicus also decreased and was lowest during the wet season. The high condition factor (K) values are considered to be an indication of better condition (Bagenal and Tesch, 1978; Ayode, 2011). In this study, *Oreochromis mossambicus* was found to be in a slightly better condition in Molepo Dam and in a fair condition in Hout River Dam during the dry season. For *Clarias gariepinus*, the mean K of 0.19 was lower than that recorded by Sara *et al*. (2013) for the same species in Hout River Dam (0.60). Although this fish species is tolerant of wide temperature range (8 - 35 °C) and water level fluctuations, wide water level fluctuations are expected to reduce food availability and metabolic functions.

Scales were successfully used for the age determination of *O. mossambicus*. The rings on the scales were validated as being true annuli by marginal increment analysis which indicated that the distance between the last annuli and the scale edge was shortest in the wet season months (November/December) in Molepo Dam and November/December/January in Hout River Dam. This is the time in which annulus formed. Annulus formation of *O. mossambicus* at these small dams coincided with the onset of increased water temperature and rainfall (increased water levels and increased water inflow into the dams) in this region. This indicates that annulus formation may be a response of these environmental factors. The results on annuls formation confirm the findings of Hadi (2008) who worked on *Oreochromis aureus* and reported that annual rings formed after the first rainfall.

Oreochromis mossambicus in this study displayed sexual dimorphism with male *Oreochromis mossambicus* growing at a higher rate and to a larger asymptotic size than female *Oreochromis mossambicus* in both Molepo Dam and Hout River Dam. Bhatta *et al*. (2012) reported similar observations where male *Oreochromis mossambicus* grew faster and bigger than female *Oreochromis mossambicus*. This implies that to maximise growth performance and increase production in aquaculture, it is important to select males instead of females because they grow faster.

The Von Bertalanffy growth curve fitted the observed length-at-age data fairly well. The asymptotic length ($L\infty$) of female *Oreochromis. mossambicus* is 22.8 and 24.8 cm in Molepo Dam and Hout River Dam respectively. The theoretical asymptotic length differed slightly with the largest length recorded for this species. Weyl and Hecht (1998) recorded slightly lower $L\infty = 22.3$ cm compared to Molepo Dam in Chicamba reservoir Mozambique for female *Oreochromis mossambicus.* Tilapia generally exhibit a rapid linear growth rate in the first year of life. Froese and Pauly (2018) reported that under natural conditions the growth achieved in the first year of life by several species of tilapia is from about 9 to 12 cm. This represents adaptations to adverse conditions for growth as a result of selection for low growth rates and relatively early maturation. This study showed similar results to the one reported by Froese and Pauly (2018) as *Oreochromis mossambicus* grew up to 9.8 and 12 cm in the first year of life in Molepo Dam and Hout River Dam respectively. This may represent an evolved adaptation to reduce its vulnerability to the environment.

Furthermore, the growth performance index (ϕ) of *O. mossambicus* (2.77) in Hout River Dam is higher than that of *O. mossambicus* (2.65) in Molepo Dam. However, growth performance of *O. mossambicus* in both small dams are higher than that estimated by Waithaka *et al*. (2018) for *Oreochromis niloticus* (2.57) in Naivasha Dam, Kenya. *Oreochromis mossambicus* (2.65) in Molepo Dam was found comparable to *Oreochromis. mossambicus* (2.60) in Sri Lanka deep reservoir reported by de Silva (1991) and *Oreochromis niloticus* (2.63) in Nam Theun reservoir reported by Beaune *et al*. (2021). This growth performance index (ϕ) is flexible and useful for determining growth potential.

CHAPTER 6: GENERAL DISCUSSION, RECOMMENDATIONS AND CONCLUSION

6.1 General discussion, recommendations and conclusion

Total nitrogen and total phosphorus concentrations were low therefore indicating that these two small dams are oligotrophic. This differs from most small waterbodies, where shallow small dams are eutrophic because of high primary production. It is therefore important for managers to implement pollution management measures to avoid these small dams being eutrophic. These management strategies will ensure that there is no massive agricultural activity in the small dam catchment areas that can introduce nitrogen and phosphorus from fertilization and also ensure that the number of livestock already existing at these small dams are retained because livestock can introduce nitrogen and phosphorus into the water. Shabalala *et al*. (2013) reported that agricultural activities have both direct and indirect effects on the quality of surface water and groundwater and it is among the leading causes of water quality degradation, mainly as a result of the excessive use of agrochemicals. Dafter *et al*. (2019) also reported that agricultural activities caused water quality degradation leading to dissolved oxygen depletion, eutrophication and salinization. It is in this regard, recommended that further studies introduce the application of PAMOLARE (Planning and Management of Lakes and Reservoirs). The PAMOLARE model has been used as an effective tool to gain insight into changes in water quality in lakes and reservoirs by simulating the response to external and internal loadings. The introduction of PAMOLARE for the management of eutrophic lakes and wetlands is based on physical, chemical and biological parameters of water resources. This PAMOLARE model is useful for predicting the outcomes from lake and wetland management strategies and thereby aiding decision making for water resource managers (Jørgensen and de Rast, 2007).

Microcystis aeruginosa were found in both Molepo Dam and Hout River Dam. However, it was not determined whether it is the *Microcystis* stain that causes liver damage in cattle and liver diseases in humans or not. Consistent with the observation that these small dams are oligotrophic, *Microcystis aeruginosa* were found in low abundance. Studies need to further investigate the presence of *Microcystis aeruginosa*. Oberholster *et al*. (2005) reported that *Microcystis aeruginosa* are the most common toxic cyanobacteria found in South African eutrophic water bodies causing death of livestock and promoting primary liver cancer in human.

Butler *et al*. (2009) reported similar observations where death of livestock was due to water contaminated with microcystins. It is important to carry out further investigations to determine the *Microcystis* strain that causes liver damage in cattle and liver diseases in humans.

Cyprinus carpio are riverine fish species. They were found in Molepo Dam and Hout River Dam at low abundance indicating water level fluctuations or low water levels in these small dams because *Cyprinus carpio* prefer deeper water levels. *Oreochromis mossambicus* were the most abundant fish species in both Molepo Dam and Hout River Dam. The general growth rate of this fish species are similar to those found in Sri Lanka reservoir (de Silva, 1991). In South Asia, temperatures are much higher than in South Africa making it ideal for the growth of *Oreochromis mossambicus.* Therefore, in South Africa results were consistent indicating no evidence of fish stunting in these small dams. The higher the temperature, the higher the growth rate. This study suggests that small dams must be fished out at the end of the growing season and introduce restocking strategy from the hatchery at the beginning of the growing season because during winter season *Oreochromis mossambicus* is not growing to the maximum growth. This will enable people to maximize exploitation. M'balaka *et al*. (2012) reported that fish restocking is commonly used to improve fish production. This often enhance the livelihoods of communities by improving an opportunity to increase food security and reduce poverty. Currently in South Africa, commercial gill netting is prohibited in waterbodies. However, this policy is under review. It is therefore important to carry out further studies to determine whether it is commercially viable to fish in these small dams.

CHAPTER 7: REFERENCES

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