University of Venda
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An Assessment of Algae and cyanotoxins in small-holder Aquaculture farms in Vhembe, South Africa

By

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Abstract

In South Africa, inland aquaculture is on the increase, especially among the rural communities. Thus aquaculture is able to provide a source of employment and improve rural incomes. This study assessed algae species and their cyanotoxins in small holder production in Vhembe district, Limpopo, South Africa. Thirteen study sites were selected to assess the algae species and their cyanotoxins. The water samples were collected in four quarters and analysed for water temperature, pH, total dissolved solids, Electrical conductivity, phosphates, nitrates, chlorophyll, cyanobacteria, cyanotoxins, metal species and quality of the water in the fish ponds. In the 1st quarter of the year there was variation in Water Temperature (23.7^{o}C-31.4^{o}C), pH (5.5-9.6), EC (3.82-46.8µS/cm), TDS (2.4-45 mg/L), Phosphate (0.0-1.09mgL^{-1}), Nitrates (0.0-1.00mgL^{-1}), Chlorophyll-a (5.8-11.5mg/m^{-3}). In the 2nd quarter there was variation inwater temperature (22.4-25.0^{o}C), pH (6.6-8.8.9), EC (19.23-21.47µS/cm), TDS (12.5-17.9 mg/L), Phosphate (1.64-1.84mgL^{-1}), Nitrates (1.02-1.88mgL^{-1}), Chlorophyll-a (4.6-15.6mg/m^{-3}). In the 3rd quarter there was variation for water temperature (22.9-25.0^{o}C), pH (7.5-9.1), EC (7.91-293.3µS/cm), TDS (11.7-180.9 mg/L), Phosphate (1.10-1.80mgL^{-1}), Nitrates (1.28-1.84mgL^{-1}),Chlorophyll-a (6.8-15.6mg/m^{-3}). In the 4th quarter there was variation forwater temperature (23.5-30.3), pH (7.1-9.3), EC (18.24-623µS/cm), TDS (23.7-136.4 mg/L), Phosphate (1.45-1.99mgL^{-1}), Nitrates (1.43-1.68mgL^{-1}), Chlorophyll-a (6.6-25.9mg/m^{-3}). The metal content of the fish pond water was variable throughout the year but with moderate levels of Al, Cd, Cr, Mn, Fe, Cu, Zn and Ba were found. The metal Fe, exceeded the DWAF guideline values during this first quarter. The presence of Cd in the fish pond water could be attributed to rainfall eroding the earthen embankments of the fish pond. The results of physico-chemical parameters promotes the growth of cyanobacteria in the fish ponds. Flow cam and SEM were used to identify the cyanobacteria species and most cyanobacteria identified are hazard to human health, fish and other aquatic organisms. Molecular technologies were used to identify cyanotoxins and there was no cyanotoxins detected which was concluded that during collection of water samples no cyanobacteria produced toxins.

Keywords: Cyanotoxins, Cyanobacteria, aquaculture, rural communities, Tilapia fish farming.

Declaration

I, ………………………………………..declare that this dissertation is my original work and has not been submitted for any degree at any other university or institution. The dissertation does not contain other persons' ideas unless specifically acknowledged and referenced accordingly.

Signed: .... Date: ....

Tshifura R.A

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Dedication

I hereby dedicate this research to my parents Mr. and Mrs. Tshifura and my husband Mr. AM Tsanwani. And to all who made this project possible.

List of abbreviations/ acronyms

DAFF	Department of Agriculture, Forest and Fisheries
DWAF	Department of Water Affairs and Forest
HABs	Harmful algal blooms
ICP-MS-	Inductively coupled plasma- mass spectrometry
LR	Leucine arginine
MCYST	Microcystin
PSP	Paralytic Shellfish Poisoning
SPE	Solid Phase Extraction
USEPA	United State Environmental Protection Agency
WQRA	Water quality research Australia

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CHAPTER ONE: INTRODUCTION

1.1 Background

The occurrence of Cyanobacteria in the fish ponds is of the most concern as their blooms appears to be increasing (Hobson et al., 2012). Cyanobacteria grow massively under ideal conditions, which include high temperature (22-32^{0}C), nitrogen and phosphate leading to algal blooms (United States Environment Protection Agency (USEPA 2012; Jubilee et al., 2010). Some of these blooms produce toxins which are harmful and degrade water quality and jeopardize aquatic ecosystem by causing fish mortality (Poovey and Netherlands, 2006).

Cyanobacteria generally affect fish production. Harmful algal blooms (HAB's) produce toxins which are hazardous to human and animal health (Metcalf and Codd, 2014). Their effects range from mild to serious, which includes irritation of skin and gills of fish, liver and neurological damage leading to the death of fish (Jubilee et al., 2010).However, not all species of cyanobacteria are toxic; there are some species which are non-toxic, which provide nutrition to fish (Smith et al., 2008).Cyanotoxins produce different toxins such as cytotoxins, neurotoxins and hepatotoxins. Hepatotoxins generally cause liver problems in human, neurotoxin affects the human body function and it can cause death, whereas cytotoxins are filaments which causes diarrhea, hair loss and constipation to human (Purkastha et al., 2010).

The United States Environment Protection Agency (USEPA)(2012)reported that the microcystin Leucine arginine (Microcystin L.R.) is the most powerful cyanotoxins causing problems in streams, ponds and lakes. Nitrogen (N) and phosphate (P) may also promote cyanobacteria species such as *Aphanizomenon, Microcystis*, *Anabaena*, *Oscillatoria* and *Lyngbya*. Cyanobacteria may occur naturally and the growth may be promoted by nitrates, which may be loaded through runoff from point sources such as industrial sites, waste water, municipal sources and also agricultural sources (USEPA, 2012).

1.2 Statement of the Problem

Cyanobacteria have adverse effects in water and also in fish ponds. They produce cyanotoxins in water, which are hazardous to fish health and humans when they are exposed to it (Sigee et al., 1999). Cyanotoxins in fish cause different sickness and may sometimes leads to the death of the fish, as a result, it affects the production of fish. The cyanobacteria produce different cyanotoxins such as neurotoxins that affect the skin, nervous system and hepatotoxins that affect the liver (USEPA, 2012).Cyanobacteria can cause oxygen depletion when it die sin water and decompose. The decomposition in turn causes the fish's death because the will be no oxygen in water for fish.

1.3 Motivation

A study by Tshifura and Gumbo (2018) showed the presence of *Microcystis*, *Mallomonas*, *Anabaena*, *Dinoflagellates Ceratium*, *Oscillatoria*, *Nostoc*, *Chlamydomonas*, *Cryptomonas*, *Scenedesmus* and *Pediastrum meyen* species in a small holder fish farm in Itsani, Vhembe District. The cyanotoxins that was present was microcystin LR, 6.17 to 732.58 µg/L which was above WHO guidelines of 1.0 µg/L. Other microcystin congeners such as YR and LY were also present in the fish tanks. Thus, the study has been extended to other fish farms in Vhembe District to assess the level of cyanobacteria species and their cyanotoxins. This study will contribute by identifying cyanobacteria and their cyanotoxins in fish ponds and raise awareness among the Limpopo Department of Agriculture staff and the farmers about the risk associating with cyanobacteria.

1.4 Research Objectives

1.4.1 General objective

To assess cyanobacteria species and their cyanotoxins in selected small holder aquaculture systems in the Vhembe district

1.4.2 Specific objectives

- Determination of the suitability of the physico-chemical properties of water in the aquaculture ponds for the growth of cyanobacteria.
- To identify the cyanobacteria species in the aquaculture ponds

- To determine the genes expressing cyanobacteria toxicity in the aquaculture ponds

1.5 Description of the Study area

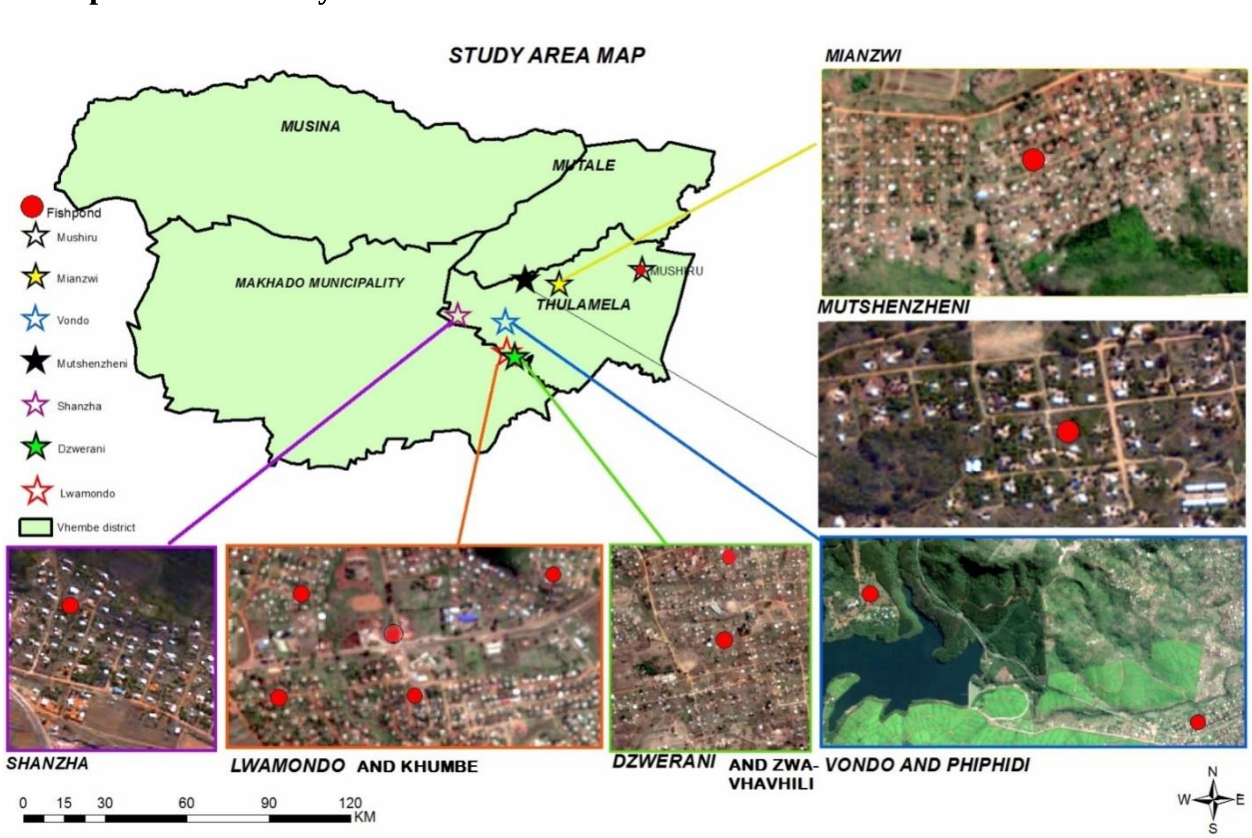


Figure 1: The location of the study area

1.5.1 Climate

Selected sites are situated in Vhembe District Municipality. The climate is subtropical, with high temperature levels (maximum up to 40^{o}C) in summer and very low temperature levels in winter, with a minimum temperature of 10^{o}C. Vhembe District receives an annual rainfall of approximately 500mm per annum between October and March (Vhembe District Municipality, 2012).

1.5.2 Hydrology

The area is characterized by few catchments, including Luvuvhu and Mutale, which are stressed by a high demand of water for activities such as human consumption and agriculture. The

District has a variety of wetlands such as Makuleke Wetlands and Sambandou and the areas are also boasted by the Fundudzi Lake (Vhembe District Municipality, 2012).

CHAPTER TWO: LITERATURE REVIEW

2.1 Aquaculture systems in Africa

Aquaculture in African countries started in Rwanda, Uganda, Zambia and Tanzania in 1940. However, these countries were only using polyculture and monoculture methods (Dadzie, 1992). From 1990 to 2004 aquaculture production has increased to 7.32 million tones, including providing livelihood and income (The World Bank, 2006).Fish has become most exported commodity. Botswana, Egypt, Ethiopia, Kenya, Morocco and South Africa are currently African countries which are extremely affected by cyanobacteria (Metcalf and Codd, 2014). Africa faces many problems in aquaculture such as ponds with poor water quality, poor fish feed, lack of good trained-workers, bad location of many fish ponds and lack of culture techniques conditions and poorly constructed ponds (Dadzie, 1992).

2.1.1 Egypt

In Egypt Tilapia, Carp, Mullet and Grass carp are farmed (Sadek, 2011). Farming in Egypt is not easy because it is a desert and the main source of water is groundwater. Therefore, groundwater is used for fish farming. Egypt consists of 100 small farms and 20 commercial aquaculture farms (Sadek, 2011).Egypt is one of the African countries with the largest population (93 million) but still a developing country. It was reported that every year the population is growing at a constant rate of 1.48 million. As a result, the demand for food and employment is very high (Macfadyen et al., 2011). Small-holder aquaculture contributes more to the economic sector than large farmers; it generates income, provides food security and nutritional food, especially in rural area because they depend on aquaculture for a living (Essa et al., 2008).

Egypt was recognized as the biggest producer of fish in Africa (1.2 MMT) because the country has enough land and suitable water but also faces some challenges such as expensive fish feeds, which has led to the use of cheaper poor-quality feeds. This decreases fish production, sometimes the shortage of water and use irrigation water for aquaculture, increases the power cost for water pumps (Macfadyen et al., 2011).Microcystis are commonly found in, lakes and rivers in Egypt and it was found that toxins have been affecting fish, human, aquatic invertebrates, and domestic animals. Copper sulfate ($CuSO_4$) was mostly used in Egypt to manage cyanobacteria because it is affordable, until they found that it has an effect on aquatic invertebrates. Currently they are replacing $CuSO_4$with potassium sulfate to manage cyanobacteria (Mostafa, 2008).

2.1.2 Ghana

In Ghana aquaculture, has been playing a major role and is still continuing to create employment. It has been reported that about 2 million people are working in aquaculture (Acquah and Onumah, 2010). Those farms mostly produce tilapia and cat fish, with tilapia producing about 88% of the total aquaculture production and catfish contributing 12% (Attipoe and Agyakwah, 2008). Fish farming is mostly practiced in cages and ponds (Abban et al., 2009)

Ghana is also facing some challenges in fish farming. The main ones are access to good quality feeds that will increase food production, lack of adequate water for fish farming due to the low rainfall in the area, lack of information on fish farming and poor management of algae in their dams and conflict over use of land and water resources. As a result, fish produced in these country's is decreasing. In addition, microcystins (*Microcystis* and *Anabaena* have been found in Ghanaian water, more-especially in fish farming (Ofori, 2000; Finegold et al., 2010).Farming is also contributing in creating employment and is mostly dominated by the private sector. However, it plays a major role in poverty alleviation (Mensah et al., 2006).

2.1.3 Kenya

Fish farming was started in 1920 using warm water and they were farming tilapia fishes. Fish production started increasing in 1960 but decreased in 1970 because of the shortage of information and resources (Poovey and Netherland, 2006). Today fish farming is increasing due to the development of methods such as monoculture and polyculture which are being used for fish production (Poovey and Netherland, 2006). Ndanga et al. (2013) reported that most fish farmers in Kenya are men and women who are involved in processing, marketing and production of fish.

Kenya aquaculture also plays a major role in the economic sector. Although aquaculture has not reached the employment target, it has created 800 000 employment opportunities indirectly and 80,000 directly (Mwangi, 2008). Aquaculture is divided into three groups; namely cold freshwater aquaculture and warm aquaculture. In Kenya farmers' practice, cold freshwater farming, producing rainbow trout using tanks and warm freshwater producing African catfish and tilapia fish (Mwangi, 2008). Tilapia fish is mostly farmed and constitute about 90% of aquaculture. Kenya aquaculture is facing many problems, which affect the production of aquaculture. Some of the challenges which are faced by Kenya farmers are: Lack of quality feeds, lack of training programs for farmers and poor funding of small farmers by government (Mwangi, 2008). Raffoul(2012) reported that cyanobacteria were dominated in Lake Naivashain Kenya which also led to a low production of fish. In addition, different cyanobacteria species such as *Microcystis, Anabaena, Aulacoseira and Synedra*were detected in Lake Naivasha.

2.1.4 Zimbabwe

In Zimbabwe Tilapia, carps and catfish are farmed. Tilapia is farmed in the northern part of Zimbabwe (Zambezi Valley and Kariba Lake) because the temperature is high and suitable for Tilapia fish (Blow and Leornard, 2007). Trout is normally farmed in a cooler temperature in the eastern part of Zimbabwe. Tilapia fish is farmed on three farms for commercial purposes. The Bream Farm, Mazvikadei Fish Farm and Lake Harvest aquaculture are examples of these farms. Trout fish is farmed at Clairmont Trout Farm. Trout farming faces some challenges of regarding cyanobacteria, which leads to low fish productivity(Blow and Leornard, 2007).

Two farms, Elanne and Lake Harvest in Zimbabwe farm Tilapia fishes which are being exported to Europe. The two farms are located along the Zambezi River, meaning they use water from ZambeziRiver. Elanne is able to produce 480 tons of fish per year although the farm faces challenges such as of mismanagement of water in the river, which causes fish loss, on the other hand, Lake Harvest produces about 2000 tons per year which is exported to the U.S and Europe (Windmar et al., 2000).

2.1.5 South Africa

South Africa produces Albalone, Prawn, Mussel and Oysterwhich is mainly farmed in the Western Cape (DAFF, 2011). The Western Capeis theleading province in aquaculture, in South Africa at 43.8%, followed by Mpumalanga, Kwazulu-Natal, Eastern Cape at 12.5% each, Limpopo and Northern Cape at 3.1% each and lastly North west at 1.6% (Botes et al., 2006). Turfloop Township in Limpopo Province has a warm water species facility which could be shared by three provinces such as North West, Mpumalanga and Limpopo. Those facilities help to increase the source of fingerlings such as tilapia, cat fish and carp (Berold, 2005). From the year 2000 Aquaculture production has increased due to an increase in Albalone and Mussels fish. As a result, the employment rate (permanent and temporary) has also increased (DAFF, 2011).

The development of aquaculture for food production was started in 1980 in rural areas of South Africa. Species such as Tilapia, Silver carp, Bighead carp, Catfish, Ornamental, salmonids and Grass carp were farmed in various areas, including Venda, Transkei, Lebowa and Gazankulu between 5 to 10 tons of fish per year (Rouhani and Britz, 2004).The production of warm water species such as ornamental fish decreases in winter because the temperature becomes too cold for fish and also salmonids (cold water fishes) production decreases during summer because it becomes too warm in the summer (Rouhani and Britz, 2004).

In the Western Cape fish production decreases every year in winter due to water availability and the low temperatures. In 2002 some farms were closed in the Western Cape due to algal problems, which were causing an unpleasant taste to the fish (Berold, 2005).The North-West Province, lowveld areas of Limpopo and Mpumalanga Province, low-lying areas of Kwazulu-Natal and lower Orange River in Northern Province have suitable temperature conditions for the culture of warm water fish species such as Tilapia, Ornamental fish, Barbel and Carp, whereas Trout culture can be farmed in the Western Cape and Mpumalanga in the Lydenburg area (Rouhani and Britz, 2004).

Aquaculture is now able to employ unskilled employees and skilled employees. For unskilled employees, training in aquaculture is offered. The Employment rate increased in 2011 at 2% and the majority of people employed in 2011 were males at 74% and females 23% (DAFF, 2012).The Western Cape had the highest fish production level in 2011, followed by the Eastern Cape, Northern Cape and Kwazulu-Natal. DAFF reported that in 2030 fish supplies will dominate fish production because the world population is increasing, which will lead to a higher demand for fish (DAFF, 2013). About 12.5 % of the freshwater fish produced is being exported to Asia, Europe and America (Botes et al., 2006)

In 2010 it was reported that in the Western Cape and Eastern Cape about seven farms were closed between April and August, and August and September due to harmful algal blooms that caused diarrheic shellfish poisoning which was caused by dinoflagellates, *Dinophysis acuminate*, and *Alexandrium catenella*. However, aluminium sulfate was used to manage the cyanobacteria in those farms (DAFF, 2012).*Escherichia coli* and cyanobacteria were also found in other farms which was caused some problems. It is still a problem now even though it is less serious than before (DAFF, 2011). South Africa uses different methods of fish farming, such as tanks, cages, recirculation, earth ponds and trays ponds. However, tanks are commonly used because they are cheap (Botes et al., 2006).

2.2 Management of cyanobacteria in aquaculture systems

The Managing of cyanobacteria using chemicals has some advantages and disadvantages. However, it is very important to check the effects before applying since it might cause some problems. Some of the advantage of using chemicals is that it is easier to apply them than other methods and it takes a short period to solve the problem. Disadvantages include the fact that they are very expensive and sometimes endanger other aquatic organisms. Also, during the treatment process, the fish water cannot be used until the treatment process is completed.

2.2.1 Copper sulphate ($CuSO_4$)

Copper sulphate ($CuSO_4$) may be found in granules or powder form and is used for the treatment of algal communities (Schulthesis, 2000). When copper sulphate is added to water it affects the cell membrane of cyanobacteria (WQRA, 2009).$CuSO_4$ is applied in warm water between 50^0C and 68^0C water temperature, more-especially during the spring season. The application of copper depends on the growth of algae: if algae is growing at a high rate, the amount of copper used must be large (Schulthesis, 2000).

The$CuSO_4$ method is mostly used in early stages of cyanobacteria because in the late stages because is very expensive. When the cyanobacteria die, it will produce cyanotoxins and managing the algae species normally depends on the size of the pond and species (WQRA, 2009). A small pond is easier to treat and it can be done by using small piece of $CuSO_4$, whereas large ponds need more pressure from boat bailer or a motor (WQRA, 2009). Some of the disadvantages of $CuSO_4$ are that it is corrosive and it is not effective for a long time.

Some of the advantages of using $CuSO_4$ to control algae, does not have any effect on quantity of water, other aquatic organisms and water which has been treated with $CuSO_4$ is safe for irrigation purposes. In addition, the water is safe for humans to handle, and it can completely treat algae. Physical parameters such as temperature, dissolved oxygen, pH, and alkalinity influence the effectiveness of$CuSO_4$. Copper sulphate inhibit the growth of *Anabaena*, *Cylindrospermopsis* and *Microcystis* and has no effect on the growth of *Nostoc* (WQRA, 2009).

2.2.2 Sodium carbonate peroxyhydrate (Green Clean, Phycomycin)

When sodium carbonate peroxyhydrateis applied, it reacts with water and become sodium carbonate and hydrogen peroxide, which kills cyanobacteria. Some of the disadvantages of using sodium carbonate are, it increases pH and the water becomes alkaline, which is detrimental to fish, other aquatic organisms and other animals such as birds (that depend on that water for drinking). Therefore, these must be removed from the water because they might die (WDNB, 2012).

2.2.3 Aluminium sulphate ($Al_2(SO_4)_3$)

Aluminium sulphate is used to precipitate, to remove phosphorus and to treat sediments against phosphorus because phosphorus influences cyanobacteria in water. This method depends on the water quality and the chemistry of the system. When using $Al_2(SO_4)_3$nutrients are absorbed in water, and those are the nutrients that cause cyanobacteria (WQRA, 2009).

2.2.4 Copper chelate compounds

Copper compounds have been used for several years to treat algae. Those compounds can be used to control algae such as filaments cyanobacteria and *Cladophora* spp (WQRA, 2009). The compounds can be sometimes toxic depending on the type of fish, and due to toxicity, the fish might die. Copper chelate compounds can be found in powder form or crystals (Clayton, 2009). Examples of copper chelate compounds are copper citrate and copper ethanolamine complexes (Chorus and Bartram, 1999). Copper chelate works differently from copper sulfate as Cu^{2+}. They are not toxic to other aquatic organisms and does not have any water restriction. The problem is that they cannot be applied to alkaline water because copper chelated compounds work effectively in non-alkaline water and they are very expensive (Helfrich et al., 2009).

2.2.5 Biological control methods

Biological management involves using bacteria, viruses, bio-manipulation and grazing to manage cyanobacteria in water. Biological management is better than other methods such as chemical and mechanical methods because when they are applied in water they have no effect on other aquatic organism (Sigee et al., 1999).

2.3 Impact of the physico-chemical parameters on fish and cyanobacteria

The most important water quality parameters that may affect the production and growth of fish promotes the growth of cyanobacteria includes temperature, turbidity, water color, carbon dioxide, pH, alkalinity, hardness, nitrite, nitrate and etc (Abowei, 2010). According to shah et al., 2000, dissolved oxygen affects survival, growth, distribution, physiology and behavior.

Temperature affects the metabolism, Growth rate, feed conversion rate and reproductive ability of fish. fish are not able to regulate their own body temperature and therefore have a body temperature similar to that of the water around them. each fish has an optimal temperature for growth for example trout are often killed or stressed by temperatures that are between 23-25˚C, whereas Tilapia, carp and catfish thrive in warm ponds of up to 33˚C and Tilapia are more affected by too low temperatures, and usually die with the temperature below 12-13˚C (Bhatnagar, 2008).

A change in pH represents a large change in water quality and fish generally prefer water that is neutral (pH 6-8). algae in the pond use carbon dioxide and produce oxygen (Bhatnagar, 2008). Carbon dioxide is acidic and causes the pH of the water to be acidic. If not carefully monitored and possibly controlled, the pH may drop to levels that are dangerous to the fish and when pH is below 5, they are stressed and will not eat and it affect the growth and production (Abowei, 2010).

2.4 Impact of cyanotoxins on fishes

In fish, exposure to cyanotoxins can occur in various ways, however, the oral route is the most important. This is mainly through drinking water, or by eating contaminated plants or other fish and dermic exposure and inhalation are both possible. Toxic blooms can reappear periodically in hydric environments, cyanotoxins such as nodularins, cylindrospermopsins, and microcystins can cause liver and kidney damage, cytotoxicity, neurotoxicity, skin toxicity, gastrointestinal disturbances, and other problems. These effects may appear days or may later take place within a few minutes of exposure (Funari et al., 2008).

Cyanotoxins can be divided into groups such as mechanism in land vertebrates and their chemical structure. mechanism in land vertebrates especially mammals, causes three toxins such as hepatotoxins, neurotoxins and dermatotoxins. The chemical structure within which they may be classified as cyclic peptides, alkaloids, or lipopolysaccharides (LPS). Neurotoxins are the most toxic compounds produced by cyanobacteria and may cause paralysis of the respiratory muscles and death (Humpage and Falconer. 2003.)

Microcystin has been reported that it can cause gill damage and led to liver necrosis. Fish can be exposed to microcystins while feeding, or the toxin can pass through the gills during breathing. Fish in the early stages of life are generally more sensitive to toxic compounds than adults. The occurrence of disturbances in the early development stages can often result in death (Chorus and Bartram.1999).

2.5 Conclusion

Cyanobacteria are common in fish ponds but become a problem when they start to produce toxins. Most countries are facing this cyanobacteria problem and it also affect fish production. *Dinoflagellates, Dinophysis acuminate, Alexandrium catenella Microcystis, Anabaena, Aulacoseira and Synedra* have been detected in most countries and algicides have been used but some of them have bad effect on water quality.

CHAPTER THREE: THE PHYSICO-CHEMICAL QUALITY OF THE AQUACULTURE POND WATER

3.1 Introduction

The physico-chemical conditions measured in four seasons from the water sample were pH, water temperature, Electrical Conductivity (EC), Total Dissolve Solids (TDS), Nitrates, phosphate and nitrates. Water used for fish farming will not give the best production if water quality is not optimal (Keremah et al., 2014).

The study was conducted in ten villages: Lwamondo (Tshifulanani), Lwamondo (murahu-ha-thavha), Lwamondo, Vondo, Dzwerani, Phiphidi, Mianzwi, Mutshenzheni, Zwavhavhili, Mushuri and Khumbe Village in Vhembe District, Limpopo Province (Figure 1).

3.2 MATERIALS AND METHODS

3.2.1 Survey of fish farms in Vhembe District and site selection

A list of fish farms from the Limpopo Provincial Department of Agriculture was used to identify Fish farms in Vhembe district. The following areas were selected, three places in Lwamondo, Phiphidi, Vondo, Zwavhavhili, Shanzha, Mianzwi, Mutshenzheni, Khumbe and Mushuri. The aquaculture ponds are located near springs which provide the source of water.

3.2.2 Sampling tools

The following tools were used during the collecting of samples, sterilized glass bottles and also a permanent marker, to mark the samples differently to avoid confusing them. The sample points were measured using a GPS, this helps in referencing the sampling points.

3.2.3 Sample collection

Water samples were collected quarterly in 2015 from different fish dams. The water samples were collected in 250ml glass bottles. The water samples were subdivided for physico-chemical analysis (Chapter 3), microcystin analysis (Chapter 4) and identification of cyanobacteria species using FlowCam and Scanning Electron Microscope (Chapter 5) and using molecular techniques (Chapter 6).

3.3SAMPLE ANALYSIS

3.3.1 Physico-chemical analysis

Cyanobacteria and fish have a pH, Temperature, EC, TDS range which is favorable for their optimal growth and production. Therefore, it was important to determine the physico-chemical parameters. pH, water temperature, Electrical conductivity (EC), Total dissolved solids (TDS) were measured to determine if the water was suitable for production of fish and if the water was promoting the growth of cyanobacteria. Samples were analysed using Crison MM40 Multimeter, calibrated as per manufacturer instructions.

3.3.2 Chlorophyll *a* analysis

A Spectrophotometer (orioon aquamate 700, VIS spectrometer) was used to analyze chlorophyll *a*, by recording the absorbance at 750 nm and 665 nm (750b and 665b).

Calculations for chlorophyll were performed by subtracting absorbance 665a-750a = corrected 665a absorbance 665b-750b = corrected 665b absorbance

Chlorophyll $a = \frac{29.62(665a - 665b) \times Ve}{Vs \times 1}$

Unit: mg m^{-3}

Using the corrected 665a and 665b absorbance to calculate.

Where: V_e = Volume of ethanol extract (ml)

V_s = Volume of water sample (litres)

l = Path length of cuvette (cm)

3.3.3 Nutrient analysis

The water samples were filtered through a 0.45µm membrane Sartorius filter, into four tests tubes. The water samples for nitrates and phosphates were analysed using Dionex Ion chromatography.

3.3.4 Heavy and trace metals species analysis

The water samples were filtered through 0.45 µm syringe filter (GVS Filter, Indiapolis, IN, USA) and acidified with a drop of nitric acid analytical grade. The water samples were analysed for the presence of metal. The metals were analysed by ICP-AES (Thermo ICAP 6300 instrument, Thermo Electron Limited, Cambridge, UK) and ICP-MS (Agilent 7700 instrument, Agilent Technologies Inc., Tokyo, Japan) in duplicate.

3.3.5 Climate data

The climate data (rainfall, air temperature, solar radiation) was obtained from the ARC Institute of Soil, Climate and Water in Pretoria, South Africa.

3.4 Data analysis

The Microsoft (MS) Excel 2013 was used to compute the mean and standard deviation of the replicates. The mean was then used to draw graphs using the program R software. The XLSTAT free software version 2016 program was used to determine any correlation relationship (Spearman) among the physico-chemical variables and climate data at $p<0.05$ level.

3.5 Results and discussion

3.5.1 The physico-chemical quality of aquaculture water: Mr. Nemaguvhuni

The fish ponds of Mr. Nemaguvhuni (Figure 2) shows that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values.The pH was within the range, between 6 and 9 as stated by Bryan et al. (2011)(Figure 2A).

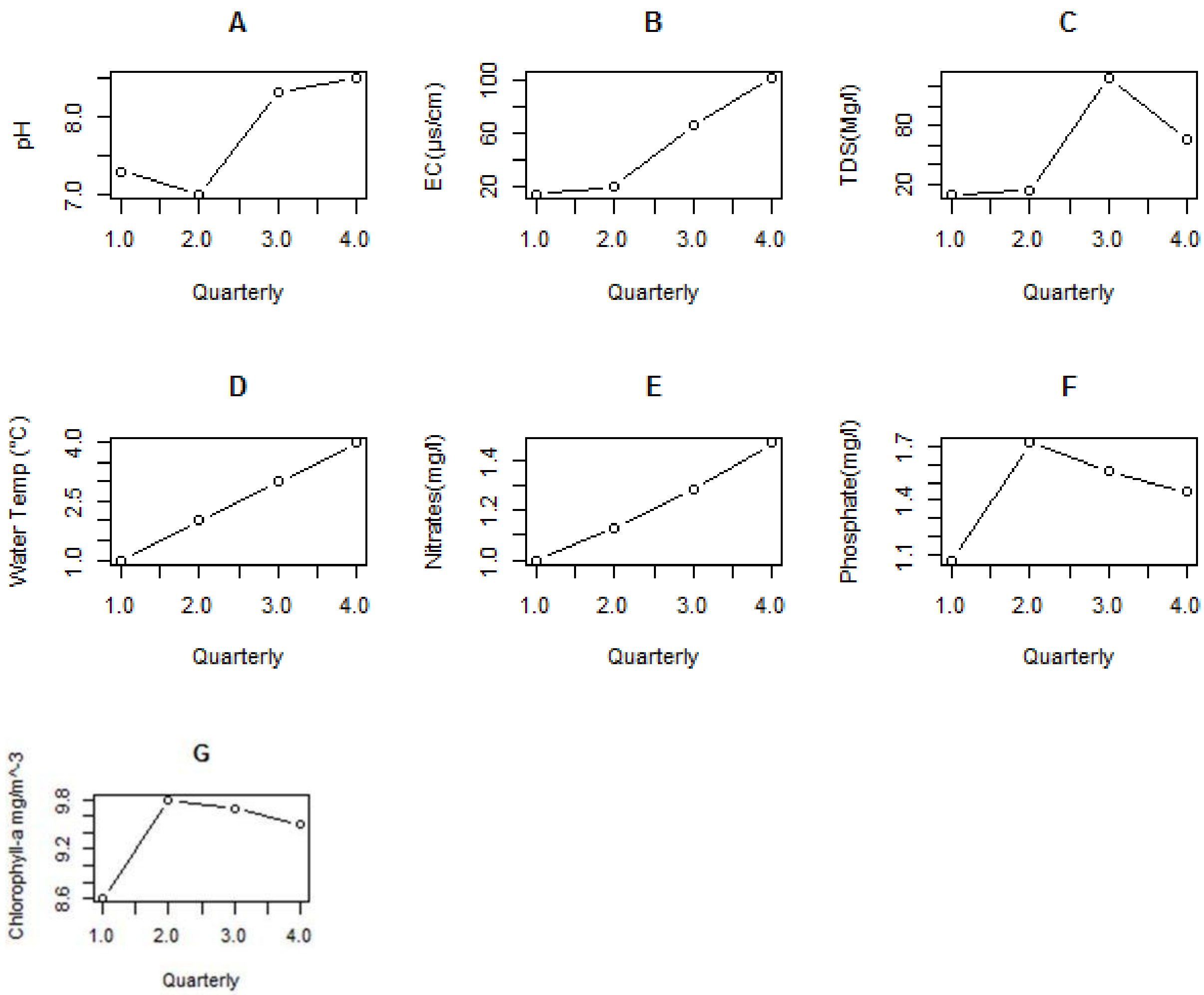


Figure 2: showing the quarterly physico-chemical parameters for Mr. Nemaguvhuni fish pond.

The electrical conductivity (EC) ranged from 13.7 to101.3 µS/cm (Figure 2B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 to 5000 µS/cm and therefore the EC of the water is below the standard. The total dissolved solids (TDS) of the water ranged from 8.02 to 65.03 mg/l (Figure 2C), while the TDS of the water should not be more than 500 mg/l (Keremah et al., 2014). The water temperature ranged from 23 to 29.7 ^{0}C (Figure 2D), because the fish ponds are under the shadow of a tree. Keremah et al. (2014) stated that water temperature must be in the range of 20 to 30 ^{0}C and the water temperature of Mr. Nemaguvhuni was within the stated range.

The study showed that nitrates ranged from 1 to 1.473 ppm (Figure 2E) which is lower than DWAF (1996) guideline value of 300 ppm and the Indonesian national standard water quality for nitrate is 10 ppm (Pangemanan et al., 2014). It means that water has low nitrate content. Nitrates are important nutrient for fish growth but can be harmful if it exceeds the optimum range. The nitrate levels were positively correlated with electrical conductivity and quarterly, with Spearman coefficient of 1.00 and $p = <0.0001$ (Tables 2& 3). This is expected since the nitrates are soluble anions that are able to conduct an electrical charge during the electrical conductivity measurements. However quarterly availability of nitrates in the fish pond water is worrisome since green algae and cyanobacteria may take advantage and proliferate.

The phosphate ranged from 1.072 to 1.724 ppm (Figure 2F) which was seventeen times above the DWAF (1996) guideline value of 0.1 ppm and almost at par with the Indonesian national standard water quality typical range for surface waters 1 ppm (Pangemanan et al,. 2014). This implies that the fish pond water has high phosphate content. The phosphate levels were significantly and positively correlated with chlorophyll-a with Spearman coefficient of 1.00 and $p = <0.0001$. This is contrary to the study of Breukelarr et al. (1994) who found no correlation between phosphate and chlorophyll-a in a bream and carp aquaculture pond. This is expected since the green algae and cyanobacteria are phototrophic organism and utilize chlorophyll-a during the photosynthesis process. The study of D'agostino et al. (2016) support this correlation that the cyanobacteria, *Anabaena circinalis*, that the presence of phosphates promotes photosynthesis and growth (not senescence) and the utilisation of chlorophyll-a (Figure 2G). The implication of high nutrient levels in the fish pond water and warm water are stimulating to the growth of green algae and cyanobacteria species.

3.5.2 The presence metal species in aquaculture water: Mr. Nemaguvhuni

The metal content of the fish pond water was variable throughout the year but with high levels of Al, Mn, Fe, Co, Ni, Cu and Ba in the first quarter (Table 1). Some of the metals such as Al, Mn, Fe exceeded the DWAF (1996) guideline values during this first quarter. The presence of these metals: Ti; Fe; Cu in the fish pond water could be attributed to rainfall eroding the earthen embankments of the fish pond (Figure 3). The Spearman correlation coefficient did show a positive relationship between these metal variables: Ti; Fe; Cu and rainfall data ($R= 1.00$; $p = <0.0001$) (Tables 2 & 3).

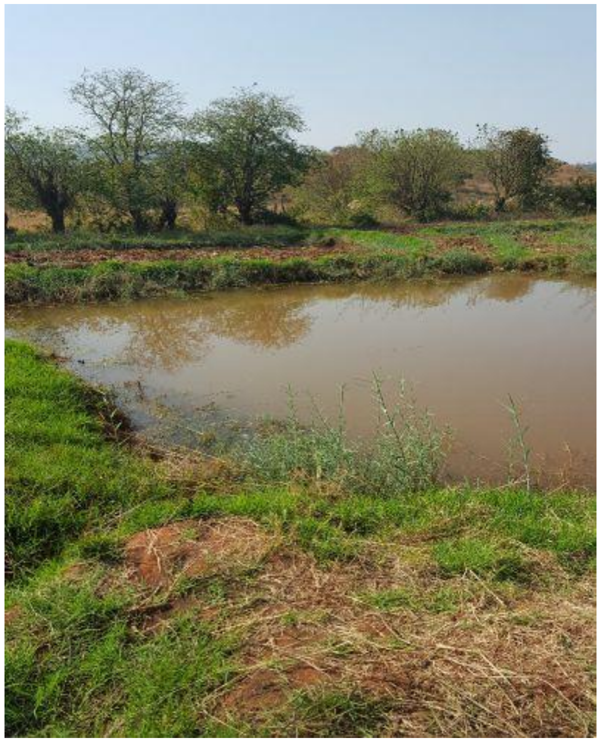


Figure 3: The earthen Lwamondo fish dam for Mr. Nemaguvhuni

The Ti was significantly and positively correlated with Fe, Cu with the Spearman coefficient of 1.00 and $p < 0.0001$ (Tables 2 & 3). The Co was significantly and positively correlated with Ni, As with the Spearman coefficient of 1.00 and $p < 0.0001$. The Mn was significantly and positively correlated with Se, Ba with the Spearman coefficient of 1.00 and $p < 0.0001$. This was expected since Ti, Co, Cu and Fe are probably found in the Basalt group which is found in the study area (Figure 4). These metals, Al, Mn, Fe, Co, Ni, Cu and Ba are probably associated with Plagioclase, $(Na,Ca)Al_{1\text{-}2}Si_{3\text{-}2}O_8$ and pyroxenes with general formula is $XY(Si,Al)_2O_6$, where X is major elements: Ca, Na, Fe^{2+}, Mg, Zn, Mn, Li and where Y is minor trace elements: Cr, Al, Fe^{3+}, Mg, Co, Mn, Sc, Ti, V, Fe^{2+} (Eggleton et al., 1987). Thus the rain induced weathering of earthen aquaculture ponds could have contributed to the presence of these metals in the aquaculture ponds.

Table 1: The presence of mean metal species in the aquaculture pond for Mr Nemaguvhuni

ppb	Nemaguvhuni				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	**2nd QTR**	**3rd QTR**	**4th QTR**	No adverse effect	toxic to stickleback	toxic to striped bas	Lethal to brown trout (*Salmotrutta*)
Al	35.68±0.35	0.88±0.06	3.84±0.25	8.64±0.44	**30**	**70**	**105**	1500
Ti	2.17±0.18	0.00±0.01	0.48±0.04	0.04±0.01				
V	0.78±0.00	0.57±0.01	2.50±0.04	0.93±0.06				
Cr	51.62±0.03	0.16±0.00	0.12±0.00	0.02±0.01	**20000**			
Mn	2119.79±4.06	0.10±0.00	0.30±0.01	0.12±0.00	**100**	**500**	**600**	
Fe	2528.85±22.33	0.38±0.01	9.56±0.19	0.31±0.03	**10**	**1750**		
Co	21.00±1.10	0.02±0.00	0.04±0.00	0.04±0.00				
Ni	496.67±22.80	0.14±0.00	0.43±0.00	0.44±0.01				
Cu	2.14±0.11	0.84±0.00	1.47±0.00	0.84±0.04	**5**			
Zn	11.39±0.47	2.16±0.01	8.14±0.02	12.48±0.12	**30**			
As	0.91±0.02	0.05±0.00	0.03±0.00	0.10±0.01		**50**		
Se	2.00±0.04	0.45±0.00	0.45±0.00	0.10±0.02	**300**	**460**		
Mo	2.16±0.07	0.13±0.00	0.18±0.01	0.03±0.00				
Cd	0.02±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.29±0.01	0.07±0.00	0.36±0.01	0.30±0.01				
Ba	133.96±1.64	105.80±0.86	40.99±0.33	85.12±0.13				
Hg	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.19±0.01	0.01±0.00	0.02±0.00	0.04±0.00	**10**	**30**	**2150**	

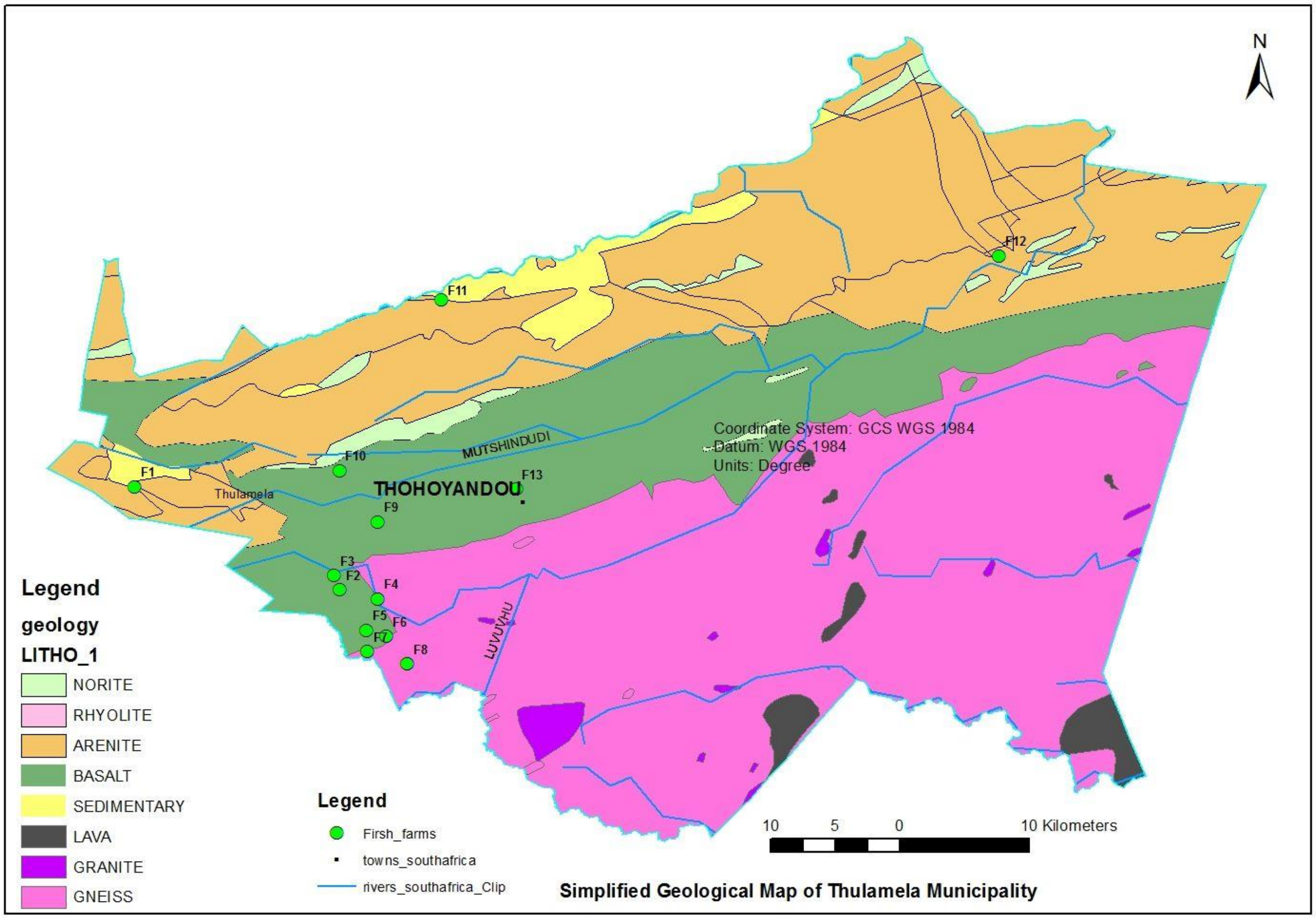


Figure 4: The geological map overlying the aquaculture ponds. F1 Mr Shavhani; F2 Mr. Nemaguvhuni; F3 Mr. Mudau; F4 Mr. Mufunwaini (Zwavhavhili); F5 Mr. Mufunwaini - (Lwamondo garage); F6 Mrs. Nemubvumoni; F7 Mrs Mushiana; F8 Mrs Mathobo; F9 Mr. Tshivhase; F10 Mr. Nevondo; F11 Mrs. Mahwasane; F11 Mr. Ramugumo; F12 Mr Rambuda

Table 2: Spearman correlation matrix of the physico-chemical & climate data parameters at Lwamondo (Nemaguvhuni fish farm)

Variables	Qtr	pH	EC	TDS	Water To	NO3	PO4	Chl-a	AirTm	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se
Qtr	**1**	0.800	**1.000**	0.800	0.949	**1.000**	0.200	0.200	0.200	-0.200	-0.200	-0.400	-0.200	0.400	-1.000	-0.800	-0.200	-0.400	-0.400	-0.200	-0.800	-0.400	-0.800
pH	0.800	**1**	0.800	0.600	0.632	0.800	-0.400	-0.400	0.400	0.400	0.400	0.000	0.400	0.200	-0.800	-0.400	0.400	0.200	0.200	0.400	-0.600	0.200	-0.400
EC (µS/cm)	**1.000**	0.800	**1**	0.800	0.949	**1.000**	0.200	0.200	0.200	-0.200	-0.200	-0.400	-0.200	0.400	-1.000	-0.800	-0.200	-0.400	-0.400	-0.200	-0.800	-0.400	-0.800
TDS (mg/l)	0.800	0.600	0.800	**1**	0.632	0.800	0.400	0.400	-0.400	-0.400	-0.400	-0.800	-0.400	-0.200	-0.800	-0.400	-0.400	-0.200	-0.200	-0.400	-1.000	-0.200	-0.400
Water ToC	0.949	0.632	0.949	0.632	**1**	0.949	0.316	0.316	0.316	-0.316	-0.316	-0.316	-0.316	0.632	-0.949	-0.949	-0.316	-0.632	-0.632	-0.316	-0.632	-0.632	-0.949
Nitrates (mg/	**1.000**	0.800	**1.000**	0.800	0.949	**1**	0.200	0.200	0.200	-0.200	-0.200	-0.400	-0.200	0.400	-1.000	-0.800	-0.200	-0.400	-0.400	-0.200	-0.800	-0.400	-0.800
Phosphates (r	0.200	-0.400	0.200	0.400	0.316	0.200	**1**	**1.000**	-0.600	-1.000	-1.000	-0.800	-1.000	0.000	-0.200	-0.400	-1.000	-0.800	-0.800	-1.000	-0.400	-0.800	-0.400
Chlorophyll-a	0.200	-0.400	0.200	0.400	0.316	0.200	**1.000**	**1**	-0.600	-1.000	-1.000	-0.800	-1.000	0.000	-0.200	-0.400	-1.000	-0.800	-0.800	-1.000	-0.400	-0.800	-0.400
Temp	0.200	0.400	0.200	-0.400	0.316	0.200	-0.600	-0.600	**1**	0.600	0.600	0.800	0.600	0.800	-0.200	-0.400	0.600	0.000	0.000	0.600	0.400	0.000	-0.400
Rain	-0.200	0.400	-0.200	-0.400	-0.316	-0.200	-1.000	-1.000	0.600	**1**	**1.000**	0.800	**1.000**	0.000	0.200	0.400	**1.000**	0.800	0.800	**1.000**	0.400	0.800	0.400
Rad	-0.200	0.400	-0.200	-0.400	-0.316	-0.200	-1.000	-1.000	0.600	**1.000**	**1**	0.800	**1.000**	0.000	0.200	0.400	**1.000**	0.800	0.800	**1.000**	0.400	0.800	0.400
Al	-0.400	0.000	-0.400	-0.800	-0.316	-0.400	-0.800	-0.800	0.800	0.800	0.800	**1**	0.800	0.400	0.400	0.200	0.800	0.400	0.400	0.800	0.800	0.400	0.200
Ti	-0.200	0.400	-0.200	-0.400	-0.316	-0.200	-1.000	-1.000	0.600	**1.000**	**1.000**	0.800	**1**	0.000	0.200	0.400	**1.000**	0.800	0.800	**1.000**	0.400	0.800	0.400
V	0.400	0.200	0.400	-0.200	0.632	0.400	0.000	0.000	0.800	0.000	0.000	0.400	0.000	**1**	-0.400	-0.800	0.000	-0.600	-0.600	0.000	0.200	-0.600	-0.800
Cr	-1.000	-0.800	-1.000	-0.800	-0.949	-1.000	-0.200	-0.200	-0.200	0.200	0.200	0.400	0.200	-0.400	**1**	0.800	0.200	0.400	0.400	0.200	0.800	0.400	0.800
Mn	-0.800	-0.400	-0.800	-0.400	-0.949	-0.800	-0.400	-0.400	-0.400	0.400	0.400	0.200	0.400	-0.800	0.800	**1**	0.400	0.800	0.800	0.400	0.400	0.800	**1.000**
Fe	-0.200	0.400	-0.200	-0.400	-0.316	-0.200	-1.000	-1.000	0.600	**1.000**	**1.000**	0.800	**1.000**	0.000	0.200	0.400	**1**	0.800	0.800	**1.000**	0.400	0.800	0.400
Co	-0.400	0.200	-0.400	-0.200	-0.632	-0.400	-0.800	-0.800	0.000	0.800	0.800	0.400	0.800	-0.600	0.400	0.800	0.800	**1**	**1.000**	0.800	0.200	**1.000**	0.800
Ni	-0.400	0.200	-0.400	-0.200	-0.632	-0.400	-0.800	-0.800	0.000	0.800	0.800	0.400	0.800	-0.600	0.400	0.800	0.800	**1.000**	**1**	0.800	0.200	**1.000**	0.800
Cu	-0.200	0.400	-0.200	-0.400	-0.316	-0.200	-1.000	-1.000	0.600	**1.000**	**1.000**	0.800	**1.000**	0.000	0.200	0.400	**1.000**	0.800	0.800	**1**	0.400	0.800	0.400
Zn	-0.800	-0.600	-0.800	-1.000	-0.632	-0.800	-0.400	-0.400	0.400	0.400	0.400	0.800	0.400	0.200	0.800	0.400	0.400	0.200	0.200	0.400	**1**	0.200	0.400
As	-0.400	0.200	-0.400	-0.200	-0.632	-0.400	-0.800	-0.800	0.000	0.800	0.800	0.400	0.800	-0.600	0.400	0.800	0.800	**1.000**	**1.000**	0.800	0.200	**1**	0.800
Se	-0.800	-0.400	-0.800	-0.400	-0.949	-0.800	-0.400	-0.400	-0.400	0.400	0.400	0.200	0.400	-0.800	0.800	**1.000**	0.400	0.800	0.800	0.400	0.400	0.800	**1**
Mo	-0.200	-0.400	-0.200	0.400	-0.316	-0.200	0.600	0.600	-1.000	-0.600	-0.600	-0.800	-0.600	-0.800	0.200	0.400	-0.600	0.000	0.000	-0.600	-0.400	0.000	0.400
Cd	-0.400	-0.800	-0.400	0.000	-0.316	-0.400	0.800	0.800	-0.800	-0.800	-0.800	-0.600	-0.800	-0.400	0.400	0.200	-0.800	-0.400	-0.400	-0.800	0.000	-0.400	0.200
Sb	0.000	0.400	0.000	0.400	-0.316	0.000	-0.400	-0.400	-0.400	0.400	0.400	-0.200	0.400	-0.800	0.000	0.600	0.400	0.800	0.800	0.400	-0.400	0.800	0.600
Ba	-0.800	-0.400	-0.800	-0.400	-0.949	-0.800	-0.400	-0.400	-0.400	0.400	0.400	0.200	0.400	-0.800	0.800	**1.000**	0.400	0.800	0.800	0.400	0.400	0.800	**1.000**
Hg	-0.775	-0.258	-0.775	-0.775	-0.816	-0.775	-0.775	-0.775	0.258	0.775	0.775	0.775	0.775	-0.258	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775	0.775

Table 3: p-values of the physico-chemical & climate data parameters at Lwamondo (Nemaguvhuni fish farm F2)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.333	**0.000**	0.333	0.083	**0.000**	0.917	0.917	0.917	0.917	0.917	0.750	0.917	0.750	0.083	0.333	0.917	0.750	0.750	0.917	0.333	0.750	0.333	0.917	0.750	1.000	0.333	0.333
pH	0.333	**0**	0.333	0.417	0.417	0.333	0.750	0.750	0.750	0.750	0.750	1.000	0.750	0.917	0.333	0.750	0.750	0.917	0.917	0.750	0.417	0.917	0.750	0.750	0.333	0.750	0.750	0.750
EC (µS/cm	**< 0.0001**	0.333	**0**	0.333	0.083	**< 0.0001**	0.917	0.917	0.917	0.917	0.917	0.750	0.917	0.750	0.083	0.333	0.917	0.750	0.750	0.917	0.333	0.750	0.333	0.917	0.750	1.000	0.333	0.333
TDS (mg/l	0.333	0.417	0.333	**0**	0.417	0.333	0.750	0.750	0.750	0.750	0.750	0.333	0.750	0.917	0.333	0.750	0.750	0.917	0.917	0.750	0.083	0.917	0.750	0.750	1.000	0.750	0.750	0.333
Water ToC	0.083	0.417	0.083	0.417	**0**	0.083	0.750	0.750	0.750	0.750	0.750	0.750	0.750	0.417	0.083	0.083	0.750	0.333	0.333	0.750	0.333	0.333	0.083	0.750	0.750	0.750	0.083	0.083
Nitrates (r	**< 0.0001**	0.333	**< 0.0001**	0.333	0.083	**0**	0.917	0.917	0.917	0.917	0.917	0.750	0.917	0.750	0.083	0.333	0.917	0.750	0.750	0.917	0.333	0.750	0.333	0.917	0.750	1.000	0.333	0.333
Phosphate	0.917	0.750	0.917	0.750	0.750	0.917	**0**	**< 0.0001**	0.417	0.083	0.083	0.333	0.083	1.000	0.917	0.750	0.083	0.333	0.333	0.083	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Chlorophy	0.917	0.750	0.917	0.750	0.750	0.917	**< 0.0001**	**0**	0.417	0.083	0.083	0.333	0.083	1.000	0.917	0.750	0.083	0.333	0.333	0.083	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Temp	0.917	0.750	0.917	0.750	0.750	0.917	0.417	0.417	**0**	0.417	0.417	0.333	0.417	0.333	0.917	0.750	0.417	1.000	1.000	0.417	0.750	1.000	0.750	0.083	0.333	0.750	0.750	0.917
Rain	0.917	0.750	0.917	0.750	0.750	0.917	0.083	0.083	0.417	**0**	**< 0.0001**	0.333	**< 0.0001**	1.000	0.917	0.750	**< 0.0001**	0.333	0.333	**< 0.0001**	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Rad	0.917	0.750	0.917	0.750	0.750	0.917	0.083	0.083	0.417	**< 0.0001**	**0**	0.333	**< 0.0001**	1.000	0.917	0.750	**< 0.0001**	0.333	0.333	**< 0.0001**	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Al	0.750	1.000	0.750	0.333	0.750	0.750	0.333	0.333	0.333	0.333	0.333	**0**	0.333	0.750	0.750	0.917	0.333	0.750	0.750	0.333	0.333	0.750	0.917	0.333	0.417	0.917	0.917	0.333
Ti	0.917	0.750	0.917	0.750	0.750	0.917	0.083	0.083	0.417	**< 0.0001**	**< 0.0001**	0.333	**0**	1.000	0.917	0.750	**< 0.0001**	0.333	0.333	**< 0.0001**	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
V	0.750	0.917	0.750	0.917	0.417	0.750	1.000	1.000	0.333	1.000	1.000	0.750	1.000	**0**	0.750	0.333	1.000	0.417	0.417	1.000	0.917	0.417	0.333	0.333	0.750	0.333	0.333	0.750
Cr	0.083	0.333	0.083	0.333	0.083	0.083	0.917	0.917	0.917	0.917	0.917	0.750	0.917	0.750	**0**	0.333	0.917	0.750	0.750	0.917	0.333	0.750	0.333	0.917	0.750	1.000	0.333	0.333
Mn	0.333	0.750	0.333	0.750	0.083	0.333	0.750	0.750	0.750	0.750	0.750	0.917	0.750	0.333	0.333	**0**	0.750	0.333	0.333	0.750	0.750	0.333	**< 0.0001**	0.750	0.917	0.417	**< 0.0001**	0.333
Fe	0.917	0.750	0.917	0.750	0.750	0.917	0.083	0.083	0.417	**< 0.0001**	**< 0.0001**	0.333	**< 0.0001**	1.000	0.917	0.750	**0**	0.333	0.333	**< 0.0001**	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Co	0.750	0.917	0.750	0.917	0.333	0.750	0.333	0.333	1.000	0.333	0.333	0.750	0.333	0.417	0.750	0.333	0.333	**0**	**< 0.0001**	0.333	0.917	**< 0.0001**	0.333	1.000	0.750	0.333	0.333	0.333
Ni	0.750	0.917	0.750	0.917	0.333	0.750	0.333	0.333	1.000	0.333	0.333	0.750	0.333	0.417	0.750	0.333	0.333	**< 0.0001**	**0**	0.333	0.917	**< 0.0001**	0.333	1.000	0.750	0.333	0.333	0.333
Cu	0.917	0.750	0.917	0.750	0.750	0.917	0.083	0.083	0.417	**< 0.0001**	**< 0.0001**	0.333	**< 0.0001**	1.000	0.917	0.750	**< 0.0001**	0.333	0.333	**0**	0.750	0.333	0.750	0.417	0.333	0.750	0.750	0.333
Zn	0.333	0.417	0.333	0.083	0.333	0.333	0.750	0.750	0.750	0.750	0.750	0.333	0.750	0.917	0.333	0.750	0.750	0.917	0.917	0.750	**0**	0.917	0.750	0.750	1.000	0.750	0.750	0.333
As	0.750	0.917	0.750	0.917	0.333	0.750	0.333	0.333	1.000	0.333	0.333	0.750	0.333	0.417	0.750	0.333	0.333	**< 0.0001**	**< 0.0001**	0.333	0.917	**0**	0.333	1.000	0.750	0.333	0.333	0.333
Se	0.333	0.750	0.333	0.750	0.083	0.333	0.750	0.750	0.750	0.750	0.750	0.917	0.750	0.333	0.333	**< 0.0001**	0.750	0.333	0.333	0.750	0.750	0.333	**0**	0.750	0.917	0.417	**< 0.0001**	0.333
Mo	0.917	0.750	0.917	0.750	0.750	0.917	0.417	0.417	0.083	0.417	0.417	0.333	0.417	0.333	0.917	0.750	0.417	1.000	1.000	0.417	0.750	1.000	0.750	**0**	0.333	0.750	0.750	0.750
Cd	0.750	0.333	0.750	1.000	0.750	0.750	0.333	0.333	0.333	0.333	0.333	0.417	0.333	0.750	0.750	0.917	0.333	0.750	0.750	0.333	1.000	0.750	0.917	0.333	**0**	0.917	0.917	0.750
Sb	1.000	0.750	1.000	0.750	0.750	1.000	0.750	0.750	0.750	0.750	0.750	0.917	0.750	0.333	1.000	0.417	0.750	0.333	0.333	0.750	0.750	0.333	0.417	0.750	0.917	**0**	0.417	0.917
Ba	0.333	0.750	0.333	0.750	0.083	0.333	0.750	0.750	0.750	0.750	0.750	0.917	0.750	0.333	0.333	**< 0.0001**	0.750	0.333	0.333	0.750	0.750	0.333	**< 0.0001**	0.750	0.917	0.417	**0**	0.333
Hg	0.333	0.750	0.333	0.333	0.083	0.333	0.333	0.333	0.917	0.333	0.333	0.333	0.333	0.750	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.333	0.750	0.750	0.917	0.333	**0**

3.5.3The physico-chemical quality of aquaculture water: Mr. Mudau

The fish ponds of Mr. Mudau (Figures5) show that the average pH of the water was ranging from 6.56 to 7.99(Figure 5A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming. The study showed that nitrates ranged from 1.0 to 1.8 ppm (Figure 5E), while DWAF (1996) guideline for aquaculture value of 300 ppm and the Indonesian national standard water quality for nitrate is 10 ppm(Pangemanan et al., 2014).

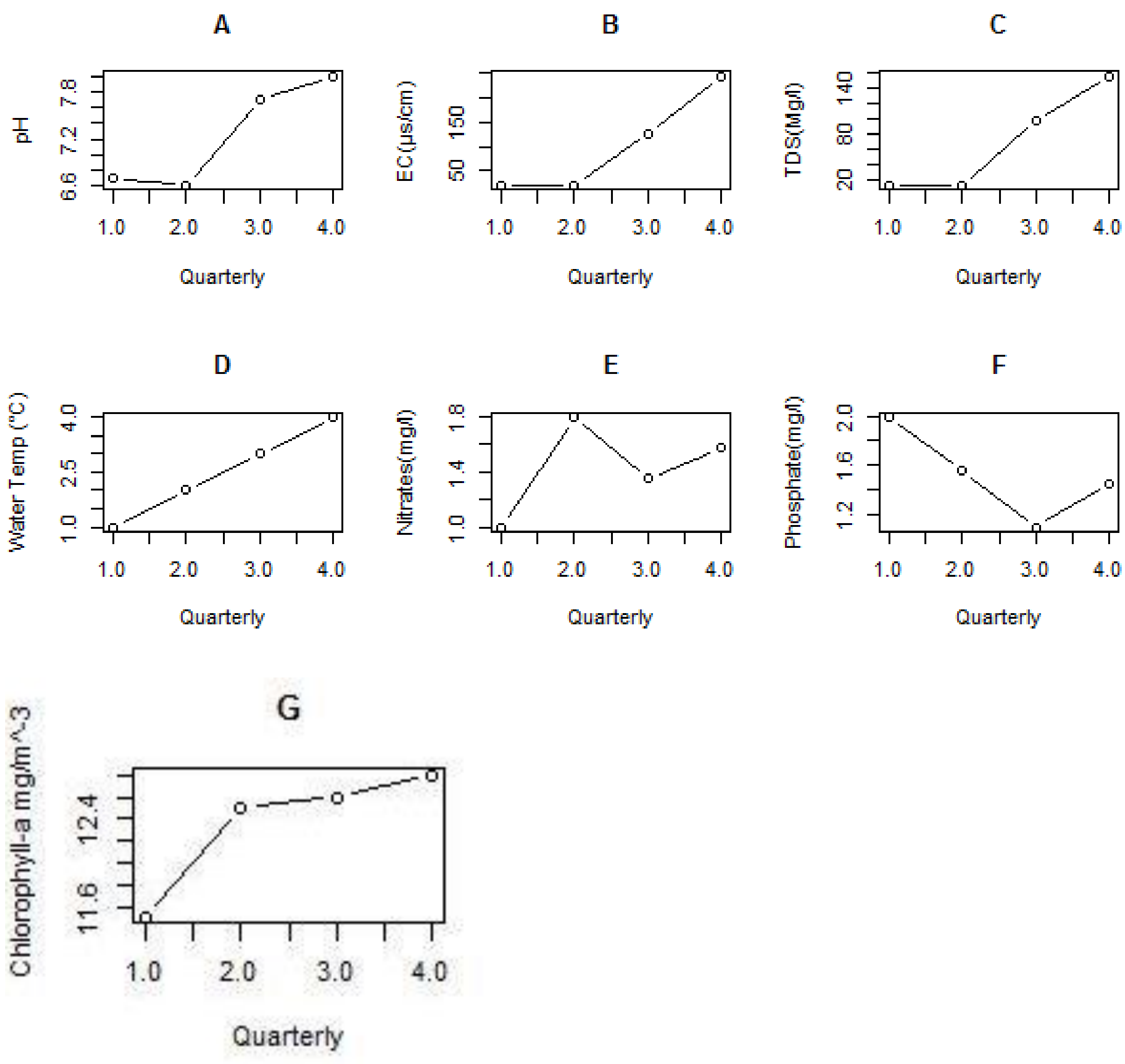


Figure 5: showing the quarterly physico-chemical parameters for Mr Mudau fish pond.

It means that water has low nitrate content. Phosphate ranged from 1.094 to 1.988 ppm, while the DWAF (1996) guideline for aquaculture value of 0.1 ppm (Figure 5F) and Indonesian national standard water quality typical range for surface waters 1 ppm (Pangemanan et al., 2014). This means that the water has a high phosphate in excess of DWAF aquaculture guidelines.

The water temperature ranged from 25 – 29.4 ^{0}C(Figure 5D), because the fish ponds are under the shadow of a tree and was within the range according to Keremah et al. (2014) with a water temperature range of 20 to 30 ^{0}C. The electrical conductivity (EC) was in the range of 16.9 to 245 µS/cm (Figure 5B) and was within the range according to Stone et al. (2013), range of 30-5000 µS/cm. The EC was positively correlated with pH and TDS, with Spearman coefficients of 0.956& 0.993and with $p < 0.05$ (Tables 3 &4). The EC is the electrical current carried by ions which are positively charged (cat ions) such as H^{+} which contribute to pH measurements and anions and these ions contribute to the measurement of total dissolved solids (Leveling, 2002).
The TDS of the water was in the range of 12.88 to 156.7 mg/l (Figure 5C), which was lower than 500 mg/l (Keremah et al., 2014). Therefore the physical parameters were within the prescribed ranges and the water is suitable for the farming of Tilapia fish.

3.5.4 The presence metal species in aquaculture water: Mr. Mudau

The metal content of the fish pond water was variable throughout the year but with moderate levels of Al, Cr, Mn, Fe, Cu, Zn and Ba in the first and second quarter (Table 4). The metal Fe, exceeded the DWAF (1996) guideline values during this first quarter. The presence of Cd in the fish pond water could be attributed to rainfall eroding the earthen embankments of the fish pond (Figure 6). The Spearman correlation coefficient did show a negative relationship between Cd and rainfall data (R= -0.975; p = 0.025) (Table 5 & 6).

Figure 6: The earthen Lwamondo fish dam for Mr. Mudau

The Spearman correlation coefficient didshow a positive relationship between these metal variables: Ti, V, Se and Ba and p = 0.010. Cr shows strong negative correlation with chlorophyll-a and positive correlation with Fe, Co, Ni, As, Hg with 1.000 and p = <0.0001 which differ with the study done by Oyem et al. (2015). Zn shows strong correlation with Cu and p = 0.046. Fe shows strong negative correlation with chlorophyll-a and positive correlation with Cr, Co, Ni, As, Hg with 1.000 and p = <0.0001. Co shows strong negative correlation with chlorophyll-a and positive correlation with Cr, Fe, Ni, As, Hg with 1.000 and p = <0.0001. Ni shows strong negative correlation with chlorophyll-a and positive correlation with Cr, Fe, Co, As, Hg with 1.000 and p = <0.0001. Zn shows strong positive correlation with Cu with 1.000 and p = <0.0001. This was expected since Ti, Fe, Cu, Ni and Coare probable found in the Basalt group which is found in the study area (Figure 4)(http://www.sandatlas.org/about-2/).

According to DWAF (1996) guidelines for aquaculturemost of the trace elements were higher than the target water quality range. Al, Cu, Fe, Mn and Se were exceeding the DWAF (1996) guideline for aquaculture values throughout the year. The Spearman correlation coefficient did show a positive relationship between these metal variables: Ti, V, Se and Ba and $p = 0.010$, This was expected since Ti and Fe are found in the geological material Guilleminite with the formula $Ba(UO_2)_3(Se^{4+}O_3)_2O_2 \cdot 3H_2O$, V and Fe are found in the geological material Hemloite with the formula $(Ti,V^{3+},Fe^{3+},Al)_{12}As_2^{3+}O_{23}(OH)$(https://www.mindat.org/min-1845.html).

Cr shows strong correlation with Fe, Co, Ni, As, Hg with 1.000 and $p = <0.0001$ which differ with the study done by Oyemet. al (2015), which the study did not show any strong correlation of heavy metals ions As, Cr and Fe, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Ni and Fe are found in the geological material Schreibersite with the formula $(Fe,Ni,Cr)_3P$, Cr and Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$ and Cr and As are found in the geological material Bellite with the formula $Pb_5(AsO_4,CrO_4,SiO_4)_3Cl$ (https://www.mindat.org/min-1845.html). Zn shows strong correlation with Cu and $p = 0.046$ zinc and copper naturally occur, this was expected since Cu and Zn are found in the geological material Danbaite with the formula $CuZn_2$ (https://www.mindat.org/min-1845.html) (Table 5).

Table 4:The presence of metal species in the aquaculture pond for Mr. Mudau

Ppb	Mudau				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	**2nd QTR**	**3rd QTR**	**4th QTR**	No adverse effect	toxic to	toxic to	lethal
Al	6.15±0.06	1.40±0.09	14.70±0.94	4.86±1.27	**30**	**70**	**105**	1500
Ti	0±0.00	0.00±0.00	0.98±0.08	0.20±0.06				
V	0.17±0.00	0.30±0.01	1.60±0.03	0.40±0.02				
Cr	8.93±0.01	0.11±0.00	0.13±0.00	0.02±0.00	**20000**			
Mn	20.60±0.04	22.86±0.44	0.25±0.00	0.06±0.01	**100**	**500**	**600**	
Fe	94.92±0.84	4.32±0.09	17.73±0.35	4.42±0.06	**10**	**1750**		
Co	2.27±0.12	0.43±0.01	0.03±0.00	0.03±0.00				
Ni	103.59±4.76	0.75±0.00	0.44±0.00	0.46±0.02				
Cu	1.67±0.09	2.46±0.00	1.51±0.00	0.52±0.01	**5**			
Zn	7.23±0.30	9.66±0.03	5.12±0.02	3.46±0.07	**30**			
As	0.59±0.01	0.04±0.00	0.06±0.00	0.12±0.01		**50**		
Se	0.05±0.00	0.45±0.00	0.45±0.00	0.10±0.04	**300**	**460**		
Mo	0.37±0.01	0.22±0.01	0.07±0.00	0.04±0.00				
Cd	0.02±0.00	0.03±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.24±0.01	0.12±0.00	0.26±0.00	0.36±0.01				
Ba	23.18±0.28	36.63±0.30	68.69±0.55	35.18±0.10				
Hg	0.01±0.00	0.00±0.00	0.001±0.00	0.00±0.00	**1000**			
Pb	0.13±0.00	0.01±0.00	0.006±0.00	0.06±0.00	**10**	**30**	**2150**	

Table 5: Spearman correlation matrix of the physico-chemical & climate data parameters at Lwamondo (Mudau fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.910	0.939	0.947	0.519	0.484	-0.731	0.889	0.107	0.037	0.021	0.281	0.471	0.379	-0.780	-0.870	-0.766	-0.860	-0.776	-0.531	-0.761	-0.693	0.428	-0.017	-0.240	0.660	0.453	-0.658
pH	0.910	1	**0.956**	**0.982**	0.555	0.082	-0.672	0.675	0.256	0.380	0.228	0.568	0.630	0.511	-0.512	**-0.986**	-0.462	-0.649	-0.509	-0.819	-0.949	-0.416	0.589	-0.202	-0.573	0.862	0.499	-0.339
EC (µS/cm	0.939	**0.956**	1	**0.993**	0.736	0.211	-0.526	0.678	0.415	0.371	0.351	0.305	0.383	0.253	-0.519	-0.894	-0.509	-0.634	-0.513	-0.756	-0.912	-0.404	0.335	-0.341	-0.545	0.872	0.268	-0.364
TDS (mg/l	0.947	**0.982**	**0.993**	1	0.662	0.189	-0.604	0.704	0.337	0.353	0.284	0.405	0.487	0.362	-0.545	-0.939	-0.520	-0.667	-0.540	-0.772	-0.927	-0.438	0.441	-0.268	-0.538	0.864	0.372	-0.384
Water To(	0.519	0.555	0.736	0.662	1	-0.030	0.185	0.128	0.894	0.640	0.828	-0.198	-0.272	-0.417	0.026	-0.414	-0.036	-0.053	0.035	-0.640	-0.678	0.159	-0.319	-0.840	-0.675	0.806	-0.444	0.130
Nitrates (r	0.484	0.082	0.211	0.189	-0.030	1	-0.429	0.754	-0.401	-0.778	-0.542	-0.438	-0.095	-0.054	-0.844	-0.038	-0.902	-0.747	-0.842	0.477	0.193	-0.851	-0.109	0.500	0.685	-0.281	0.151	-0.916
Phosphate	-0.731	-0.672	-0.526	-0.604	0.185	-0.429	1	-0.865	0.542	0.332	0.565	-0.623	-0.855	-0.853	0.838	0.750	0.755	0.893	0.841	0.234	0.435	0.839	-0.843	-0.589	-0.124	-0.215	-0.926	0.755
Chlorophy	0.889	0.675	0.678	0.704	0.128	0.754	-0.865	1	-0.326	-0.415	-0.424	0.197	0.499	0.476	**-0.979**	-0.673	**-0.962**	**-0.997**	**-0.978**	-0.129	-0.413	-0.946	0.471	0.420	0.213	0.250	0.614	-0.923
Temp	0.107	0.256	0.415	0.337	0.894	-0.401	0.542	-0.326	1	0.826	**0.987**	-0.226	-0.440	-0.571	0.471	-0.128	0.411	0.395	0.479	-0.593	-0.495	0.583	-0.472	**-0.993**	-0.774	0.685	-0.666	0.553
Rain	0.037	0.380	0.371	0.353	0.640	-0.778	0.332	-0.415	0.826	1	0.896	0.317	0.021	-0.106	0.591	-0.338	0.611	0.454	0.595	-0.833	-0.652	0.682	0.000	-0.866	**-0.975**	0.775	-0.281	0.728
Rad	0.021	0.228	0.351	0.284	0.828	-0.542	0.565	-0.424	**0.987**	0.896	1	-0.124	-0.380	-0.508	0.574	-0.120	0.530	0.487	0.581	-0.633	-0.495	0.679	-0.407	**-0.998**	-0.834	0.684	-0.631	0.664
Al	0.281	0.568	0.305	0.405	-0.198	-0.438	-0.623	0.197	-0.226	0.317	-0.124	1	0.935	0.904	-0.099	-0.690	0.036	-0.234	-0.104	-0.615	-0.567	-0.099	0.937	0.185	-0.441	0.421	0.800	0.040
Ti	0.471	0.630	0.383	0.487	-0.272	-0.095	-0.855	0.499	-0.440	0.021	-0.380	0.935	1	**0.987**	-0.433	-0.752	-0.306	-0.541	-0.439	-0.463	-0.518	-0.442	**0.999**	0.431	-0.190	0.318	**0.954**	-0.313
V	0.379	0.511	0.253	0.362	-0.417	-0.054	-0.853	0.476	-0.571	-0.106	-0.508	0.904	**0.987**	1	-0.441	-0.647	-0.312	-0.527	-0.448	-0.322	-0.377	-0.471	**0.993**	0.557	-0.051	0.164	**0.979**	-0.346
Cr	-0.780	-0.512	-0.519	-0.545	0.026	-0.844	0.838	**-0.979**	0.471	0.591	0.574	-0.099	-0.433	-0.441	1	0.519	**0.990**	**0.985**	**1.000**	-0.073	0.220	**0.991**	-0.413	-0.563	-0.407	-0.049	-0.603	**0.981**
Mn	-0.870	**-0.986**	-0.894	-0.939	-0.414	-0.038	0.750	-0.673	-0.128	-0.338	-0.120	-0.690	-0.752	-0.647	0.519	1	0.448	0.660	0.518	0.802	0.922	0.439	-0.716	0.086	0.537	-0.806	-0.628	0.345
Fe	-0.766	-0.462	-0.509	-0.520	-0.036	-0.902	0.755	**-0.962**	0.411	0.611	0.530	0.036	-0.306	-0.312	**0.990**	0.448	1	**0.961**	**0.989**	-0.128	0.173	**0.976**	-0.283	-0.511	-0.440	-0.024	-0.487	**0.986**
Co	-0.860	-0.649	-0.634	-0.667	-0.053	-0.747	0.893	**-0.997**	0.395	0.454	0.487	-0.234	-0.541	-0.527	**0.985**	0.660	**0.961**	1	**0.984**	0.098	0.379	**0.961**	-0.516	-0.484	-0.251	-0.203	-0.665	0.933
Ni	-0.776	-0.509	-0.513	-0.540	0.035	-0.842	0.841	**-0.978**	0.479	0.595	0.581	-0.104	-0.439	-0.448	**1.000**	0.518	**0.989**	**0.984**	1	-0.076	0.216	**0.992**	-0.419	-0.571	-0.411	-0.043	-0.609	**0.982**
Cu	-0.531	-0.819	-0.756	-0.772	-0.640	0.477	0.234	-0.129	-0.593	-0.833	-0.633	-0.615	-0.463	-0.322	-0.073	0.802	-0.128	0.098	-0.076	1	**0.954**	-0.176	-0.430	0.594	0.934	**-0.963**	-0.198	-0.262
Zn	-0.761	-0.949	-0.912	-0.927	-0.678	0.193	0.435	-0.413	-0.495	-0.652	-0.495	-0.567	-0.518	-0.377	0.220	0.922	0.173	0.379	0.216	**0.954**	1	0.110	-0.477	0.464	0.801	**-0.972**	-0.309	0.032
As	-0.693	-0.416	-0.404	-0.438	0.159	-0.851	0.839	-0.946	0.583	0.682	0.679	-0.099	-0.442	-0.471	**0.991**	0.439	**0.976**	**0.961**	**0.992**	-0.176	0.110	1	-0.428	-0.668	-0.508	0.074	-0.637	**0.990**
Se	0.428	0.589	0.335	0.441	-0.319	-0.109	-0.843	0.471	-0.472	0.000	-0.407	0.937	**0.999**	**0.993**	-0.413	-0.716	-0.283	-0.516	-0.419	-0.430	-0.477	-0.428	1	0.458	-0.164	0.275	**0.958**	-0.299
Mo	-0.017	-0.202	-0.341	-0.268	-0.840	0.500	-0.589	0.420	**-0.993**	-0.866	**-0.998**	0.185	0.431	0.557	-0.563	0.086	-0.511	-0.484	-0.571	0.594	0.464	-0.668	0.458	1	0.799	-0.659	0.671	-0.644
Cd	-0.240	-0.573	-0.545	-0.538	-0.675	0.685	-0.124	0.213	-0.774	**-0.975**	-0.834	-0.441	-0.190	-0.051	-0.407	0.537	-0.440	-0.251	-0.411	0.934	0.801	-0.508	-0.164	0.799	1	-0.885	0.109	-0.570
Sb	0.660	0.862	0.872	0.864	0.806	-0.281	-0.215	0.250	0.685	0.775	0.684	0.421	0.318	0.164	-0.049	-0.806	-0.024	-0.203	-0.043	**-0.963**	**-0.972**	0.074	0.275	-0.659	-0.885	1	0.080	0.132
Ba	0.453	0.499	0.268	0.372	-0.444	0.151	-0.926	0.614	-0.666	-0.281	-0.631	0.800	**0.954**	**0.979**	-0.603	-0.628	-0.487	-0.665	-0.609	-0.198	-0.309	-0.637	**0.958**	0.671	0.109	0.080	1	-0.528
Hg	-0.658	-0.339	-0.364	-0.384	0.130	-0.916	0.755	-0.923	0.553	0.728	0.664	0.040	-0.313	-0.346	**0.981**	0.345	**0.986**	0.933	**0.982**	-0.262	0.032	**0.990**	-0.299	-0.644	-0.570	0.132	-0.528	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 6: p-values of the physico-chemical & climate data parameters at Lwamondo (Mudau fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.090	0.061	0.053	0.481	0.516	0.269	0.111	0.893	0.963	0.979	0.719	0.529	0.621	0.220	0.130	0.234	0.140	0.224	0.469	0.239	0.307	0.572	0.983	0.760	0.340	0.547	0.342
pH	0.090	**0**	**0.044**	**0.018**	0.445	0.918	0.328	0.325	0.744	0.620	0.772	0.432	0.370	0.489	0.488	**0.014**	0.538	0.351	0.491	0.181	0.051	0.584	0.411	0.798	0.427	0.138	0.501	0.661
EC (µS/cm	0.061	**0.044**	**0**	**0.007**	0.264	0.789	0.474	0.322	0.585	0.629	0.649	0.695	0.617	0.747	0.481	0.106	0.491	0.366	0.487	0.244	0.088	0.596	0.665	0.659	0.455	0.128	0.732	0.636
TDS (mg/l	0.053	**0.018**	**0.007**	**0**	0.338	0.811	0.396	0.296	0.663	0.647	0.716	0.595	0.513	0.638	0.455	0.061	0.480	0.333	0.460	0.228	0.073	0.562	0.559	0.732	0.462	0.136	0.628	0.616
Water To(	0.481	0.445	0.264	0.338	**0**	0.970	0.815	0.872	0.106	0.360	0.172	0.802	0.728	0.583	0.974	0.586	0.964	0.947	0.965	0.360	0.322	0.841	0.681	0.160	0.325	0.194	0.556	0.870
Nitrates (r	0.516	0.918	0.789	0.811	0.970	**0**	0.571	0.246	0.599	0.222	0.458	0.562	0.905	0.946	0.156	0.962	0.098	0.253	0.158	0.523	0.807	0.149	0.891	0.500	0.315	0.719	0.849	0.084
Phosphate	0.269	0.328	0.474	0.396	0.815	0.571	**0**	0.135	0.458	0.668	0.435	0.377	0.145	0.147	0.162	0.250	0.245	0.107	0.159	0.766	0.565	0.161	0.157	0.411	0.876	0.785	0.074	0.245
Chlorophy	0.111	0.325	0.322	0.296	0.872	0.246	0.135	**0**	0.674	0.585	0.576	0.803	0.501	0.524	**0.021**	0.327	**0.038**	**0.003**	**0.022**	0.871	0.587	0.054	0.529	0.580	0.787	0.750	0.386	0.077
Temp	0.893	0.744	0.585	0.663	0.106	0.599	0.458	0.674	**0**	0.174	**0.013**	0.774	0.560	0.429	0.529	0.872	0.589	0.605	0.521	0.407	0.505	0.417	0.528	**0.007**	0.226	0.315	0.334	0.447
Rain	0.963	0.620	0.629	0.647	0.360	0.222	0.668	0.585	0.174	**0**	0.104	0.683	0.979	0.894	0.409	0.662	0.389	0.546	0.405	0.167	0.348	0.318	1.000	0.134	**0.025**	0.225	0.719	0.272
Rad	0.979	0.772	0.649	0.716	0.172	0.458	0.435	0.576	**0.013**	0.104	**0**	0.876	0.620	0.492	0.426	0.880	0.470	0.513	0.419	0.367	0.505	0.321	0.593	**0.002**	0.166	0.316	0.369	0.336
Al	0.719	0.432	0.695	0.595	0.802	0.562	0.377	0.803	0.774	0.683	0.876	**0**	0.065	0.096	0.901	0.310	0.964	0.766	0.896	0.385	0.433	0.901	0.063	0.815	0.559	0.579	0.200	0.960
Ti	0.529	0.370	0.617	0.513	0.728	0.905	0.145	0.501	0.560	0.979	0.620	0.065	**0**	**0.013**	0.567	0.248	0.694	0.459	0.561	0.537	0.482	0.558	**0.001**	0.569	0.810	0.682	**0.046**	0.687
V	0.621	0.489	0.747	0.638	0.583	0.946	0.147	0.524	0.429	0.894	0.492	0.096	**0.013**	**0**	0.559	0.353	0.688	0.473	0.552	0.678	0.623	0.529	**0.007**	0.443	0.949	0.836	**0.021**	0.654
Cr	0.220	0.488	0.481	0.455	0.974	0.156	0.162	**0.021**	0.529	0.409	0.426	0.901	0.567	0.559	**0**	0.481	**0.010**	**0.015**	**< 0.0001**	0.927	0.780	**0.009**	0.587	0.437	0.593	0.951	0.397	**0.019**
Mn	0.130	**0.014**	0.106	0.061	0.586	0.962	0.250	0.327	0.872	0.662	0.880	0.310	0.248	0.353	0.481	**0**	0.552	0.340	0.482	0.198	0.078	0.561	0.284	0.914	0.463	0.194	0.372	0.655
Fe	0.234	0.538	0.491	0.480	0.964	0.098	0.245	**0.038**	0.589	0.389	0.470	0.964	0.694	0.688	**0.010**	0.552	**0**	**0.039**	**0.011**	0.872	0.827	**0.024**	0.717	0.489	0.560	0.976	0.513	**0.014**
Co	0.140	0.351	0.366	0.333	0.947	0.253	0.107	**0.003**	0.605	0.546	0.513	0.766	0.459	0.473	**0.015**	0.340	**0.039**	**0**	**0.016**	0.902	0.621	**0.039**	0.484	0.516	0.749	0.797	0.335	0.067
Ni	0.224	0.491	0.487	0.460	0.965	0.158	0.159	**0.022**	0.521	0.405	0.419	0.896	0.561	0.552	**< 0.0001**	0.482	**0.011**	**0.016**	**0**	0.924	0.784	**0.008**	0.581	0.429	0.589	0.957	0.391	**0.018**
Cu	0.469	0.181	0.244	0.228	0.360	0.523	0.766	0.871	0.407	0.167	0.367	0.385	0.537	0.678	0.927	0.198	0.872	0.902	0.924	**0**	**0.046**	0.824	0.570	0.406	0.066	**0.037**	0.802	0.738
Zn	0.239	0.051	0.088	0.073	0.322	0.807	0.565	0.587	0.505	0.348	0.505	0.433	0.482	0.623	0.780	0.078	0.827	0.621	0.784	**0.046**	**0**	0.890	0.523	0.536	0.199	**0.028**	0.691	0.968
As	0.307	0.584	0.596	0.562	0.841	0.149	0.161	0.054	0.417	0.318	0.321	0.901	0.558	0.529	**0.009**	0.561	**0.024**	**0.039**	**0.008**	0.824	0.890	**0**	0.572	0.332	0.492	0.926	0.363	**0.010**
Se	0.572	0.411	0.665	0.559	0.681	0.891	0.157	0.529	0.528	1.000	0.593	0.063	**0.001**	**0.007**	0.587	0.284	0.717	0.484	0.581	0.570	0.523	0.572	**0**	0.542	0.836	0.725	**0.042**	0.701
Mo	0.983	0.798	0.659	0.732	0.160	0.500	0.411	0.580	**0.007**	0.134	**0.002**	0.815	0.569	0.443	0.437	0.914	0.489	0.516	0.429	0.406	0.536	0.332	0.542	**0**	0.201	0.341	0.329	0.356
Cd	0.760	0.427	0.455	0.462	0.325	0.315	0.876	0.787	0.226	**0.025**	0.166	0.559	0.810	0.949	0.593	0.463	0.560	0.749	0.589	0.066	0.199	0.492	0.836	0.201	**0**	0.115	0.891	0.430
Sb	0.340	0.138	0.128	0.136	0.194	0.719	0.785	0.750	0.315	0.225	0.316	0.579	0.682	0.836	0.951	0.194	0.976	0.797	0.957	**0.037**	**0.028**	0.926	0.725	0.341	0.115	**0**	0.920	0.868
Ba	0.547	0.501	0.732	0.628	0.556	0.849	0.074	0.386	0.334	0.719	0.369	0.200	**0.046**	**0.021**	0.397	0.372	0.513	0.335	0.391	0.802	0.691	0.363	**0.042**	0.329	0.891	0.920	**0**	0.472
Hg	0.342	0.661	0.636	0.616	0.870	0.084	0.245	0.077	0.447	0.272	0.336	0.960	0.687	0.654	**0.019**	0.655	**0.014**	0.067	**0.018**	0.738	0.968	**0.010**	0.701	0.356	0.430	0.868	0.472	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.5The physico-chemical quality of aquaculture water: Mrs. Nemubvumoni

The fish ponds of Mrs. Nemubvumoni show that the average pH of the water was ranging from 6.96 to 7.84 (Figure 7A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming. EC ranged from 20.56-274.66 µS/cm, while according to Stone et al. (2013), EC of the water for fish farming is between 30-5000 µs/cm (Figure 7B) and therefore the EC of the water was below the standard but now increasing. TDS of the water ranged from 8.79-175.7 mg/l (Figure 7C), while the TDS of the water should not be more than 500mg/l (Keremah et al, 2014). Therefore the TDS is good for the fish. pH shows positive correlation coefficient with EC and TDS, with 0.998 and p = 0.018. EC is the current carried by ions which are positively charged (cat ions) such as H+. ions move differently according to the conductivity, and since the pH is a measure of concentration of hydrogen, the higher the H+, the higher the EC (Leveling, 2002) and the TDs measures those ions.

The study showed that nitrates ranged from 1- 1.578 ppm(Figure 7E), which is lower than DWAF (1996) aquaculture guideline value of 300 ppm, while the Indonesian national standard water quality for nitrate is 10 mg/l(Pangemanan et al., 2014). It means that water has low nitrate content and which is not really good for fish because nitrates are good for fish growth. Phosphate ranged from 1.094-1.988 mg/l (Figure 7F), while the Indonesian national standard water quality typical range for surface waters 1 mg/l (Pangemanan et al,. 2014) and phosphate is above the DWAF (1996) aquaculture guideline value of 0.1, meaning that the water has a high phosphate content. Nitrates positively correlate with EC and TDS, with 0.99 and p =0.965. nitrates in water may be from fish feeds or fish waste which causes more solids to dissolve and EC reflects the status of inorganic pollution which may be caused by fish feed in the water (nutrients) and is a measure of TDS in water (Zare Garizi et al., 2011).

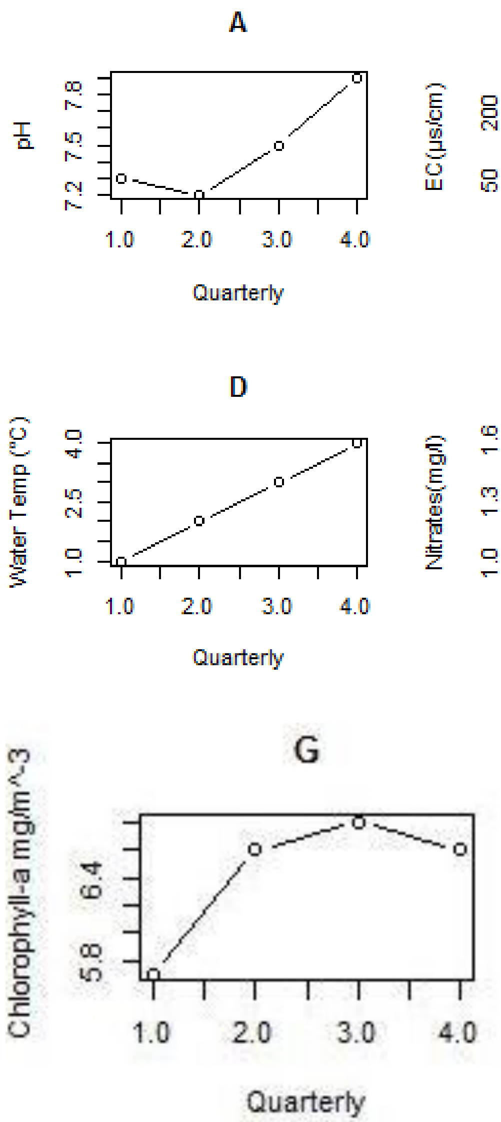


Figure 7: showing the Quarterly physico-chemical parameters for Mrs. Nemubvumoni fish pond.

Water temperature ranged from 24.3 – 30.33 ^{0}C (figure 7D), the water temperature increased because the fish ponds are situated directly to the sunlight. Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C. Temperature positively correlate with solar radiation, with 0.987and p = 0.1. Radiation is the heat from the sun so the water is heated and this contributes to water temperature

3.5.6 The presence metal species in aquaculture water: Mrs. Nemubvumoni

Al, Cr, Cu, Fe, Mn but Fe and Mn were too high in first quarter and they have exceeded water quality guidelines (DWAF, 1996) (Table 7). The presence of these metals :Al, Cr, Cu, Fe, Mn and Fe in the fish pond water could be attributed to rainfall eroding the earthen embankments of the fish pond (Figure 8) Most of the trace metals were positively correlating, Cr positively corrected with Mn, Fe, Co, Ni with the Spearman coefficient of 0.956 and $p = 0.013$ (Table 8 & 9).

Figure 8: The earthen fish dam for Mrs. Nemubvumoni

This was expected since Mn and Fe, Cr are found in the geological material Heideite with the formula (Fe, Cr) and columbite (Mn, Fe) and Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$ (https://www.mindat.org/min-1845.html) . As positively correlated with Cr, Mn, Fe, Co, Ni, Se, Hg with, 0.967 and $p = 0.012$. This was expected sinceMn and Fe are found in the geological material Earlshannonite with the formula $Mn^{2+}Fe_2^{3+}(PO_4)_2(OH)_2 \cdot 4H_2O$, Cr and As are found in the geological material Bellite with the formula $Pb_5(AsO_4,CrO_4,SiO_4)_3Cl$, Cr and Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$ (https://www.mindat.org/min-1845.html) and the fish farm use groundwater which may contain trace metals from the soil. This was expected since Mn, Fe, Co, Ni and Cu are probable found in the Basalt group which is found in the study area (Figure 4) (http://www.sandatlas.org/about-2/).

Table 7: The presence of metal species in the aquaculture pond for Mrs. Nemubvumoni

Ppb	Nemubvumoni				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	7.21±0.01	1.39±0.09	1.32±0.08	9.08±0.37	**30**	**70**	**105**	1500
Ti	0.01±0.00	0.00±0.00	0.04±0.00	0.08±0.04				
V	0.40±0.00	0.91±0.02	0.25±0.00	2.29±0.03				
Cr	8.89±0.00	0.16±0.00	0.13±0.00	0.0±0.00	**20000**			
Mn	26.91±0.00	0.05±0.00	0.20±0.00	0.04±0.01	**100**	**500**	**600**	
Fe	172.73±1.40	0.41±0.01	0.70±0.01	3.46±0.20	**10**	**1750**		
Co	3.18±0.00	0.01±0.00	0.03±0.00	0.02±0.00				
Ni	150.86±6.54	0.16±0.00	0.36±0.00	0.34±0.03				
Cu	2.12±0.00	0.33±0.00	0.95±0.00	0.00±1.18	**5**			
Zn	8.15±0.03	4.84±0.02	3.80±0.01	3.94±0.09	**30**			
As	0.52±0.00	0.02±0.00	0.05±0.00	0.04±0.00		**50**		
Se	2.00±0.00	0.45±0.00	0.45±0.00	0.05±0.02	**300**	**460**		
Mo	0.22±0.00	0.16±0.00	0.06±0.00	0.02±0.00				
Cd	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.33±0.00	0.16±0.00	0.35±0.01	0.21±0.00				
Ba	27.13±1.25	34.43±0.28	85.99±0.69	24.94±0.05				
Hg	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.17±0.00	0.01±0.00	0.01±0.00	0.04±0.00	**10**	**30**	**2150**	

Table 8: Spearman correlation matrix of the physico-chemical parameters at Lwamondo (Nemubvumoni fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.844	0.911	0.936	0.306	0.858	-0.143	0.762	0.107	0.037	0.021	0.295	0.318	0.457	-0.783	-0.774	-0.774	-0.772	-0.774	-0.342	0.582	-0.715	-0.750	-0.205	**0.986**	-0.039	0.381	-0.775
pH	0.844	1	**0.982**	**0.970**	0.696	0.922	-0.329	0.310	0.564	0.564	0.523	0.755	0.182	0.285	-0.327	-0.314	-0.314	-0.311	-0.313	0.193	0.925	-0.232	-0.293	-0.684	0.806	0.309	-0.010	-0.315
EC (µS/cm	0.911	**0.982**	1	**0.998**	0.658	**0.968**	-0.182	0.426	0.499	0.414	0.430	0.660	0.120	0.244	-0.465	-0.454	-0.459	-0.451	-0.452	0.013	0.843	-0.365	-0.453	-0.539	0.897	0.130	0.180	-0.454
TDS (mg/l	0.936	**0.970**	**0.998**	1	0.613	**0.965**	-0.167	0.484	0.446	0.356	0.372	0.610	0.143	0.272	-0.522	-0.511	-0.516	-0.508	-0.510	-0.048	0.809	-0.425	-0.508	-0.488	0.923	0.095	0.222	-0.511
Water To(	0.306	0.696	0.658	0.613	1	0.740	0.087	-0.365	**0.977**	0.762	0.939	0.935	-0.494	-0.440	0.271	0.280	0.258	0.285	0.284	0.489	0.802	0.396	0.195	-0.726	0.342	0.129	-0.050	0.283
Nitrates (r	0.858	0.922	**0.968**	**0.965**	0.740	1	0.058	0.356	0.582	0.358	0.487	0.658	-0.120	0.012	-0.438	-0.428	-0.444	-0.425	-0.425	-0.061	0.773	-0.320	-0.475	-0.447	0.885	-0.072	0.343	-0.427
Phosphat	-0.143	-0.329	-0.182	-0.167	0.087	0.058	1	-0.041	0.058	-0.499	-0.064	-0.268	-0.833	-0.784	-0.124	-0.133	-0.173	-0.130	-0.128	-0.555	-0.465	-0.074	-0.311	0.608	0.024	-0.943	0.811	-0.127
Chlorophy	0.762	0.310	0.426	0.484	-0.365	0.356	-0.041	1	-0.553	-0.564	-0.632	-0.389	0.520	0.629	**-0.983**	**-0.982**	**-0.973**	**-0.983**	**-0.983**	-0.763	-0.045	**-0.992**	-0.928	0.390	0.750	-0.278	0.543	**-0.984**
Temp	0.107	0.564	0.499	0.446	**0.977**	0.582	0.058	-0.553	1	0.826	**0.987**	0.935	-0.536	-0.514	0.469	0.478	0.457	0.482	0.481	0.627	0.743	0.582	0.394	-0.757	0.136	0.206	-0.191	0.480
Rain	0.037	0.564	0.414	0.356	0.762	0.358	-0.499	-0.564	0.826	1	0.896	0.928	-0.038	-0.066	0.588	0.599	0.603	0.601	0.599	0.910	0.834	0.648	0.624	**-0.979**	-0.030	0.721	-0.681	0.597
Rad	0.021	0.523	0.430	0.372	0.939	0.487	-0.064	-0.632	**0.987**	0.896	1	0.946	-0.459	-0.459	0.572	0.581	0.565	0.584	0.584	0.743	0.750	0.671	0.519	-0.824	0.029	0.340	-0.344	0.583
Al	0.295	0.755	0.660	0.610	0.935	0.658	-0.268	-0.389	0.935	0.928	0.946	1	-0.204	-0.177	0.357	0.369	0.361	0.372	0.370	0.701	0.924	0.457	0.347	-0.922	0.271	0.469	-0.364	0.369
Ti	0.318	0.182	0.120	0.143	-0.494	-0.120	-0.833	0.520	-0.536	-0.038	-0.459	-0.204	1	**0.988**	-0.356	-0.351	-0.310	-0.355	-0.357	0.008	0.123	-0.435	-0.165	-0.125	0.171	0.604	-0.420	-0.358
V	0.457	0.285	0.244	0.272	-0.440	0.012	-0.784	0.629	-0.514	-0.066	-0.459	-0.177	**0.988**	1	-0.480	-0.475	-0.436	-0.478	-0.480	-0.080	0.178	-0.545	-0.298	-0.114	0.319	0.532	-0.307	-0.481
Cr	-0.783	-0.327	-0.465	-0.522	0.271	-0.438	-0.124	**-0.983**	0.469	0.588	0.572	0.357	-0.356	-0.480	1	**1.000**	**0.999**	**1.000**	**1.000**	0.824	0.049	**0.991**	**0.980**	-0.430	-0.800	0.422	-0.679	**1.000**
Mn	-0.774	-0.314	-0.454	-0.511	0.280	-0.428	-0.133	**-0.982**	0.478	0.599	0.581	0.369	-0.351	-0.475	**1.000**	1	**0.999**	**1.000**	**1.000**	0.831	0.062	**0.991**	**0.981**	-0.443	-0.793	0.431	-0.685	**1.000**
Fe	-0.774	-0.314	-0.459	-0.516	0.258	-0.444	-0.173	**-0.973**	0.457	0.603	0.565	0.361	-0.310	-0.436	**0.999**	**0.999**	1	**0.999**	**0.999**	0.843	0.065	**0.986**	**0.989**	-0.452	-0.800	0.465	-0.715	**0.999**
Co	-0.772	-0.311	-0.451	-0.508	0.285	-0.425	-0.130	**-0.983**	0.482	0.601	0.584	0.372	-0.355	-0.478	**1.000**	**1.000**	**0.999**	1	**1.000**	0.832	0.065	**0.992**	**0.981**	-0.444	-0.791	0.429	-0.683	**1.000**
Ni	-0.774	-0.313	-0.452	-0.510	0.284	-0.425	-0.128	**-0.983**	0.481	0.599	0.584	0.370	-0.357	-0.480	**1.000**	**1.000**	**0.999**	**1.000**	1	0.830	0.063	**0.992**	**0.980**	-0.442	-0.791	0.427	-0.681	**1.000**
Cu	-0.342	0.193	0.013	-0.048	0.489	-0.061	-0.555	-0.763	0.627	0.910	0.743	0.701	0.008	-0.080	0.824	0.831	0.843	0.832	0.830	1	0.548	0.836	0.878	-0.848	-0.425	0.801	-0.878	0.829
Zn	0.582	0.925	0.843	0.809	0.802	0.773	-0.465	-0.045	0.743	0.834	0.750	0.924	0.123	0.178	0.049	0.062	0.065	0.065	0.063	0.548	1	0.137	0.092	-0.907	0.523	0.550	-0.330	0.061
As	-0.715	-0.232	-0.365	-0.425	0.396	-0.320	-0.074	**-0.992**	0.582	0.648	0.671	0.457	-0.435	-0.545	**0.991**	**0.991**	**0.986**	**0.992**	**0.992**	0.836	0.137	1	**0.955**	-0.489	-0.721	0.390	-0.630	**0.992**
Se	-0.750	-0.293	-0.453	-0.508	0.195	-0.475	-0.311	-0.928	0.394	0.624	0.519	0.347	-0.165	-0.298	**0.980**	**0.981**	**0.989**	**0.981**	**0.980**	0.878	0.092	**0.955**	1	-0.493	-0.800	0.578	-0.808	**0.980**
Mo	-0.205	-0.684	-0.539	-0.488	-0.726	-0.447	0.608	0.390	-0.757	**-0.979**	-0.824	-0.922	-0.125	-0.114	-0.430	-0.443	-0.452	-0.444	-0.442	-0.848	-0.907	-0.489	-0.493	1	-0.120	-0.774	0.668	-0.441
Cd	**0.986**	0.806	0.897	0.923	0.342	0.885	0.024	0.750	0.136	-0.030	0.029	0.271	0.171	0.319	-0.800	-0.793	-0.800	-0.791	-0.791	-0.425	0.523	-0.721	-0.800	-0.120	1	-0.193	0.516	-0.792
Sb	-0.039	0.309	0.130	0.095	0.129	-0.072	-0.943	-0.278	0.206	0.721	0.340	0.469	0.604	0.532	0.422	0.431	0.465	0.429	0.427	0.801	0.550	0.390	0.578	-0.774	-0.193	1	-0.938	0.426
Ba	0.381	-0.010	0.180	0.222	-0.050	0.343	0.811	0.543	-0.191	-0.681	-0.344	-0.364	-0.420	-0.307	-0.679	-0.685	-0.715	-0.683	-0.681	-0.878	-0.330	-0.630	-0.808	0.668	0.516	-0.938	1	-0.680
Hg	-0.775	-0.315	-0.454	-0.511	0.283	-0.427	-0.127	**-0.984**	0.480	0.597	0.583	0.369	-0.358	-0.481	**1.000**	**1.000**	**0.999**	**1.000**	**1.000**	0.829	0.061	**0.992**	**0.980**	-0.441	-0.792	0.426	-0.680	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 9: p-value of the physico-chemical parameters at Lwamondo (Nemubvumoni fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To	Nitrates (mg	Phosphates (m	Chlorophyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.156	0.089	0.064	0.694	0.142	0.857	0.238	0.893	0.963	0.979	0.705	0.682	0.543	0.217	0.226	0.226	0.228	0.226	0.658	0.418	0.285	0.250	0.795	**0.014**	0.961	0.619	0.225
pH	0.156	**0**	**0.018**	**0.030**	0.304	0.078	0.671	0.690	0.436	0.436	0.477	0.245	0.818	0.715	0.673	0.686	0.686	0.689	0.687	0.807	0.075	0.768	0.707	0.316	0.194	0.691	0.990	0.685
EC (µS/cm	0.089	**0.018**	**0**	**0.002**	0.342	**0.032**	0.818	0.574	0.501	0.586	0.570	0.340	0.880	0.756	0.535	0.546	0.541	0.549	0.548	0.987	0.157	0.635	0.547	0.461	0.103	0.870	0.820	0.546
TDS (mg/l	0.064	**0.030**	**0.002**	**0**	0.387	**0.035**	0.833	0.516	0.554	0.644	0.628	0.390	0.857	0.728	0.478	0.489	0.484	0.492	0.490	0.952	0.191	0.575	0.492	0.512	0.077	0.905	0.778	0.489
Water To(	0.694	0.304	0.342	0.387	**0**	0.260	0.913	0.635	**0.023**	0.238	0.061	0.065	0.506	0.560	0.729	0.720	0.742	0.715	0.716	0.511	0.198	0.604	0.805	0.274	0.658	0.871	0.950	0.717
Nitrates (r	0.142	0.078	**0.032**	**0.035**	0.260	**0**	0.942	0.644	0.418	0.642	0.513	0.342	0.880	0.988	0.562	0.572	0.556	0.575	0.575	0.939	0.227	0.680	0.525	0.553	0.115	0.928	0.657	0.573
Phosphate	0.857	0.671	0.818	0.833	0.913	0.942	**0**	0.959	0.942	0.501	0.936	0.732	0.167	0.216	0.876	0.867	0.827	0.870	0.872	0.445	0.535	0.926	0.689	0.392	0.976	0.057	0.189	0.873
Chlorophy	0.238	0.690	0.574	0.516	0.635	0.644	0.959	**0**	0.447	0.436	0.368	0.611	0.480	0.371	**0.017**	**0.018**	**0.027**	**0.017**	**0.017**	0.237	0.955	**0.008**	0.072	0.610	0.250	0.722	0.457	**0.016**
Temp	0.893	0.436	0.501	0.554	**0.023**	0.418	0.942	0.447	**0**	0.174	**0.013**	0.065	0.464	0.486	0.531	0.522	0.543	0.518	0.519	0.373	0.257	0.418	0.606	0.243	0.864	0.794	0.809	0.520
Rain	0.963	0.436	0.586	0.644	0.238	0.642	0.501	0.436	0.174	**0**	0.104	0.072	0.962	0.934	0.412	0.401	0.397	0.399	0.401	0.090	0.166	0.352	0.376	**0.021**	0.970	0.279	0.319	0.403
Rad	0.979	0.477	0.570	0.628	0.061	0.513	0.936	0.368	**0.013**	0.104	**0**	0.054	0.541	0.541	0.428	0.419	0.435	0.416	0.416	0.257	0.250	0.329	0.481	0.176	0.971	0.660	0.656	0.417
Al	0.705	0.245	0.340	0.390	0.065	0.342	0.732	0.611	0.065	0.072	0.054	**0**	0.796	0.823	0.643	0.631	0.639	0.628	0.630	0.299	0.076	0.543	0.653	0.078	0.729	0.531	0.636	0.631
Ti	0.682	0.818	0.880	0.857	0.506	0.880	0.167	0.480	0.464	0.962	0.541	0.796	**0**	**0.012**	0.644	0.649	0.690	0.645	0.643	0.992	0.877	0.565	0.835	0.875	0.829	0.396	0.580	0.642
V	0.543	0.715	0.756	0.728	0.560	0.988	0.216	0.371	0.486	0.934	0.541	0.823	**0.012**	**0**	0.520	0.525	0.564	0.522	0.520	0.920	0.822	0.455	0.702	0.886	0.681	0.468	0.693	0.519
Cr	0.217	0.673	0.535	0.478	0.729	0.562	0.876	**0.017**	0.531	0.412	0.428	0.643	0.644	0.520	**0**	**< 0.0001**	**0.001**	**0.000**	**0.000**	0.176	0.951	**0.009**	**0.020**	0.570	0.200	0.578	0.321	**< 0.0001**
Mn	0.226	0.686	0.546	0.489	0.720	0.572	0.867	**0.018**	0.522	0.401	0.419	0.631	0.649	0.525	**< 0.0001**	**0**	**0.001**	**< 0.0001**	**< 0.0001**	0.169	0.938	**0.009**	**0.019**	0.557	0.207	0.569	0.315	**< 0.0001**
Fe	0.226	0.686	0.541	0.484	0.742	0.556	0.827	**0.027**	0.543	0.397	0.435	0.639	0.690	0.564	**0.001**	**0.001**	**0**	**0.001**	**0.001**	0.157	0.935	**0.014**	**0.011**	0.548	0.200	0.535	0.285	**0.001**
Co	0.228	0.689	0.549	0.492	0.715	0.575	0.870	**0.017**	0.518	0.399	0.416	0.628	0.645	0.522	**0.000**	**< 0.0001**	**0.001**	**0**	**< 0.0001**	0.168	0.935	**0.008**	**0.019**	0.556	0.209	0.571	0.317	**< 0.0001**
Ni	0.226	0.687	0.548	0.490	0.716	0.575	0.872	**0.017**	0.519	0.401	0.416	0.630	0.643	0.520	**0.000**	**< 0.0001**	**0.001**	**< 0.0001**	**0**	0.170	0.937	**0.008**	**0.020**	0.558	0.209	0.573	0.319	**< 0.0001**
Cu	0.658	0.807	0.987	0.952	0.511	0.939	0.445	0.237	0.373	0.090	0.257	0.299	0.992	0.920	0.176	0.169	0.157	0.168	0.170	**0**	0.452	0.164	0.122	0.152	0.575	0.199	0.122	0.171
Zn	0.418	0.075	0.157	0.191	0.198	0.227	0.535	0.955	0.257	0.166	0.250	0.076	0.877	0.822	0.951	0.938	0.935	0.935	0.937	0.452	**0**	0.863	0.908	0.093	0.477	0.450	0.670	0.939
As	0.285	0.768	0.635	0.575	0.604	0.680	0.926	**0.008**	0.418	0.352	0.329	0.543	0.565	0.455	**0.009**	**0.009**	**0.014**	**0.008**	**0.008**	0.164	0.863	**0**	**0.045**	0.511	0.279	0.610	0.370	**0.008**
Se	0.250	0.707	0.547	0.492	0.805	0.525	0.689	0.072	0.606	0.376	0.481	0.653	0.835	0.702	**0.020**	**0.019**	**0.011**	**0.019**	**0.020**	0.122	0.908	**0.045**	**0**	0.507	0.200	0.422	0.192	**0.020**
Mo	0.795	0.316	0.461	0.512	0.274	0.553	0.392	0.610	0.243	**0.021**	0.176	0.078	0.875	0.886	0.570	0.557	0.548	0.556	0.558	0.152	0.093	0.511	0.507	**0**	0.880	0.226	0.332	0.559
Cd	**0.014**	0.194	0.103	0.077	0.658	0.115	0.976	0.250	0.864	0.970	0.971	0.729	0.829	0.681	0.200	0.207	0.200	0.209	0.209	0.575	0.477	0.279	0.200	0.880	**0**	0.807	0.484	0.208
Sb	0.961	0.691	0.870	0.905	0.871	0.928	0.057	0.722	0.794	0.279	0.660	0.531	0.396	0.468	0.578	0.569	0.535	0.571	0.573	0.199	0.450	0.610	0.422	0.226	0.807	**0**	0.062	0.574
Ba	0.619	0.990	0.820	0.778	0.950	0.657	0.189	0.457	0.809	0.319	0.656	0.636	0.580	0.693	0.321	0.315	0.285	0.317	0.319	0.122	0.670	0.370	0.192	0.332	0.484	0.062	**0**	0.320
Hg	0.225	0.685	0.546	0.489	0.717	0.573	0.873	**0.016**	0.520	0.403	0.417	0.631	0.642	0.519	**< 0.0001**	**< 0.0001**	**0.001**	**< 0.0001**	**< 0.0001**	0.171	0.939	**0.008**	**0.020**	0.559	0.208	0.574	0.320	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.7The physico-chemical quality of aquaculture water: Mrs. Mathobo

The fish ponds of Mrs. Mathobo (Figure 10) show shows that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values (Figure 9). The average pH of the water was alkaline ranging from 8.82 to 8.61 (Figure 9A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming.

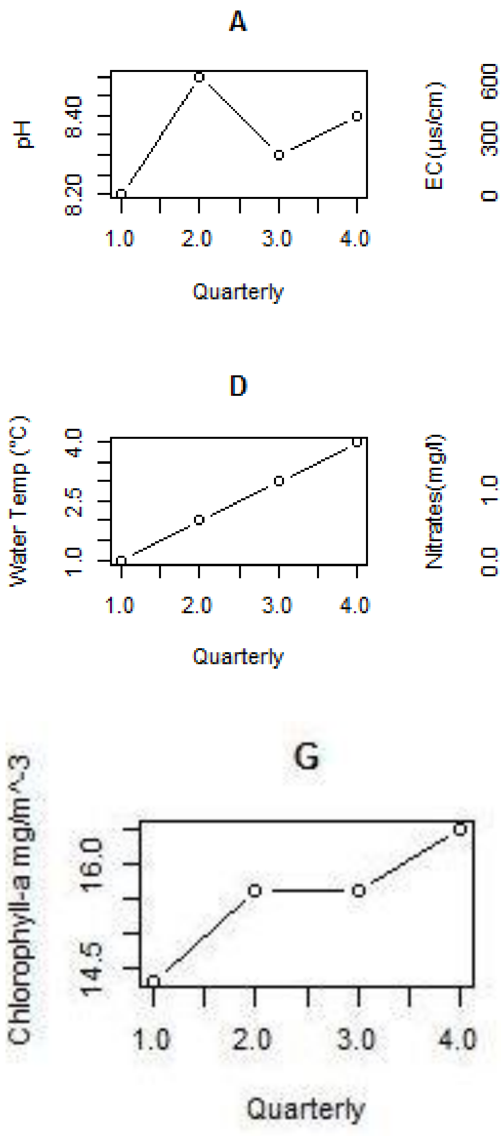


Figure 9: showing the quarterly physico-chemical parameters for fish pond. Mrs. Mathobo.

The study showed that nitrates ranged from 1.426 to 1.643 ppm(Figure 9E),which is very low to DWAF (1996) guideline value of 300 ppm, while the Indonesian national standard water quality for nitrate is 10 mg/l. Phosphate ranged from 1.204 to 1.643 mg/l (Figure 9F), while the Indonesian national standard water quality typical range for surface waters 1 mg/l(Pangemanan et al., 2014),meaning that the water has a high phosphate content. Nitrates positively correlate with phosphate, with 0.996 and p = 0.009.The relationship between nitrates and phosphates is expected since nitrates can be found from unconsumed fish feeds, fish waste or dead plants in water which decompose or breakdown to form building blocks of phosphate.

Water temperature ranged from 24 – 29.13 ^{0}C (Figure 9D), because the fish ponds are under the shadow of a tree. According to Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mrs. Mathobo is still normal. Water temperature positively correlates with radiation and temperature, with 0.995 and p = 0.006. Water temperature depends on temperature and radiation, if there is high heat from the sun the temperature will be high and also the water temperature will also change. The fish dams are located directly to the sun (as shown figure 10).

EC ranged from 19.93 to 660 µS/cm (Figure 9B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard but now increasing. TDS of the water ranged from 13 to 428 mg/l (Figure 9C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore, the TDS is good for the fish. TDS positively correlate with EC, with 0.996 and p = 0.004. EC reflects the status of inorganic pollution which may be caused by fish feed in the water and it measure TDS in water (Garizi et al., 2011).

3.5.8 The presence metal species in aquaculture water: Mrs. Mathobo

Most of the trace elements were very high in the first quarter such as Al, Fe, Mn, Ni, Cu, and Cr (Table 10). The presence of these metals: Al, Cr, Cu, Fe, Mn and Fe in the fish pond water could be attributed to rainfall eroding the earthen embankments of the fish pond (Figure 10) Trace shows positive correlation coefficient greater than 0.5, which means there is strong correlation Ti and V, Al, Cr, Mn, Fe, Co, Ni, Cu, Zn and p = <0.0001 (Table 11 and 12). This was expected since Ti, Cr and Fe are found in the geological material Heideite with the formula

$(Fe,Cr)_{1.15}(Ti,Fe)_2S_4$, Cu and Zn are found in the geological material Danbaitewith the formula $CuZn_2$, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Ti, Al, V and Fe are found in the geological material Hemloite with the formula $(Ti,V^{3+},Fe^{3+},Al)_{12}As_2^{3+}O_{23}(OH)$(https://www.mindat.org/min-1845.html) and Ti and Cu are found in the geological material, norite-hyperthenite (Gadd-Claxton, 1981).

Figure 10: The earthen fish dam for Mrs. Mathobo

Hg positively correlated with Zn, Cu, Ni, Co, Fe, Mn, Cr, V, As and radiation and $p = <0.0001$(Table 4). Cu and Zn are found in the geological material Danbaite with the formula $CuZn_2$, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Mn and Fe are found in the geological material Earlshannonite with the formula $Mn^{2+}Fe_2^{3+}(PO_4)_2(OH)_2 \cdot 4H_2O$, Cr and Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$ (https://www.mindat.org/min-1845.html)..The high availability of metals could be result of human activity (agricultural and industrial) and naturally from the soil (Bam et al., 2011). The presence of Mn, Fe, Ti, Cu and Cr were expected in the fish dams since those elements are probable found in the gneiss group which is found in the study area (Figure 4).

Table 10:The presence of metal species in the aquaculture pond for Mrs. Mathobo

Ppb	Mathobo				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	15.60±0.15	1.93±0.12	1.76±0.11	2.27±0.59	**30**	**70**	**105**	1500
Ti	0.78±0.07	0.04±0.00	0.23±0.02	0.11±0.01				
V	6.62±0.03	19.46±0.33	17.93±0.30	23.66±0.83				
Cr	240.01±0.14	0.29±0.00	0.23±0.00	0.20±0.01	**20000**			
Mn	242.12±0.46	0.03±0.00	0.06±0.00	0.16±0.01	**100**	**500**	**600**	
Fe	3246.83±28.67	0.40±0.01	1.42±0.03	0.75±0.07	**10**	**1750**		
Co	21.78±1.15	0.06±0.00	0.11±0.00	0.06±0.00				
Ni	994.31±45.65	1.29±0.00	1.87±0.00	0.86±0.05				
Cu	6.77±0.35	1.88±0.00	3.08±0.00	0.87±0.34	**5**			
Zn	9.00±0.37	4.24±0.01	3.35±0.01	3.76±0.43	**30**			
As	0.99±0.02	0.44±0.01	0.61±0.02	0.68±0.04		**50**		
Se	0.50±0.01	0.45±0.00	0.45±0.00	0.31±0.03	**300**	**460**		
Mo	15.42±0.49	0.89±0.03	0.98±0.03	1.08±0.04				
Cd	0.01±0.00	0.01±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.37±0.01	0.12±0.00	0.33±0.01	0.25±0.01				
Ba	125.39±1.54	155.21±1.27	134.69±1.08	140.95±5.63				
Hg	0.01±0.00	0.00±0.00	0.001±0.00	0.00±0.00	**1000**			
Pb	0.32±0.01	0.01±0.00	0.006±0.00	0.03±0.00	**10**	**30**	**2150**	

Table 11: Spearman correlation matrix of the physico-chemical parameters at Dzwerani (Mathobo fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.455	0.941	0.906	0.005	0.771	0.799	0.932	0.107	0.037	0.021	-0.777	-0.704	0.869	-0.775	-0.774	-0.775	-0.775	-0.775	-0.610	-0.842	-0.476	-0.051	-0.069	0.020	-0.193	0.147	-0.775
pH	0.455	1	0.208	0.138	-0.451	0.872	0.876	0.738	-0.371	-0.772	-0.514	-0.807	-0.926	0.831	-0.813	-0.813	-0.813	-0.814	-0.813	-0.917	-0.726	-0.915	-0.911	0.468	0.411	**-0.960**	0.936	-0.813
EC (µS/cm	0.941	0.208	1	**0.996**	0.329	0.523	0.570	0.809	0.419	0.361	0.351	-0.521	-0.447	0.680	-0.517	-0.517	-0.517	-0.517	-0.517	-0.319	-0.610	-0.162	0.189	-0.394	-0.299	0.049	-0.140	-0.517
TDS (mg/l	0.906	0.138	**0.996**	1	0.413	0.445	0.496	0.760	0.497	0.441	0.436	-0.439	-0.368	0.615	-0.436	-0.436	-0.436	-0.436	-0.436	-0.234	-0.533	-0.074	0.247	-0.476	-0.382	0.111	-0.214	-0.436
Water To(	0.005	-0.451	0.329	0.413	1	-0.510	-0.438	-0.106	**0.994**	0.849	**0.995**	0.574	0.520	-0.308	0.573	0.573	0.573	0.572	0.573	0.651	0.518	0.740	0.468	**-0.996**	**-0.998**	0.452	-0.635	0.573
Nitrates (r	0.771	0.872	0.523	0.445	-0.510	1	**0.997**	0.905	-0.413	-0.605	-0.531	**-0.990**	**-0.992**	**0.975**	**-0.991**	**-0.991**	**-0.991**	**-0.992**	**-0.991**	**-0.975**	**-0.969**	-0.926	-0.611	0.482	0.503	-0.709	0.725	**-0.991**
Phosphate	0.799	0.876	0.570	0.496	-0.438	**0.997**	1	0.934	-0.338	-0.560	-0.462	**-0.978**	**-0.990**	**0.989**	**-0.980**	**-0.980**	**-0.980**	**-0.980**	**-0.980**	**-0.959**	**-0.960**	-0.901	-0.607	0.411	0.430	-0.709	0.707	**-0.980**
Chlorophy	0.932	0.738	0.809	0.760	-0.106	0.905	0.934	1	0.004	-0.240	-0.123	-0.874	-0.879	**0.977**	-0.875	-0.875	-0.875	-0.876	-0.875	-0.795	-0.890	-0.688	-0.402	0.067	0.106	-0.529	0.468	-0.875
Temp	0.107	-0.371	0.419	0.497	**0.994**	-0.413	-0.338	0.004	1	0.826	**0.987**	0.481	0.426	-0.202	0.480	0.481	0.480	0.479	0.479	0.567	0.423	0.668	0.424	**-0.994**	**-0.992**	0.394	-0.585	0.480
Rain	0.037	-0.772	0.361	0.441	0.849	-0.605	-0.560	-0.240	0.826	1	0.896	0.593	0.671	-0.434	0.597	0.598	0.598	0.598	0.597	0.768	0.485	0.861	0.860	-0.881	-0.812	0.836	-0.934	0.597
Rad	0.021	-0.514	0.351	0.436	**0.995**	-0.531	-0.462	-0.123	**0.987**	0.896	1	0.582	0.552	-0.329	0.582	0.583	0.583	0.582	0.582	0.681	0.515	0.773	0.548	**-0.998**	**-0.986**	0.529	-0.701	0.583
Al	-0.777	-0.807	-0.521	-0.439	0.574	**-0.990**	**-0.978**	-0.874	0.481	0.593	0.582	1	**0.969**	**-0.952**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.964**	**0.990**	0.916	0.530	-0.537	-0.575	0.629	-0.671	**1.000**
Ti	-0.704	-0.926	-0.447	-0.368	0.520	**-0.992**	**-0.990**	-0.879	0.426	0.671	0.552	**0.969**	1	**-0.959**	**0.972**	**0.972**	**0.972**	**0.972**	**0.972**	**0.987**	0.933	**0.950**	0.704	-0.503	-0.505	0.791	-0.800	**0.972**
V	0.869	0.831	0.680	0.615	-0.308	**0.975**	**0.989**	**0.977**	-0.202	-0.434	-0.329	**-0.952**	**-0.959**	1	**-0.953**	**-0.953**	**-0.953**	**-0.953**	**-0.953**	-0.906	-0.948	-0.826	-0.528	0.275	0.304	-0.642	0.617	**-0.953**
Cr	-0.775	-0.813	-0.517	-0.436	0.573	**-0.991**	**-0.980**	-0.875	0.480	0.597	0.582	**1.000**	**0.972**	**-0.953**	1	**1.000**	**1.000**	**1.000**	**1.000**	**0.966**	**0.989**	0.919	0.538	-0.537	-0.574	0.636	-0.677	**1.000**
Mn	-0.774	-0.813	-0.517	-0.436	0.573	**-0.991**	**-0.980**	-0.875	0.481	0.598	0.583	**1.000**	**0.972**	**-0.953**	**1.000**	1	**1.000**	**1.000**	**1.000**	**0.966**	**0.989**	0.919	0.538	-0.538	-0.574	0.637	-0.677	**1.000**
Fe	-0.775	-0.813	-0.517	-0.436	0.573	**-0.991**	**-0.980**	-0.875	0.480	0.598	0.583	**1.000**	**0.972**	**-0.953**	**1.000**	**1.000**	1	**1.000**	**1.000**	**0.966**	**0.989**	0.919	0.538	-0.537	-0.574	0.637	-0.677	**1.000**
Co	-0.775	-0.814	-0.517	-0.436	0.572	**-0.992**	**-0.980**	-0.876	0.479	0.598	0.582	**1.000**	**0.972**	**-0.953**	**1.000**	**1.000**	**1.000**	1	**1.000**	**0.966**	**0.989**	0.920	0.539	-0.537	-0.573	0.638	-0.678	**1.000**
Ni	-0.775	-0.813	-0.517	-0.436	0.573	**-0.991**	**-0.980**	-0.875	0.479	0.597	0.582	**1.000**	**0.972**	**-0.953**	**1.000**	**1.000**	**1.000**	**1.000**	1	**0.966**	**0.989**	0.919	0.538	-0.537	-0.573	0.637	-0.677	**1.000**
Cu	-0.610	-0.917	-0.319	-0.234	0.651	**-0.975**	**-0.959**	-0.795	0.567	0.768	0.681	**0.964**	**0.987**	-0.906	**0.966**	**0.966**	**0.966**	**0.966**	**0.966**	1	0.917	**0.987**	0.731	-0.637	-0.635	0.803	-0.844	**0.966**
Zn	-0.842	-0.726	-0.610	-0.533	0.518	**-0.969**	**-0.960**	-0.890	0.423	0.485	0.515	**0.990**	0.933	-0.948	**0.989**	**0.989**	**0.989**	**0.989**	**0.989**	0.917	1	0.854	0.409	-0.470	-0.528	0.520	-0.561	**0.989**
As	-0.476	-0.915	-0.162	-0.074	0.740	-0.926	-0.901	-0.688	0.668	0.861	0.773	0.916	**0.950**	-0.826	0.919	0.919	0.919	0.920	0.919	**0.987**	0.854	1	0.787	-0.736	-0.719	0.839	-0.899	0.919
Se	-0.051	-0.911	0.189	0.247	0.468	-0.611	-0.607	-0.402	0.424	0.860	0.548	0.530	0.704	-0.528	0.538	0.538	0.538	0.539	0.538	0.731	0.409	0.787	1	-0.517	-0.410	**0.990**	**-0.973**	0.538
Mo	-0.069	0.468	-0.394	-0.476	**-0.996**	0.482	0.411	0.067	**-0.994**	-0.881	**-0.998**	-0.537	-0.503	0.275	-0.537	-0.538	-0.537	-0.537	-0.537	-0.637	-0.470	-0.736	-0.517	1	**0.988**	-0.492	0.670	-0.537
Cd	0.020	0.411	-0.299	-0.382	**-0.998**	0.503	0.430	0.106	**-0.992**	-0.812	**-0.986**	-0.575	-0.505	0.304	-0.574	-0.574	-0.574	-0.573	-0.573	-0.635	-0.528	-0.719	-0.410	**0.988**	1	-0.399	0.588	-0.574
Sb	-0.193	**-0.960**	0.049	0.111	0.452	-0.709	-0.709	-0.529	0.394	0.836	0.529	0.629	0.791	-0.642	0.636	0.637	0.637	0.638	0.637	0.803	0.520	0.839	**0.990**	-0.492	-0.399	1	**-0.976**	0.637
Ba	0.147	0.936	-0.140	-0.214	-0.635	0.725	0.707	0.468	-0.585	-0.934	-0.701	-0.671	-0.800	0.617	-0.677	-0.677	-0.677	-0.678	-0.677	-0.844	-0.561	-0.899	**-0.973**	0.670	0.588	**-0.976**	1	-0.677
Hg	-0.775	-0.813	-0.517	-0.436	0.573	**-0.991**	**-0.980**	-0.875	0.480	0.597	0.583	**1.000**	**0.972**	**-0.953**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.966**	**0.989**	0.919	0.538	-0.537	-0.574	0.637	-0.677	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 12: p- value of the physico-chemical parameters at Dzwerani (Mathobo fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	Nitrates (mg	Phosphates (m	Chlorophyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.545	0.059	0.094	0.995	0.229	0.201	0.068	0.893	0.963	0.979	0.223	0.296	0.131	0.225	0.226	0.225	0.225	0.225	0.390	0.158	0.524	0.949	0.931	0.980	0.807	0.853	0.225
pH	0.545	**0**	0.792	0.862	0.549	0.128	0.124	0.262	0.629	0.228	0.486	0.193	0.074	0.169	0.187	0.187	0.187	0.186	0.187	0.083	0.274	0.085	0.089	0.532	0.589	**0.040**	0.064	0.187
EC (µS/cm	0.059	0.792	**0**	**0.004**	0.671	0.477	0.430	0.191	0.581	0.639	0.649	0.479	0.553	0.320	0.483	0.483	0.483	0.483	0.483	0.681	0.390	0.838	0.811	0.606	0.701	0.951	0.860	0.483
TDS (mg/l	0.094	0.862	**0.004**	**0**	0.587	0.555	0.504	0.240	0.503	0.559	0.564	0.561	0.632	0.385	0.564	0.564	0.564	0.564	0.564	0.766	0.467	0.926	0.753	0.524	0.618	0.889	0.786	0.564
Water ToC	0.995	0.549	0.671	0.587	**0**	0.490	0.562	0.894	**0.006**	0.151	**0.005**	0.426	0.480	0.692	0.427	0.427	0.427	0.428	0.427	0.349	0.482	0.260	0.532	**0.004**	**0.002**	0.548	0.365	0.427
Nitrates (r	0.229	0.128	0.477	0.555	0.490	**0**	**0.003**	0.095	0.587	0.395	0.469	**0.010**	**0.008**	**0.025**	**0.009**	**0.009**	**0.009**	**0.008**	**0.009**	**0.025**	**0.031**	0.074	0.389	0.518	0.497	0.291	0.275	**0.009**
Phosphate	0.201	0.124	0.430	0.504	0.562	**0.003**	**0**	0.066	0.662	0.440	0.538	**0.022**	**0.010**	**0.011**	**0.020**	**0.020**	**0.020**	**0.020**	**0.020**	**0.041**	**0.040**	0.099	0.393	0.589	0.570	0.291	0.293	**0.020**
Chlorophy	0.068	0.262	0.191	0.240	0.894	0.095	0.066	**0**	0.996	0.760	0.877	0.126	0.121	**0.023**	0.125	0.125	0.125	0.124	0.125	0.205	0.110	0.312	0.598	0.933	0.894	0.471	0.532	0.125
Temp	0.893	0.629	0.581	0.503	**0.006**	0.587	0.662	0.996	**0**	0.174	**0.013**	0.519	0.574	0.798	0.520	0.519	0.520	0.521	0.521	0.433	0.577	0.332	0.576	**0.006**	**0.008**	0.606	0.415	0.520
Rain	0.963	0.228	0.639	0.559	0.151	0.395	0.440	0.760	0.174	**0**	0.104	0.407	0.329	0.566	0.403	0.402	0.402	0.402	0.403	0.232	0.515	0.139	0.140	0.119	0.188	0.164	0.066	0.403
Rad	0.979	0.486	0.649	0.564	**0.005**	0.469	0.538	0.877	**0.013**	0.104	**0**	0.418	0.448	0.671	0.418	0.417	0.417	0.418	0.418	0.319	0.485	0.227	0.452	**0.002**	**0.014**	0.471	0.299	0.417
Al	0.223	0.193	0.479	0.561	0.426	**0.010**	**0.022**	0.126	0.519	0.407	0.418	**0**	**0.031**	**0.048**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.036**	**0.010**	0.084	0.470	0.463	0.425	0.371	0.329	**< 0.0001**
Ti	0.296	0.074	0.553	0.632	0.480	**0.008**	**0.010**	0.121	0.574	0.329	0.448	**0.031**	**0**	**0.041**	**0.028**	**0.028**	**0.028**	**0.028**	**0.028**	**0.013**	0.067	**0.050**	0.296	0.497	0.495	0.209	0.200	**0.028**
V	0.131	0.169	0.320	0.385	0.692	**0.025**	**0.011**	**0.023**	0.798	0.566	0.671	**0.048**	**0.041**	**0**	**0.047**	**0.047**	**0.047**	**0.047**	**0.047**	0.094	0.052	0.174	0.472	0.725	0.696	0.358	0.383	**0.047**
Cr	0.225	0.187	0.483	0.564	0.427	**0.009**	**0.020**	0.125	0.520	0.403	0.418	**< 0.0001**	**0.028**	**0.047**	**0**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.034**	**0.011**	0.081	0.462	0.463	0.426	0.364	0.323	**< 0.0001**
Mn	0.226	0.187	0.483	0.564	0.427	**0.009**	**0.020**	0.125	0.519	0.402	0.417	**< 0.0001**	**0.028**	**0.047**	**< 0.0001**	**0**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.034**	**0.011**	0.081	0.462	0.462	0.426	0.363	0.323	**< 0.0001**
Fe	0.225	0.187	0.483	0.564	0.427	**0.009**	**0.020**	0.125	0.520	0.402	0.417	**< 0.0001**	**0.028**	**0.047**	**< 0.0001**	**< 0.0001**	**0**	**< 0.0001**	**< 0.0001**	**0.034**	**0.011**	0.081	0.462	0.463	0.426	0.363	0.323	**< 0.0001**
Co	0.225	0.186	0.483	0.564	0.428	**0.008**	**0.020**	0.124	0.521	0.402	0.418	**< 0.0001**	**0.028**	**0.047**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	**< 0.0001**	**0.034**	**0.011**	0.080	0.461	0.463	0.427	0.362	0.322	**< 0.0001**
Ni	0.225	0.187	0.483	0.564	0.427	**0.009**	**0.020**	0.125	0.521	0.403	0.418	**< 0.0001**	**0.028**	**0.047**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	**0.034**	**0.011**	0.081	0.462	0.463	0.427	0.363	0.323	**< 0.0001**
Cu	0.390	0.083	0.681	0.766	0.349	**0.025**	**0.041**	0.205	0.433	0.232	0.319	**0.036**	**0.013**	0.094	**0.034**	**0.034**	**0.034**	**0.034**	**0.034**	**0**	0.083	**0.013**	0.269	0.363	0.365	0.197	0.156	**0.034**
Zn	0.158	0.274	0.390	0.467	0.482	**0.031**	**0.040**	0.110	0.577	0.515	0.485	**0.010**	0.067	0.052	**0.011**	**0.011**	**0.011**	**0.011**	**0.011**	0.083	**0**	0.146	0.591	0.530	0.472	0.480	0.439	**0.011**
As	0.524	0.085	0.838	0.926	0.260	0.074	0.099	0.312	0.332	0.139	0.227	0.084	**0.050**	0.174	0.081	0.081	0.081	0.080	0.081	**0.013**	0.146	**0**	0.213	0.264	0.281	0.161	0.101	0.081
Se	0.949	0.089	0.811	0.753	0.532	0.389	0.393	0.598	0.576	0.140	0.452	0.470	0.296	0.472	0.462	0.462	0.462	0.461	0.462	0.269	0.591	0.213	**0**	0.483	0.590	**0.010**	**0.027**	0.462
Mo	0.931	0.532	0.606	0.524	**0.004**	0.518	0.589	0.933	**0.006**	0.119	**0.002**	0.463	0.497	0.725	0.463	0.462	0.463	0.463	0.463	0.363	0.530	0.264	0.483	**0**	**0.012**	0.508	0.330	0.463
Cd	0.980	0.589	0.701	0.618	**0.002**	0.497	0.570	0.894	**0.008**	0.188	**0.014**	0.425	0.495	0.696	0.426	0.426	0.426	0.427	0.427	0.365	0.472	0.281	0.590	**0.012**	**0**	0.601	0.412	0.426
Sb	0.807	**0.040**	0.951	0.889	0.548	0.291	0.291	0.471	0.606	0.164	0.471	0.371	0.209	0.358	0.364	0.363	0.363	0.362	0.363	0.197	0.480	0.161	**0.010**	0.508	0.601	**0**	**0.024**	0.363
Ba	0.853	0.064	0.860	0.786	0.365	0.275	0.293	0.532	0.415	0.066	0.299	0.329	0.200	0.383	0.323	0.323	0.323	0.322	0.323	0.156	0.439	0.101	**0.027**	0.330	0.412	**0.024**	**0**	0.323
Hg	0.225	0.187	0.483	0.564	0.427	**0.009**	**0.020**	0.125	0.520	0.403	0.417	**< 0.0001**	**0.028**	**0.047**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.034**	**0.011**	0.081	0.462	0.463	0.426	0.363	0.323	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.9The physico-chemical quality of aquaculture water: Mr. Tshivhase

The fish ponds of Mr. Tshivhase (Figure 11) show that most of the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values. The pH of the water was ranging from 6.65 to 8.54. According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9(Figure 11A). Therefore the pH of the water is normal and suitable for fish farming.

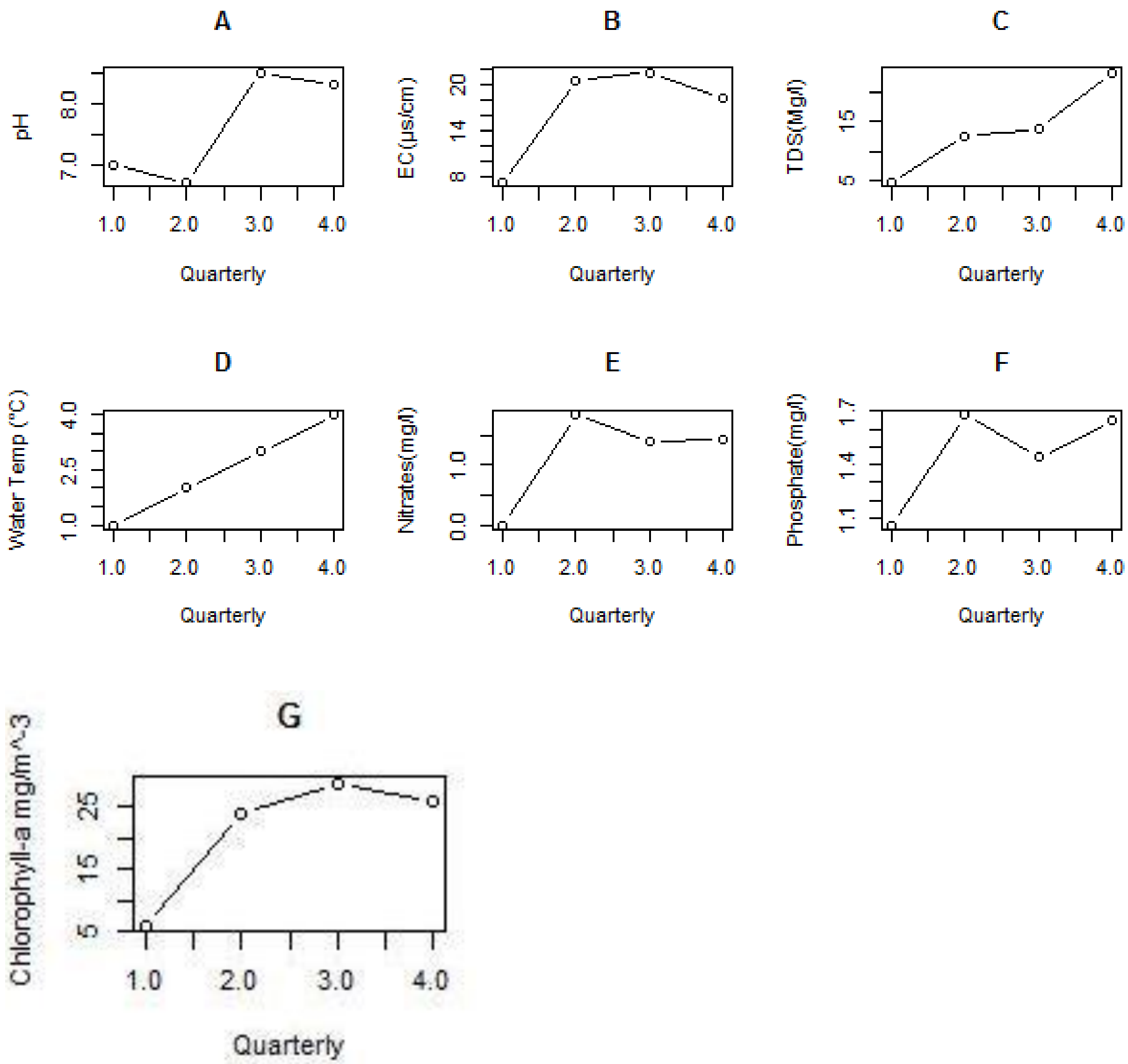


Figure 11: showing the quarterly physico-chemical parameters for Mr Tshivhase fish pond.

This is expected since the nutrients influences the green algae and cyanobacteria and they are phototrophic organism that utilize chlorophyll-a during the photosynthesis process. Phosphate ranged from 1.063- 1.678 mg/l (Figure 11F), which is above the DWAF (1996) guideline value of 0.1 ppm, while the Indonesian national standard water quality typical range for surface waters 1 mg/l (Pangemanan et al., 2014), meaning that the water has a high phosphate content.

The study showed that nitrates ranged from 1.386-1.843 ppm(Figure 11E), which is lower than DWAF (1996) guideline value of 300 ppm while the Indonesian national standard water quality for nitrate is 10 mg/l. It means that water has low nitrate content. Nitrates positively correlates with EC, phosphate and chlorophyll, with 0.961 and $p = 0.049$.

Water temperature ranged from 25 – 28.27 ^{0}C (Figure 11D), because the fish ponds are under the shadow of a tree. According to Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mr. Tshivhase is still normal. Water temperature positively correlates with trace metals such as Cr, Mn, Fe, Co, Ni, As, Se with 0.957 and $p = 0.044$. Solar radiation positively correlates with Temperature, with 0.981 and $p = 0.013$. According to Alley (2007), temperature also increases the toxicity of metal species.

EC ranged from 7.31 to 26.56 µS/cm (figure 11B), while according to Stone et al. (2013), EC of the water for fish farming is between 30-5000 µs/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 4.68 to 22.16 mg/l (figure 11C), while the TDS of the water should not be more than 500 (Keremah et al., 2014). Therefore the TDS is good for the fish.

3.5.10The presence metal species in aquaculture water: Mr. Tshivhase

Al, Mn, Fe, Zn, Cu, Cr, Se were detected in water samples (Table 13) that originated from the earthen ponds (Figure 12) and according to DWAF (1996)aquaculture guidelines they are exceeding water guidelines for aquaculture during the first quarter. Al positively correlate with Mn, Cr, Fe, Co, Ni, As and Se. This is expected since Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Mn correlated with Fe. This was expected since

Mn and Fe are found in the geological material Earlshannonite with the formula $Mn^{2+}Fe_2^{3+}(PO_4)_2(OH)_2 \cdot 4H_2O$, Ni, As and Se are found in the geological material Jolliffeite with the formulaNiAsSe(https://www.mindat.org/min-1845.html).

Figure 12: The earthen fish dam for Mr. Tshivhase

Hg positively correlates with Cr, Mn, Fe, Co, Ni, As and Se This was expected since Ti and Fe are found in the geological material Heideite with the formula $(Fe,Cr)_{1.15}(Ti,Fe)_2S_4$, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Cr and Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$, Mn and Fe are found in the geological material Earlshannonite with the formula $Mn^{2+}Fe_2^{3+}(PO_4)_2(OH)_2 \cdot 4H_2O$, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$(https://www.mindat.org/min-1845.html).

Ti positively correlates with Al, Fe and Se with a coefficient greater than 0.5 and p = < 0. 0001 (Table 14 and 15). Ti, Al, Fe and Fe are found in the geological material Hemloite with the formula $(Ti,V^{3+},Fe^{3+},Al)_{12}As_2^{3+}O_{23}(OH)$, Ni, As and Se are found in the geological material Jolliffeite with the formula NiAsSe(https://www.mindat.org/min-1845.html). The presence of Cr, Mn, Fe, Co, Ni and Se were expected since those elements are probable found in the Basalt group which is found in the study area (Figure 4).

Table 13: The presence of metal species in the aquaculture pond for Mr Tshivhase

Ppb	Tshivhase				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	169.35±1.68	9.20±0.59	35.56±2.28	44.50±2.96	**30**	**70**	**105**	1500
Ti	5.84±0.48	0.55±0.05	2.29±0.19	2.15±0.20				
V	0.86±0.00	1.57±0.03	1.07±0.02	0.70±0.01				
Cr	21.07±0.01	0.26±0.00	0.25±0.00	0.14±0.01	**20000**			
Mn	106.72±0.20	0.17±0.00	0.40±0.01	0.50±0.03	**100**	**500**	**600**	
Fe	794.37±7.01	8.72±0.18	42.41±0.85	34.20±1.84	**10**	**1750**		
Co	12.43±0.65	0.02±0.00	0.04±0.00	0.02±0.00				
Ni	566.81±26.02	0.30±0.00	0.43±0.00	0.35±0.03				
Cu	1.74±0.09	2.67±0.00	2.98±0.00	1.46±0.15	**5**			
Zn	5.18±0.21	3.16±0.01	7.45±0.02	6.30±0.30	**30**			
As	0.56±0.01	0.05±0.00	0.04±0.00	0.05±0.00		**50**		
Se	2.00±0.04	0.45±0.00	0.45±0.00	0.06±0.06	**300**	**460**		
Mo	1.54±0.05	0.05±0.00	0.07±0.00	0.01±0.00				
Cd	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.23±0.01	0.47±0.01	0.16±0.00	0.26±0.01				
Ba	15.59±0.19	18.61±0.15	43.19±0.35	17.78±17.37				
Hg	0.01±0.00	0.00±0.00	0.00±0.00	0.07±0.00	**1000**			
Pb	0.17±0.01	0.03±0.00	0.05±0.00	0.07±0.00	**10**	**30**	**2150**	

Table 14: Spearman correlation matrix of the physico-chemical parameters at Phiphidi (Tshivhase fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	Nitrates (mg	Phosphates (m	Chlorophyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.816	0.669	**0.967**	-0.901	0.621	0.688	0.814	0.085	0.278	-0.004	-0.620	-0.560	-0.332	-0.777	-0.773	-0.756	-0.775	-0.775	-0.310	0.576	-0.777	-0.746	-0.086	-0.069	-0.169	0.323	-0.775
pH	0.816	1	0.456	0.647	-0.561	0.246	0.217	0.627	0.026	0.506	0.030	-0.294	-0.157	-0.537	-0.485	-0.481	-0.449	-0.482	-0.483	-0.113	0.932	-0.498	-0.356	-0.035	0.104	-0.683	0.674	-0.483
EC (µS/cm	0.669	0.456	1	0.641	-0.878	**0.951**	0.853	**0.974**	-0.653	-0.492	-0.737	**-0.976**	-0.924	0.448	**-0.977**	**-0.978**	**-0.977**	**-0.978**	**-0.978**	0.423	0.139	**-0.981**	-0.932	0.655	0.608	0.241	0.561	**-0.978**
TDS (mg/l	**0.967**	0.647	0.641	1	-0.926	0.673	0.788	0.767	0.162	0.201	0.043	-0.648	-0.631	-0.258	-0.781	-0.776	-0.767	-0.778	-0.778	-0.416	0.370	-0.775	-0.799	-0.159	-0.193	0.052	0.100	-0.778
Water To(	-0.901	-0.561	-0.878	-0.926	1	-0.896	-0.929	-0.933	0.213	0.155	0.334	0.886	0.863	-0.098	**0.958**	**0.956**	**0.952**	**0.957**	**0.957**	0.063	-0.226	**0.954**	**0.961**	-0.217	-0.157	-0.221	-0.275	**0.957**
Nitrates (r	0.621	0.246	**0.951**	0.673	-0.896	1	**0.961**	0.904	-0.549	-0.577	-0.667	**-0.995**	**-0.996**	0.529	**-0.967**	**-0.968**	**-0.976**	**-0.968**	**-0.968**	0.287	-0.111	**-0.963**	**-0.982**	0.556	0.447	0.504	0.281	**-0.968**
Phosphate	0.688	0.217	0.853	0.788	-0.929	**0.961**	1	0.836	-0.305	-0.438	-0.448	-0.931	**-0.962**	0.386	-0.926	-0.925	-0.935	-0.926	-0.925	0.020	-0.151	-0.916	**-0.982**	0.314	0.183	0.565	0.056	-0.925
Chlorophy	0.814	0.627	**0.974**	0.767	-0.933	0.904	0.836	1	-0.500	-0.284	-0.583	-0.929	-0.861	0.235	**-0.980**	**-0.980**	**-0.973**	**-0.980**	**-0.980**	0.263	0.321	**-0.984**	-0.925	0.501	0.481	0.088	0.579	**-0.980**
Temp	0.085	0.026	-0.653	0.162	0.213	-0.549	-0.305	-0.500	1	0.812	**0.987**	0.609	0.553	-0.812	0.484	0.490	0.497	0.487	0.488	**-0.958**	0.156	0.495	0.402	**-1.000**	**-0.979**	-0.227	-0.647	0.488
Rain	0.278	0.506	-0.492	0.201	0.155	-0.577	-0.438	-0.284	0.812	1	0.855	0.580	0.630	**-0.998**	0.384	0.391	0.417	0.388	0.388	-0.733	0.686	0.381	0.420	-0.820	-0.682	-0.740	-0.086	0.388
Rad	-0.004	0.030	-0.737	0.043	0.334	-0.667	-0.448	-0.583	**0.987**	0.855	1	0.716	0.675	-0.847	0.590	0.596	0.605	0.593	0.594	-0.903	0.211	0.598	0.528	**-0.989**	-0.941	-0.338	-0.585	0.594
Al	-0.620	-0.294	**-0.976**	-0.648	0.886	**-0.995**	-0.931	-0.929	0.609	0.580	0.716	1	**0.985**	-0.534	**0.975**	**0.976**	**0.982**	**0.975**	**0.975**	-0.357	0.053	**0.973**	**0.971**	-0.615	-0.522	-0.439	-0.375	**0.975**
Ti	-0.560	-0.157	-0.924	-0.631	0.863	**-0.996**	**-0.962**	-0.861	0.553	0.630	0.675	**0.985**	1	-0.584	0.940	0.941	**0.953**	0.941	0.941	-0.292	0.202	0.934	**0.969**	-0.561	-0.436	-0.580	-0.215	0.940
V	-0.332	-0.537	0.448	-0.258	-0.098	0.529	0.386	0.235	-0.812	**-0.998**	-0.847	-0.534	-0.584	1	-0.333	-0.340	-0.366	-0.337	-0.337	0.748	-0.698	-0.331	-0.367	0.820	0.685	0.725	0.081	-0.337
Cr	-0.777	-0.485	**-0.977**	-0.781	**0.958**	**-0.967**	-0.926	**-0.980**	0.484	0.384	0.590	**0.975**	0.940	-0.333	1	**1.000**	**0.999**	**1.000**	**1.000**	-0.223	-0.144	**1.000**	**0.981**	-0.487	-0.425	-0.276	-0.426	**1.000**
Mn	-0.773	-0.481	**-0.978**	-0.776	**0.956**	**-0.968**	-0.925	**-0.980**	0.490	0.391	0.596	**0.976**	0.941	-0.340	**1.000**	1	**0.999**	**1.000**	**1.000**	-0.229	-0.140	**1.000**	**0.981**	-0.493	-0.430	-0.280	-0.428	**1.000**
Fe	-0.756	-0.449	**-0.977**	-0.767	**0.952**	**-0.976**	-0.935	**-0.973**	0.497	0.417	0.605	**0.982**	**0.953**	-0.366	**0.999**	**0.999**	1	**0.999**	**0.999**	-0.235	-0.105	**0.998**	**0.985**	-0.501	-0.431	-0.313	-0.406	**0.999**
Co	-0.775	-0.482	**-0.978**	-0.778	**0.957**	**-0.968**	-0.926	**-0.980**	0.487	0.388	0.593	**0.975**	0.941	-0.337	**1.000**	**1.000**	**0.999**	1	**1.000**	-0.227	-0.142	**1.000**	**0.981**	-0.491	-0.428	-0.279	-0.427	**1.000**
Ni	-0.775	-0.483	**-0.978**	-0.778	**0.957**	**-0.968**	-0.925	**-0.980**	0.488	0.388	0.594	**0.975**	0.941	-0.337	**1.000**	**1.000**	**0.999**	**1.000**	1	-0.228	-0.142	**1.000**	**0.981**	-0.492	-0.429	-0.278	-0.428	**1.000**
Cu	-0.310	-0.113	0.423	-0.416	0.063	0.287	0.020	0.263	**-0.958**	-0.733	-0.903	-0.357	-0.292	0.748	-0.223	-0.229	-0.235	-0.227	-0.228	1	-0.140	-0.238	-0.123	**0.956**	**0.969**	0.086	0.646	-0.228
Zn	0.576	0.932	0.139	0.370	-0.226	-0.111	-0.151	0.321	0.156	0.686	0.211	0.053	0.202	-0.698	-0.144	-0.140	-0.105	-0.142	-0.142	-0.140	1	-0.161	0.005	-0.169	0.020	-0.900	0.649	-0.142
As	-0.777	-0.498	**-0.981**	-0.775	**0.954**	**-0.963**	-0.916	**-0.984**	0.495	0.381	0.598	**0.973**	0.934	-0.331	**1.000**	**1.000**	**0.998**	**1.000**	**1.000**	-0.238	-0.161	1	**0.976**	-0.499	-0.441	-0.258	-0.449	**1.000**
Se	-0.746	-0.356	-0.932	-0.799	**0.961**	**-0.982**	**-0.982**	-0.925	0.402	0.420	0.528	**0.971**	**0.969**	-0.367	**0.981**	**0.981**	**0.985**	**0.981**	**0.981**	-0.123	0.005	**0.976**	1	-0.408	-0.309	-0.430	-0.244	**0.981**
Mo	-0.086	-0.035	0.655	-0.159	-0.217	0.556	0.314	0.501	**-1.000**	-0.820	**-0.989**	-0.615	-0.561	0.820	-0.487	-0.493	-0.501	-0.491	-0.492	**0.956**	-0.169	-0.499	-0.408	1	**0.976**	0.241	0.637	-0.492
Cd	-0.069	0.104	0.608	-0.193	-0.157	0.447	0.183	0.481	**-0.979**	-0.682	-0.941	-0.522	-0.436	0.685	-0.425	-0.430	-0.431	-0.428	-0.429	**0.969**	0.020	-0.441	-0.309	**0.976**	1	0.025	0.773	-0.429
Sb	-0.169	-0.683	0.241	0.052	-0.221	0.504	0.565	0.088	-0.227	-0.740	-0.338	-0.439	-0.580	0.725	-0.276	-0.280	-0.313	-0.279	-0.278	0.086	-0.900	-0.258	-0.430	0.241	0.025	1	-0.546	-0.278
Ba	0.323	0.674	0.561	0.100	-0.275	0.281	0.056	0.579	-0.647	-0.086	-0.585	-0.375	-0.215	0.081	-0.426	-0.428	-0.406	-0.427	-0.428	0.646	0.649	-0.449	-0.244	0.637	0.773	-0.546	1	-0.428
Hg	-0.775	-0.483	**-0.978**	-0.778	**0.957**	**-0.968**	-0.925	**-0.980**	0.488	0.388	0.594	**0.975**	0.940	-0.337	**1.000**	**1.000**	**0.999**	**1.000**	**1.000**	-0.228	-0.142	**1.000**	**0.981**	-0.492	-0.429	-0.278	-0.428	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 15: p- value of the physico-chemical parameters at Phiphidi (Tshivhase fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.184	0.331	**0.033**	0.099	0.379	0.312	0.186	0.915	0.722	0.996	0.380	0.440	0.668	0.223	0.227	0.244	0.225	0.225	0.690	0.424	0.223	0.254	0.914	0.931	0.831	0.677	0.225
pH	0.184	**0**	0.544	0.353	0.439	0.754	0.783	0.373	0.974	0.494	0.970	0.706	0.843	0.463	0.515	0.519	0.551	0.518	0.517	0.887	0.068	0.502	0.644	0.965	0.896	0.317	0.326	0.517
EC (µS/cm	0.331	0.544	**0**	0.359	0.122	**0.049**	0.147	**0.026**	0.347	0.508	0.263	**0.024**	0.076	0.552	**0.023**	**0.022**	**0.023**	**0.022**	**0.022**	0.577	0.861	**0.019**	0.068	0.345	0.392	0.759	0.439	**0.022**
TDS (mg/l	**0.033**	0.353	0.359	**0**	0.074	0.327	0.212	0.233	0.838	0.799	0.957	0.352	0.369	0.742	0.219	0.224	0.233	0.222	0.222	0.584	0.630	0.225	0.201	0.841	0.807	0.948	0.900	0.222
Water ToC	0.099	0.439	0.122	0.074	**0**	0.104	0.071	0.067	0.787	0.845	0.666	0.114	0.137	0.902	**0.042**	**0.044**	**0.048**	**0.043**	**0.043**	0.937	0.774	**0.046**	**0.039**	0.783	0.843	0.779	0.725	**0.043**
Nitrates (r	0.379	0.754	**0.049**	0.327	0.104	**0**	**0.039**	0.096	0.451	0.423	0.333	**0.005**	**0.004**	0.471	**0.033**	**0.032**	**0.024**	**0.032**	**0.032**	0.713	0.889	**0.037**	**0.018**	0.444	0.553	0.496	0.719	**0.032**
Phosphate	0.312	0.783	0.147	0.212	0.071	**0.039**	**0**	0.164	0.695	0.562	0.552	0.069	**0.038**	0.614	0.074	0.075	0.065	0.074	0.075	0.980	0.849	0.084	**0.018**	0.686	0.817	0.435	0.944	0.075
Chlorophy	0.186	0.373	**0.026**	0.233	0.067	0.096	0.164	**0**	0.500	0.716	0.417	0.071	0.139	0.765	**0.020**	**0.020**	**0.027**	**0.020**	**0.020**	0.737	0.679	**0.016**	0.075	0.499	0.519	0.912	0.421	**0.020**
Temp	0.915	0.974	0.347	0.838	0.787	0.451	0.695	0.500	**0**	0.188	**0.013**	0.391	0.447	0.188	0.516	0.510	0.503	0.513	0.512	**0.042**	0.844	0.505	0.598	**0.000**	**0.021**	0.773	0.353	0.512
Rain	0.722	0.494	0.508	0.799	0.845	0.423	0.562	0.716	0.188	**0**	0.145	0.420	0.370	**0.002**	0.616	0.609	0.583	0.612	0.612	0.267	0.314	0.619	0.580	0.180	0.318	0.260	0.914	0.612
Rad	0.996	0.970	0.263	0.957	0.666	0.333	0.552	0.417	**0.013**	0.145	**0**	0.284	0.325	0.153	0.410	0.404	0.395	0.407	0.406	0.097	0.789	0.402	0.472	**0.011**	0.059	0.662	0.415	0.406
Al	0.380	0.706	**0.024**	0.352	0.114	**0.005**	0.069	0.071	0.391	0.420	0.284	**0**	**0.015**	0.466	**0.025**	**0.024**	**0.018**	**0.025**	**0.025**	0.643	0.947	**0.027**	**0.029**	0.385	0.478	0.561	0.625	**0.025**
Ti	0.440	0.843	0.076	0.369	0.137	**0.004**	**0.038**	0.139	0.447	0.370	0.325	**0.015**	**0**	0.416	0.060	0.059	**0.047**	0.059	0.059	0.708	0.798	0.066	**0.031**	0.439	0.564	0.420	0.785	0.060
V	0.668	0.463	0.552	0.742	0.902	0.471	0.614	0.765	0.188	**0.002**	0.153	0.466	0.416	**0**	0.667	0.660	0.634	0.663	0.663	0.252	0.302	0.669	0.633	0.180	0.315	0.275	0.919	0.663
Cr	0.223	0.515	**0.023**	0.219	**0.042**	**0.033**	0.074	**0.020**	0.516	0.616	0.410	**0.025**	0.060	0.667	**0**	**< 0.0001**	**0.001**	**< 0.0001**	**< 0.0001**	0.777	0.856	**0.000**	**0.019**	0.513	0.575	0.724	0.574	**< 0.0001**
Mn	0.227	0.519	**0.022**	0.224	**0.044**	**0.032**	0.075	**0.020**	0.510	0.609	0.404	**0.024**	0.059	0.660	**< 0.0001**	**0**	**0.001**	**< 0.0001**	**< 0.0001**	0.771	0.860	**0.000**	**0.019**	0.507	0.570	0.720	0.572	**< 0.0001**
Fe	0.244	0.551	**0.023**	0.233	**0.048**	**0.024**	0.065	**0.027**	0.503	0.583	0.395	**0.018**	**0.047**	0.634	**0.001**	**0.001**	**0**	**0.001**	**0.001**	0.765	0.895	**0.002**	**0.015**	0.499	0.569	0.687	0.594	**0.001**
Co	0.225	0.518	**0.022**	0.222	**0.043**	**0.032**	0.074	**0.020**	0.513	0.612	0.407	**0.025**	0.059	0.663	**< 0.0001**	**< 0.0001**	**0.001**	**0**	**< 0.0001**	0.773	0.858	**0.000**	**0.019**	0.509	0.572	0.721	0.573	**< 0.0001**
Ni	0.225	0.517	**0.022**	0.222	**0.043**	**0.032**	0.075	**0.020**	0.512	0.612	0.406	**0.025**	0.059	0.663	**< 0.0001**	**< 0.0001**	**0.001**	**< 0.0001**	**0**	0.772	0.858	**0.000**	**0.019**	0.508	0.571	0.722	0.572	**< 0.0001**
Cu	0.690	0.887	0.577	0.584	0.937	0.713	0.980	0.737	**0.042**	0.267	0.097	0.643	0.708	0.252	0.777	0.771	0.765	0.773	0.772	**0**	0.860	0.762	0.877	**0.044**	**0.031**	0.914	0.354	0.772
Zn	0.424	0.068	0.861	0.630	0.774	0.889	0.849	0.679	0.844	0.314	0.789	0.947	0.798	0.302	0.856	0.860	0.895	0.858	0.858	0.860	**0**	0.839	0.995	0.831	0.980	0.100	0.351	0.858
As	0.223	0.502	**0.019**	0.225	**0.046**	**0.037**	0.084	**0.016**	0.505	0.619	0.402	**0.027**	0.066	0.669	**0.000**	**0.000**	**0.002**	**0.000**	**0.000**	0.762	0.839	**0**	**0.024**	0.501	0.559	0.742	0.551	**0.000**
Se	0.254	0.644	0.068	0.201	**0.039**	**0.018**	**0.018**	0.075	0.598	0.580	0.472	**0.029**	**0.031**	0.633	**0.019**	**0.019**	**0.015**	**0.019**	**0.019**	0.877	0.995	**0.024**	**0**	0.592	0.691	0.570	0.756	**0.019**
Mo	0.914	0.965	0.345	0.841	0.783	0.444	0.686	0.499	**0.000**	0.180	**0.011**	0.385	0.439	0.180	0.513	0.507	0.499	0.509	0.508	**0.044**	0.831	0.501	0.592	**0**	**0.024**	0.759	0.363	0.508
Cd	0.931	0.896	0.392	0.807	0.843	0.553	0.817	0.519	**0.021**	0.318	0.059	0.478	0.564	0.315	0.575	0.570	0.569	0.572	0.571	**0.031**	0.980	0.559	0.691	**0.024**	**0**	0.975	0.227	0.571
Sb	0.831	0.317	0.759	0.948	0.779	0.496	0.435	0.912	0.773	0.260	0.662	0.561	0.420	0.275	0.724	0.720	0.687	0.721	0.722	0.914	0.100	0.742	0.570	0.759	0.975	**0**	0.454	0.722
Ba	0.677	0.326	0.439	0.900	0.725	0.719	0.944	0.421	0.353	0.914	0.415	0.625	0.785	0.919	0.574	0.572	0.594	0.573	0.572	0.354	0.351	0.551	0.756	0.363	0.227	0.454	**0**	0.572
Hg	0.225	0.517	**0.022**	0.222	**0.043**	**0.032**	0.075	**0.020**	0.512	0.612	0.406	**0.025**	0.060	0.663	**< 0.0001**	**< 0.0001**	**0.001**	**< 0.0001**	**< 0.0001**	0.772	0.858	**0.000**	**0.019**	0.508	0.571	0.722	0.572	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.11The physico-chemical quality of aquaculture water: Mr. Shavhani

The fish ponds of Mr. Shavhani show that the pH of the water was ranging from 5.5 to 8.37(Figure 13A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming but if the pH keeps on rising it cause danger to fish.

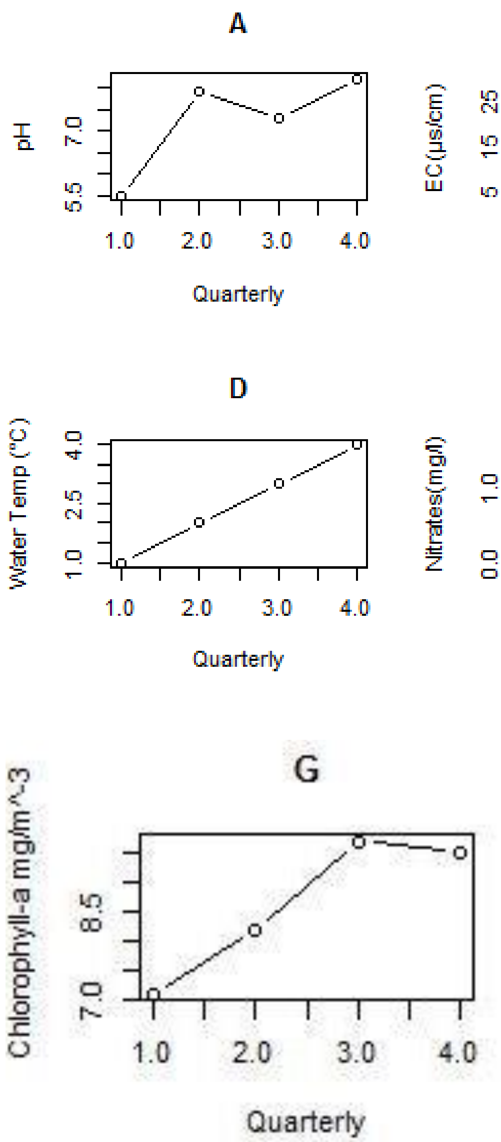


Figure 13: showing the Quarterly physico-chemical parameters for Mr. Shavhani fish pond.

The study showed that nitrates ranged from 1.43 to 1.564 ppm (Figure 13E),which is lower than DWAF (1996) aquaculture guideline value of 300 ppm, while the Indonesian national standard water quality for nitrate is 10 mg/l. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.09 to 1.99 mg/l (Figure 13F), which is above the DWAF (1996) aquaculture guideline value of 0.1 ppm, while the Indonesian national standard water quality typical range for surface waters 1 mg/l(Pangemanan et al,. 2014), meaning that the water has a high phosphate content. Phosphate positively correlates with nitrates and EC, with 0.991 and p = 0.0009. Nitrates can be found from unconsumed fish feeds, fish waste or dead plants in water which decompose or breakdown to form building blocks of phosphate and it uses energy in cells so it may influence ions in water. The higher the ions in water the higher the current (EC) which is carried by those ions.

Water temperature ranged from 22.63 to 29.8 ^{0}C (Figure 13D) because the fish ponds are under the shadow of a tree and there is little sunlight during the day. Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mr. Shavhani is normal. EC ranged from 6.98 to 151.63 µS/cm (Figure 13B), while according to Stone et al. (2013), EC of the water for fish farming is between 30-5000 µS/cm and therefore the EC of the water was below the standard. Water temperature positively correlates with TDS and Mn and Temperature also correlates with the solar radiation, with 0.989 and p = 0.011. Temperature and Water temperature depends on radiation which is the heat energy from the sun, from the sun to be high. When temperature is high it also has effect on Mn which causes the solids to dissolve (http://www.lenntech.com/periodic/elements/mn.htm).

TDS of the water ranged from 4.47 to 89.43 mg/l (Figure 13C), while the TDS of the water should not be more than 500 (Keremah et al., 2014). Therefore the TDS is good for the fish.

3.5.12The presence metal species in aquaculture water: Mr. Shavhani

The metals were present in the water samples at different concentrations during the study period (Table 16). Al, Cr, Fe, Ni and Zn were high in the first quarter and Ti shows positive correlation coefficient of 0.996 with Cr, Ni, As and Se and p = 0.004 (Table 17 & 18) and these water samples were collected from an earthen pond (Figure 14). This was expected since Ti and Cr are found in the geological material Olkhonskite with the formula $Cr_2Ti_3O_9$ and Ni, As and Se are found in the geological material Jolliffeite with the formula NiAsSe(https://www.mindat.org/min-1845.html).

Figure 14: The earthen fish dam for Mr Shavhani (White flakes are maize bran used to feed the fish)

Cr shows positive correlation coefficient of <0.0001 with V, Fe, Ni, As and Se, Hg shows positive correlation coefficient of 1.000 with Ti, Cr, Fe and Se , p =<0.0001 This was expected since V, Fe and Cr are found in the geological material with Crichtonite the formula $Sr(Mn,Y,U)Fe_2(Ti,Fe,Cr,V)_{18}(O,OH)_{38}$ (https://www.mindat.org/min-1845.html). Cu, As, Ti, Cr elements were expected since they are probable found in the sedimentary group which is found in the study area (Figure 4).

Mo correlates with Zn, Cd and Se with coefficient greater than 0.5, which means there is strong correlation. This was expected since Mo and Se are found in the geological material Drysdallite with the formula $MoSe_2$ and Zn and Cd are found in the geological material Aldridgeite with the formula $(Cd,Ca)(Cu,Zn)_4(SO_4)_2(OH)_6 \cdot 3H_2O$ (https://www.mindat.org/min-1845.html).

Table 16: The presence of metal species in the aquaculture pond for Mr Shavhani

Ppb	Shavhani				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	**2nd QTR**	**3rd QTR**	**4th QTR**	No adverse effect	toxic to	toxic to	lethal
Al	14.25±0.14	4.97±0.32	1.19±0.08	7.56±0.52	**30**	**70**	**105**	1500
Ti	0.76±0.06	0.10±0.01	0.03±0.00	8.64±0.44				
V	0.27±0.00	0.19±0.00	0.18±0.00	0.24±0.00				
Cr	12.10±0.01	0.22±0.00	0.18±0.00	0.12±0.01	**20000**			
Mn	0.71±0.00	0.04±0.00	0.54±0.01	3.30±0.01	**100**	**500**	**600**	
Fe	91.83±0.81	3.60±0.07	5.36±0.11	3.13±0.33	**10**	**1750**		
Co	0.14±0.01	0.02±0.00	0.03±0.00	0.07±0.00				
Ni	94.38±4.33	0.84±0.00	0.57±0.00	0.82±0.01				
Cu	2.19±0.11	1.62±0.00	1.00±0.00	1.47±0.03	**5**			
Zn	8.63±0.36	16.41±0.05	17.81±0.05	9.04±0.28	**30**			
As	0.58±0.01	0.07±0.00	0.09±0.00	0.16±0.01		**50**		
Se	2.00±0.04	0.45±0.00	0.45±0.00	0.13±0.07	**300**	**460**		
Mo	0.73±0.02	0.07±0.00	0.08±0.00	0.02±0.01				
Cd	0.01±0.00	0.01±0.00	0.00±0.00	0.01±0.00	**200**			
Sb	0.24±0.01	0.41±0.01	0.36±0.01	0.15±0.00				
Ba	374.20±4.59	37.98±0.31	22.9±0.18	24.01±0.34				
Hg	0.01±0.00	0.00±0.00	0.001±0.00	0.00±0.00	**1000**			
Pb	0.16±0.00	0.01±0.00	0.006±0.00	0.05±0.00	**10**	**30**	**2150**	

Table 17:Spearman correlation matrix of the physico-chemical parameters at Shanzha (Shavhani fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.805	0.721	0.828	0.680	0.726	0.834	0.923	0.067	0.262	0.145	-0.587	-0.828	-0.373	-0.779	0.730	-0.778	-0.495	-0.775	-0.383	0.054	-0.685	-0.750	-0.074	0.127	-0.359	-0.729	-0.775
pH	0.805	1	0.849	0.636	0.405	0.943	**0.991**	0.736	-0.276	-0.302	-0.270	-0.712	-0.946	-0.606	**-0.953**	0.390	**-0.959**	-0.817	**-0.952**	-0.415	0.348	-0.922	**-0.989**	0.300	0.397	0.065	**-0.967**	**-0.952**
EC (µS/cm	0.721	0.849	1	0.867	0.746	0.625	0.781	0.459	0.232	0.025	0.202	-0.237	-0.651	-0.097	-0.652	0.690	-0.666	-0.409	-0.647	0.118	-0.179	-0.580	-0.766	-0.195	-0.135	-0.366	-0.941	-0.649
TDS (mg/l	0.828	0.636	0.867	1	**0.962**	0.388	0.595	0.550	0.546	0.502	0.569	-0.073	-0.492	0.148	-0.448	**0.955**	-0.458	-0.090	-0.442	0.198	-0.460	-0.326	-0.515	-0.535	-0.399	-0.729	-0.705	-0.443
Water To(	0.680	0.405	0.746	**0.962**	1	0.122	0.354	0.364	0.753	0.684	0.771	0.184	-0.239	0.405	-0.189	**0.990**	-0.199	0.184	-0.182	0.411	-0.680	-0.057	-0.265	-0.744	-0.627	-0.884	-0.509	-0.183
Nitrates (r	0.726	0.943	0.625	0.388	0.122	1	**0.971**	0.789	-0.559	-0.472	-0.532	-0.900	**-0.986**	-0.835	**-0.997**	0.133	**-0.997**	**-0.952**	**-0.997**	-0.684	0.630	**-0.998**	**-0.979**	0.572	0.674	0.335	-0.838	**-0.997**
Phosphate	0.834	**0.991**	0.781	0.595	0.354	**0.971**	1	0.811	-0.344	-0.298	-0.320	-0.792	**-0.981**	-0.682	**-0.982**	0.357	**-0.985**	-0.854	**-0.981**	-0.527	0.425	**-0.953**	**-0.990**	0.360	0.478	0.109	-0.924	**-0.981**
Chlorophy	0.923	0.736	0.459	0.550	0.364	0.789	0.811	1	-0.250	0.086	-0.146	-0.807	-0.875	-0.635	-0.828	0.447	-0.821	-0.644	-0.827	-0.700	0.373	-0.769	-0.735	0.229	0.442	-0.062	-0.573	-0.826
Temp	0.067	-0.276	0.232	0.546	0.753	-0.559	-0.344	-0.250	1	0.855	**0.989**	0.767	0.459	0.901	0.503	0.729	0.494	0.780	0.510	0.825	**-0.991**	0.612	0.418	**-0.998**	**-0.979**	**-0.951**	0.109	0.509
Rain	0.262	-0.302	0.025	0.502	0.684	-0.472	-0.298	0.086	0.855	1	0.921	0.497	0.321	0.680	0.400	0.736	0.402	0.698	0.406	0.446	-0.798	0.521	0.419	-0.884	-0.765	-0.918	0.259	0.407
Rad	0.145	-0.270	0.202	0.569	0.771	-0.532	-0.320	-0.146	**0.989**	0.921	1	0.701	0.414	0.857	0.470	0.768	0.463	0.766	0.476	0.737	**-0.965**	0.587	0.410	**-0.995**	-0.945	**-0.975**	0.133	0.476
Al	-0.587	-0.712	-0.237	-0.073	0.184	-0.900	-0.792	-0.807	0.767	0.497	0.701	1	0.889	**0.968**	0.891	0.126	0.882	0.932	0.893	0.933	-0.840	0.917	0.793	-0.757	-0.878	-0.534	0.518	0.892
Ti	-0.828	-0.946	-0.651	-0.492	-0.239	**-0.986**	**-0.981**	-0.875	0.459	0.321	0.414	0.889	1	0.786	**0.996**	-0.265	**0.995**	0.897	**0.995**	0.677	-0.547	**0.976**	**0.967**	-0.465	-0.600	-0.203	0.833	**0.995**
V	-0.373	-0.606	-0.097	0.148	0.405	-0.835	-0.682	-0.635	0.901	0.680	0.857	**0.968**	0.786	1	0.807	0.361	0.797	0.940	0.811	0.935	-0.945	0.866	0.715	-0.896	**-0.966**	-0.728	0.417	0.810
Cr	-0.779	**-0.953**	-0.652	-0.448	-0.189	**-0.997**	**-0.982**	-0.828	0.503	0.400	0.470	0.891	**0.996**	0.807	1	-0.205	**1.000**	0.926	**1.000**	0.671	-0.582	**0.990**	**0.980**	-0.514	-0.631	-0.265	0.848	**1.000**
Mn	0.730	0.390	0.690	**0.955**	**0.990**	0.133	0.357	0.447	0.729	0.736	0.768	0.126	-0.265	0.361	-0.205	1	-0.213	0.177	-0.198	0.322	-0.644	-0.068	-0.254	-0.729	-0.585	-0.889	-0.462	-0.199
Fe	-0.778	**-0.959**	-0.666	-0.458	-0.199	**-0.997**	**-0.985**	-0.821	0.494	0.402	0.463	0.882	**0.995**	0.797	**1.000**	-0.213	1	0.924	**1.000**	0.655	-0.572	**0.989**	**0.984**	-0.506	-0.620	-0.258	0.859	**1.000**
Co	-0.495	-0.817	-0.409	-0.090	0.184	**-0.952**	-0.854	-0.644	0.780	0.698	0.766	0.932	0.897	0.940	0.926	0.177	0.924	1	0.929	0.777	-0.824	**0.970**	0.894	-0.793	-0.849	-0.608	0.691	0.929
Ni	-0.775	**-0.952**	-0.647	-0.442	-0.182	**-0.997**	**-0.981**	-0.827	0.510	0.406	0.476	0.893	**0.995**	0.811	**1.000**	-0.198	**1.000**	0.929	1	0.675	-0.588	**0.991**	**0.980**	-0.521	-0.637	-0.272	0.845	**1.000**
Cu	-0.383	-0.415	0.118	0.198	0.411	-0.684	-0.527	-0.700	0.825	0.446	0.737	0.933	0.677	0.935	0.671	0.322	0.655	0.777	0.675	1	-0.889	0.714	0.522	-0.798	-0.917	-0.621	0.177	0.673
Zn	0.054	0.348	-0.179	-0.460	-0.680	0.630	0.425	0.373	**-0.991**	-0.798	**-0.965**	-0.840	-0.547	-0.945	-0.582	-0.644	-0.572	-0.824	-0.588	-0.889	1	-0.678	-0.485	**0.985**	**0.997**	0.902	-0.163	-0.587
As	-0.685	-0.922	-0.580	-0.326	-0.057	**-0.998**	**-0.953**	-0.769	0.612	0.521	0.587	0.917	**0.976**	0.866	**0.990**	-0.068	**0.989**	**0.970**	**0.991**	0.714	-0.678	1	**0.968**	-0.624	-0.719	-0.396	0.810	**0.991**
Se	-0.750	**-0.989**	-0.766	-0.515	-0.265	**-0.979**	**-0.990**	-0.735	0.418	0.419	0.410	0.793	**0.967**	0.715	**0.980**	-0.254	**0.984**	0.894	**0.980**	0.522	-0.485	**0.968**	1	-0.440	-0.529	-0.211	0.931	**0.980**
Mo	-0.074	0.300	-0.195	-0.535	-0.744	0.572	0.360	0.229	**-0.998**	-0.884	**-0.995**	-0.757	-0.465	-0.896	-0.514	-0.729	-0.506	-0.793	-0.521	-0.798	**0.985**	-0.624	-0.440	1	**0.971**	**0.957**	-0.144	-0.520
Cd	0.127	0.397	-0.135	-0.399	-0.627	0.674	0.478	0.442	**-0.979**	-0.765	-0.945	-0.878	-0.600	**-0.966**	-0.631	-0.585	-0.620	-0.849	-0.637	-0.917	**0.997**	-0.719	-0.529	**0.971**	1	0.867	-0.205	-0.635
Sb	-0.359	0.065	-0.366	-0.729	-0.884	0.335	0.109	-0.062	**-0.951**	-0.918	**-0.975**	-0.534	-0.203	-0.728	-0.265	-0.889	-0.258	-0.608	-0.272	-0.621	0.902	-0.396	-0.211	**0.957**	0.867	1	0.052	-0.272
Ba	-0.729	**-0.967**	-0.941	-0.705	-0.509	-0.838	-0.924	-0.573	0.109	0.259	0.133	0.518	0.833	0.417	0.848	-0.462	0.859	0.691	0.845	0.177	-0.163	0.810	0.931	-0.144	-0.205	0.052	1	0.847
Hg	-0.775	**-0.952**	-0.649	-0.443	-0.183	**-0.997**	**-0.981**	-0.826	0.509	0.407	0.476	0.892	**0.995**	0.810	**1.000**	-0.199	**1.000**	0.929	**1.000**	0.673	-0.587	**0.991**	**0.980**	-0.520	-0.635	-0.272	0.847	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 18: Spearman correlation matrix of the physico-chemical parameters at Shanzha (Shavhani fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.195	0.279	0.172	0.320	0.274	0.166	0.077	0.933	0.738	0.855	0.413	0.172	0.627	0.221	0.270	0.222	0.505	0.225	0.617	0.946	0.315	0.250	0.926	0.873	0.641	0.271	0.225
pH	0.195	**0**	0.151	0.364	0.595	0.057	**0.009**	0.264	0.724	0.698	0.730	0.288	0.054	0.394	**0.047**	0.610	**0.041**	0.183	**0.048**	0.585	0.652	0.078	**0.011**	0.700	0.603	0.935	**0.033**	**0.048**
EC (µS/cm	0.279	0.151	**0**	0.133	0.254	0.375	0.219	0.541	0.768	0.975	0.798	0.763	0.349	0.903	0.348	0.310	0.334	0.591	0.353	0.882	0.821	0.420	0.234	0.805	0.865	0.634	0.059	0.351
TDS (mg/l	0.172	0.364	0.133	**0**	**0.038**	0.612	0.405	0.450	0.454	0.498	0.431	0.927	0.508	0.852	0.552	**0.045**	0.542	0.910	0.558	0.802	0.540	0.674	0.485	0.465	0.601	0.271	0.295	0.557
Water ToC	0.320	0.595	0.254	**0.038**	**0**	0.878	0.646	0.636	0.247	0.316	0.229	0.816	0.761	0.595	0.811	**0.010**	0.801	0.816	0.818	0.589	0.320	0.943	0.735	0.256	0.373	0.116	0.491	0.817
Nitrates (r	0.274	0.057	0.375	0.612	0.878	**0**	**0.029**	0.211	0.441	0.528	0.468	0.100	**0.014**	0.165	**0.003**	0.867	**0.003**	**0.048**	**0.003**	0.316	0.370	**0.002**	**0.021**	0.428	0.326	0.665	0.162	**0.003**
Phosphate	0.166	**0.009**	0.219	0.405	0.646	**0.029**	**0**	0.189	0.656	0.702	0.680	0.208	**0.019**	0.318	**0.018**	0.643	**0.015**	0.146	**0.019**	0.473	0.575	**0.047**	**0.010**	0.640	0.522	0.891	0.076	**0.019**
Chlorophy	0.077	0.264	0.541	0.450	0.636	0.211	0.189	**0**	0.750	0.914	0.854	0.193	0.125	0.365	0.172	0.553	0.179	0.356	0.173	0.300	0.627	0.231	0.265	0.771	0.558	0.938	0.427	0.174
Temp	0.933	0.724	0.768	0.454	0.247	0.441	0.656	0.750	**0**	0.145	**0.011**	0.233	0.541	0.099	0.497	0.271	0.506	0.220	0.490	0.175	**0.009**	0.388	0.582	**0.002**	**0.021**	**0.049**	0.891	0.491
Rain	0.738	0.698	0.975	0.498	0.316	0.528	0.702	0.914	0.145	**0**	0.079	0.503	0.679	0.320	0.600	0.264	0.598	0.302	0.594	0.554	0.202	0.479	0.581	0.116	0.235	0.082	0.741	0.593
Rad	0.855	0.730	0.798	0.431	0.229	0.468	0.680	0.854	**0.011**	0.079	**0**	0.299	0.586	0.143	0.530	0.232	0.537	0.234	0.524	0.263	**0.035**	0.413	0.590	**0.005**	0.055	**0.025**	0.867	0.524
Al	0.413	0.288	0.763	0.927	0.816	0.100	0.208	0.193	0.233	0.503	0.299	**0**	0.111	**0.032**	0.109	0.874	0.118	0.068	0.107	0.067	0.160	0.083	0.207	0.243	0.122	0.466	0.482	0.108
Ti	0.172	0.054	0.349	0.508	0.761	**0.014**	**0.019**	0.125	0.541	0.679	0.586	0.111	**0**	0.214	**0.004**	0.735	**0.005**	0.103	**0.005**	0.323	0.453	**0.024**	**0.033**	0.535	0.400	0.797	0.167	**0.005**
V	0.627	0.394	0.903	0.852	0.595	0.165	0.318	0.365	0.099	0.320	0.143	**0.032**	0.214	**0**	0.193	0.639	0.203	0.060	0.189	0.065	0.055	0.134	0.285	0.104	**0.034**	0.272	0.583	0.190
Cr	0.221	**0.047**	0.348	0.552	0.811	**0.003**	**0.018**	0.172	0.497	0.600	0.530	0.109	**0.004**	0.193	**0**	0.795	**0.000**	0.074	**< 0.0001**	0.329	0.418	**0.010**	**0.020**	0.486	0.369	0.735	0.152	**< 0.0001**
Mn	0.270	0.610	0.310	**0.045**	**0.010**	0.867	0.643	0.553	0.271	0.264	0.232	0.874	0.735	0.639	0.795	**0**	0.787	0.823	0.802	0.678	0.356	0.932	0.746	0.271	0.415	0.111	0.538	0.801
Fe	0.222	**0.041**	0.334	0.542	0.801	**0.003**	**0.015**	0.179	0.506	0.598	0.537	0.118	**0.005**	0.203	**0.000**	0.787	**0**	0.076	**0.000**	0.345	0.428	**0.011**	**0.016**	0.494	0.380	0.742	0.141	**0.000**
Co	0.505	0.183	0.591	0.910	0.816	**0.048**	0.146	0.356	0.220	0.302	0.234	0.068	0.103	0.060	0.074	0.823	0.076	**0**	0.071	0.223	0.176	**0.030**	0.106	0.207	0.151	0.392	0.309	0.071
Ni	0.225	**0.048**	0.353	0.558	0.818	**0.003**	**0.019**	0.173	0.490	0.594	0.524	0.107	**0.005**	0.189	**< 0.0001**	0.802	**0.000**	0.071	**0**	0.325	0.412	**0.009**	**0.020**	0.479	0.363	0.728	0.155	**< 0.0001**
Cu	0.617	0.585	0.882	0.802	0.589	0.316	0.473	0.300	0.175	0.554	0.263	0.067	0.323	0.065	0.329	0.678	0.345	0.223	0.325	**0**	0.111	0.286	0.478	0.202	0.083	0.379	0.823	0.327
Zn	0.946	0.652	0.821	0.540	0.320	0.370	0.575	0.627	**0.009**	0.202	**0.035**	0.160	0.453	0.055	0.418	0.356	0.428	0.176	0.412	0.111	**0**	0.322	0.515	**0.015**	**0.003**	0.098	0.837	0.413
As	0.315	0.078	0.420	0.674	0.943	**0.002**	**0.047**	0.231	0.388	0.479	0.413	0.083	**0.024**	0.134	**0.010**	0.932	**0.011**	**0.030**	**0.009**	0.286	0.322	**0**	**0.032**	0.376	0.281	0.604	0.190	**0.009**
Se	0.250	**0.011**	0.234	0.485	0.735	**0.021**	**0.010**	0.265	0.582	0.581	0.590	0.207	**0.033**	0.285	**0.020**	0.746	**0.016**	0.106	**0.020**	0.478	0.515	**0.032**	**0**	0.560	0.471	0.789		
Mo	0.926	0.700	0.805	0.465	0.256	0.428	0.640	0.771	**0.002**	0.116	**0.005**	0.243	0.535	0.104	0.486	0.271	0.494	0.207	0.479	0.202	**0.015**	0.376	0.560					
Cd	0.873	0.603	0.865	0.601	0.373	0.326	0.522	0.558	**0.021**	0.235	0.055	0.122	0.400	**0.034**	0.369	0.415	0.380	0.151	0.363	0.083	**0.003**	0.281	0.471					
Sb	0.641	0.935	0.634	0.271	0.116	0.665	0.891	0.938	**0.049**	0.082	**0.025**	0.466	0.797	0.272	0.735	0.111	0.742	0.392	0.728	0.379	0.098	0.604	1					
Ba	0.271	**0.033**	0.059	0.295	0.491	0.162	0.076	0.427	0.891	0.741	0.867	0.482	0.167	0.583	0.152	0.538	0.141	0.309	0.155	0.823	0.837	0.190						
Hg	0.225	**0.048**	0.351	0.557	0.817	**0.003**	**0.019**	0.174	0.491	0.593	0.524	0.108	**0.005**	0.190	**< 0.0001**	0.801	**0.000**	0.071	**< 0.0001**	0.327	0.413	**0.009**						

3.5.13The physico-chemical quality of aquaculture water: Mr Nevondo

The fish ponds of Mr. Nevondo show that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values. The pH of the water was ranging from 5.53 to 7.89(Figure 15A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming. The pH positively correlates with chlorophyll, with 0.951 and p = 0.0008.The relationship between this two is expected because chlorophyll release carbon dioxide in water which tend to decrease pH in water.

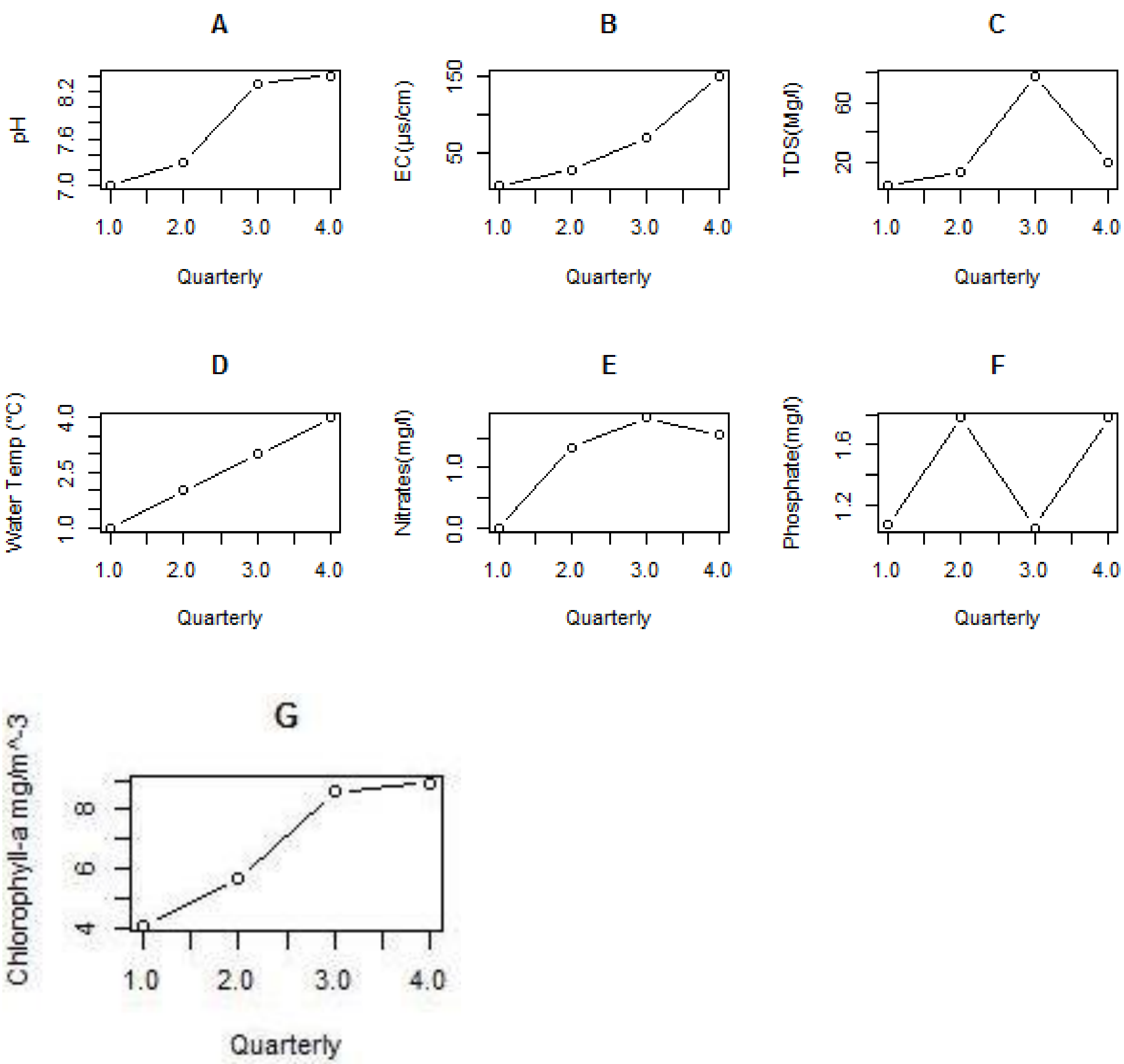


Figure 15: showing the quarterly physico-chemical parameters for Mr. Nevondo fish pond.

The study showed that nitrates ranged from 1 to 1.842 ppm (Figure 15E), which is lower than DWAF (1996) guideline value of 300 ppm while the Indonesian national standard water quality for nitrate is 10 mg/l. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.046 to 1.784 mg/l (Figure 15F),which was above the DWAF (1996) guideline value of 0.1 ppm, while the Indonesian national standard water quality typical range for surface waters 1 mg/l(Pangemanan et al. (2014),meaning that the water has a high phosphate content.

Water temperature ranged from 23.62 to 27.55 ^{0}C (Figure 15D), because the fish ponds are under the shadow of a tree. According to Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mr. Nevondo is still normal. EC ranged from 2.95-30.3µS/cm (Figure 15B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 2.44 to 19.77 mg/l (Figure 15C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore the TDS is good for the fish.

3.5.14The presence metal species in aquaculture water: Mr. Nevondo

Most of the trace elements in the earthen fish dam (Figure 16) were extremely high, such as Al, V, Cr, Mn, Fe, Co, Ni, Cu, Zn and Mo (DWAF, 1996) (Table 19). Al positively correlates with Ti, V, Cr, Mn, Fe, Co, Ni, Cu, Zn, As, Mo and Hg, with 1.000 and p = <0.0001 (Table 20&21).

Figure 16: The earthen fish dam for Mr. Nevondo

This was expected since Ti, Fe, Al, As and V are found in the geological material Hemloite with the formula $(Ti,V^{3+},Fe^{3+},Al)_{12}As_2^{3+}O_{23}(OH)$, Cr and Mn are found in the geological material Joegoldsteinite with the formula $MnCr_2S_4$, Mo and Hg are found in the geological material. Mosesite with the formula $Hg_2Ni(Cl,SO_4,MoO_4,CO_3) \cdot H_2O$, Cu and Zn are found in the geological material Danbaitewith the formula $CuZn_2$and Co, Ni, As, and Cu are found in the geological material Hloušekite with the formula $(Ni,Co)Cu_4(AsO_4)_2(AsO_3OH)_2 \cdot 9H_2O$ (https://www.mindat.org/min-1845.html). The presence of this elements were expected since those elements are found in the Basalt group which is found in the study area (Figure 4).

Table 19: The presence of metal species in the aquaculture pond for Mr Nevondo

Ppb	Nevondo				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	**2nd QTR**	**3rd QTR**	**4th QTR**	No adverse effect	toxic to	toxic to	lethal
Al	26.66±0.26	1.52±2.12	3.34±0.21	2.63±0.35	**30**	**70**	**105**	1500
Ti	0.49±0.04	0.01±0.00	0.07±0.01	0.04±0.01				
V	5.51±0.02	0.09±0.00	0.03±0.00	0.04±0.01				
Cr	1328.53±0.75	0.18±0.00	0.26±0.00	0.20±0.01	**20000**			
Mn	933.28±1.79	16.16±0.04	0.94±0.02	1.22±0.02	**100**	**500**	**600**	
Fe	18152.70±160.28	45.86±4.62	5.48±0.11	1.73±0.10	**10**	**1750**		
Co	134.36±7.06	0.73±0.00	0.03±0.00	0.02±0.01				
Ni	6832.92±313.69	0.80±0.00	0.78±0.00	1.32±0.03				
Cu	59.40±3.04	0.25±0.00	0.30±0.00	0.41±0.00	**5**			
Zn	55.98±2.32	15.40±0.45	10.19±0.03	15.53±0.56	**30**			
As	0.63±0.01	0.03±0.00	0.03±0.00	0.02±0.01		**50**		
Se	0.66±0.01	0.45±0.00	0.45±0.00	0.04±0.00	**300**	**460**		
Mo	60.45±1.94	0.10±0.00	0.19±0.01	0.00±0.00				
Cd	0.02±0.00	0.01±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.40±0.01	0.06±0.00	0.31±0.01	0.29±0.01				
Ba	65.03±0.80	110.64±25.27	16.88±0.13	29.54±0.04				
Hg	0.03±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.82±0.03	0.01±0.00	0.00±0.00	0.04±0.00	**10**	**30**	**2150**	

Table 20: Spearman correlation matrix of the physico-chemical & climate data parameters at Vondo (Nevondo fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	**0.951**	**0.961**	0.429	-0.775	0.817	0.431	**0.966**	0.085	0.278	-0.004	-0.755	-0.729	-0.780	-0.775	-0.783	-0.776	-0.777	-0.775	-0.773	-0.773	-0.776	-0.610	-0.814	0.063	-0.066	-0.615	-0.775
pH	**0.951**	1	0.886	0.651	-0.626	0.805	0.135	**0.992**	0.002	0.365	-0.043	-0.654	-0.620	-0.698	-0.691	-0.702	-0.693	-0.695	-0.691	-0.690	-0.724	-0.695	-0.357	-0.731	0.231	0.140	-0.802	-0.691
EC (µS/cm	**0.961**	0.886	1	0.224	-0.913	0.628	0.457	0.878	0.358	0.475	0.268	-0.581	-0.555	-0.603	-0.597	-0.606	-0.598	-0.600	-0.597	-0.595	-0.580	-0.598	-0.566	-0.647	-0.208	0.073	-0.622	-0.597
TDS (mg/l	0.429	0.651	0.224	1	0.181	0.673	-0.452	0.648	-0.590	-0.026	-0.540	-0.437	-0.408	-0.492	-0.487	-0.495	-0.488	-0.489	-0.487	-0.487	-0.582	-0.492	0.162	-0.487	0.830	0.157	-0.657	-0.487
Water ToC	-0.775	-0.626	-0.913	0.181	1	-0.304	-0.577	-0.608	-0.659	-0.570	-0.559	0.334	0.317	0.338	0.333	0.340	0.335	0.336	0.333	0.331	0.282	0.333	0.561	0.388	0.583	-0.104	0.413	0.333
Nitrates (r	0.817	0.805	0.628	0.673	-0.304	1	0.356	0.870	-0.502	-0.259	-0.579	**-0.953**	-0.940	**-0.972**	**-0.970**	**-0.973**	**-0.970**	**-0.971**	**-0.970**	**-0.970**	**-0.989**	**-0.971**	-0.620	**-0.973**	0.574	-0.423	-0.361	**-0.970**
Phosphate	0.431	0.135	0.457	-0.452	-0.577	0.356	1	0.220	0.123	-0.301	-0.035	-0.600	-0.621	-0.552	-0.557	-0.550	-0.556	-0.554	-0.556	-0.556	-0.460	-0.552	**-0.953**	-0.559	-0.344	-0.724	0.412	-0.556
Chlorophy	**0.966**	**0.992**	0.878	0.648	-0.608	0.870	0.220	1	-0.080	0.250	-0.138	-0.746	-0.715	-0.784	-0.778	-0.787	-0.779	-0.781	-0.778	-0.776	-0.804	-0.781	-0.452	-0.812	0.280	0.013	-0.723	-0.778
Temp	0.085	0.002	0.358	-0.590	-0.659	-0.502	0.123	-0.080	1	0.812	**0.987**	0.483	0.494	0.484	0.488	0.482	0.487	0.486	0.488	0.490	0.534	0.489	0.079	0.437	-0.936	0.550	-0.221	0.488
Rain	0.278	0.365	0.475	-0.026	-0.570	-0.259	-0.301	0.250	0.812	1	0.855	0.420	0.454	0.380	0.388	0.375	0.386	0.384	0.388	0.390	0.370	0.385	0.359	0.329	-0.554	0.873	-0.724	0.388
Rad	-0.004	-0.043	0.268	-0.540	-0.559	-0.579	-0.035	-0.138	**0.987**	0.855	1	0.595	0.608	0.589	0.594	0.587	0.593	0.592	0.594	0.596	0.626	0.594	0.236	0.544	-0.894	0.662	-0.267	0.594
Al	-0.755	-0.654	-0.581	-0.437	0.334	**-0.953**	-0.600	-0.746	0.483	0.420	0.595	1	**0.999**	**0.998**	**0.998**	**0.997**	**0.998**	**0.998**	**0.998**	**0.998**	**0.986**	**0.998**	0.813	**0.994**	-0.450	0.653	0.096	**0.998**
Ti	-0.729	-0.620	-0.555	-0.408	0.317	-0.940	-0.621	-0.715	0.494	0.454	0.608	**0.999**	1	**0.994**	**0.995**	**0.993**	**0.994**	**0.994**	**0.995**	**0.995**	**0.979**	**0.994**	0.827	**0.989**	-0.445	0.687	0.050	**0.995**
V	-0.780	-0.698	-0.603	-0.492	0.338	**-0.972**	-0.552	-0.784	0.484	0.380	0.589	**0.998**	**0.994**	1	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.994**	**1.000**	0.778	**0.998**	-0.476	0.603	0.161	**1.000**
Cr	-0.775	-0.691	-0.597	-0.487	0.333	**-0.970**	-0.557	-0.778	0.488	0.388	0.594	**0.998**	**0.995**	**1.000**	1	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.994**	**1.000**	0.781	**0.998**	-0.476	0.611	0.151	**1.000**
Mn	-0.783	-0.702	-0.606	-0.495	0.340	**-0.973**	-0.550	-0.787	0.482	0.375	0.587	**0.997**	**0.993**	**1.000**	**1.000**	1	**1.000**	**1.000**	**1.000**	**1.000**	**0.995**	**1.000**	0.776	**0.999**	-0.476	0.599	0.166	**1.000**
Fe	-0.776	-0.693	-0.598	-0.488	0.335	**-0.970**	-0.556	-0.779	0.487	0.386	0.593	**0.998**	**0.994**	**1.000**	**1.000**	**1.000**	1	**1.000**	**1.000**	**1.000**	**0.994**	**1.000**	0.780	**0.998**	-0.476	0.609	0.153	**1.000**
Co	-0.777	-0.695	-0.600	-0.489	0.336	**-0.971**	-0.554	-0.781	0.486	0.384	0.592	**0.998**	**0.994**	**1.000**	**1.000**	**1.000**	**1.000**	1	**1.000**	**1.000**	**0.994**	**1.000**	0.780	**0.998**	-0.476	0.607	0.156	**1.000**
Ni	-0.775	-0.691	-0.597	-0.487	0.333	**-0.970**	-0.556	-0.778	0.488	0.388	0.594	**0.998**	**0.995**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	1	**1.000**	**0.994**	**1.000**	0.781	**0.998**	-0.477	0.611	0.151	**1.000**
Cu	-0.773	-0.690	-0.595	-0.487	0.331	**-0.970**	-0.556	-0.776	0.490	0.390	0.596	**0.998**	**0.995**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	1	**0.994**	**1.000**	0.781	**0.998**	-0.478	0.612	0.150	**1.000**
Zn	-0.773	-0.724	-0.580	-0.582	0.282	**-0.989**	-0.460	-0.804	0.534	0.370	0.626	**0.986**	**0.979**	**0.994**	**0.994**	**0.995**	**0.994**	**0.994**	**0.994**	**0.994**	1	**0.994**	0.706	**0.991**	-0.553	0.552	0.221	**0.994**
As	-0.776	-0.695	-0.598	-0.492	0.333	**-0.971**	-0.552	-0.781	0.489	0.385	0.594	**0.998**	**0.994**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.994**	1	0.777	**0.998**	-0.479	0.606	0.157	**1.000**
Se	-0.610	-0.357	-0.566	0.162	0.561	-0.620	**-0.953**	-0.452	0.079	0.359	0.236	0.813	0.827	0.778	0.781	0.776	0.780	0.780	0.781	0.781	0.706	0.777	1	0.783	0.090	0.760	-0.248	0.781
Mo	-0.814	-0.731	-0.647	-0.487	0.388	**-0.973**	-0.559	-0.812	0.437	0.329	0.544	**0.994**	**0.989**	**0.998**	**0.998**	**0.999**	**0.998**	**0.998**	**0.998**	**0.998**	**0.991**	**0.998**	0.783	1	-0.440	0.570	0.199	**0.998**
Cd	0.063	0.231	-0.208	0.830	0.583	0.574	-0.344	0.280	-0.936	-0.554	-0.894	-0.450	-0.445	-0.476	-0.476	-0.476	-0.476	-0.476	-0.477	-0.478	-0.553	-0.479	0.090	-0.440	1	-0.264	-0.128	-0.476
Sb	-0.066	0.140	0.073	0.157	-0.104	-0.423	-0.724	0.013	0.550	0.873	0.662	0.653	0.687	0.603	0.611	0.599	0.609	0.607	0.611	0.612	0.552	0.606	0.760	0.570	-0.264	1	-0.690	0.611
Ba	-0.615	-0.802	-0.622	-0.657	0.413	-0.361	0.412	-0.723	-0.221	-0.724	-0.267	0.096	0.050	0.161	0.151	0.166	0.153	0.156	0.151	0.150	0.221	0.157	-0.248	0.199	-0.128	-0.690	1	0.151
Hg	-0.775	-0.691	-0.597	-0.487	0.333	**-0.970**	-0.556	-0.778	0.488	0.388	0.594	**0.998**	**0.995**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**0.994**	**1.000**	0.781	**0.998**	-0.476	0.611	0.151	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 21: p- value of the physico-chemical & climate data parameters at Vondo (Nevondo fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	**0.049**	**0.039**	0.571	0.225	0.183	0.569	**0.034**	0.915	0.722	0.996	0.245	0.271	0.220	0.225	0.217	0.224	0.223	0.225	0.227	0.227	0.224	0.390	0.186	0.937	0.934	0.385	0.225
pH	**0.049**	**0**	0.114	0.349	0.374	0.195	0.865	**0.008**	0.998	0.635	0.957	0.346	0.380	0.302	0.309	0.298	0.307	0.305	0.309	0.310	0.276	0.305	0.643	0.269	0.769	0.860	0.198	0.309
EC (µS/cm	**0.039**	0.114	**0**	0.776	0.087	0.372	0.543	0.122	0.642	0.525	0.732	0.419	0.445	0.397	0.403	0.394	0.402	0.400	0.403	0.405	0.420	0.402	0.434	0.353	0.792	0.927	0.378	0.403
TDS (mg/l	0.571	0.349	0.776	**0**	0.819	0.327	0.548	0.352	0.410	0.974	0.460	0.563	0.592	0.508	0.513	0.505	0.512	0.511	0.513	0.513	0.418	0.508	0.838	0.513	0.170	0.843	0.343	0.513
Water ToC	0.225	0.374	0.087	0.819	**0**	0.696	0.423	0.392	0.341	0.430	0.441	0.666	0.683	0.662	0.667	0.660	0.665	0.664	0.667	0.669	0.718	0.667	0.439	0.612	0.417	0.896	0.587	0.667
Nitrates (r	0.183	0.195	0.372	0.327	0.696	**0**	0.644	0.130	0.498	0.741	0.421	**0.047**	0.060	**0.028**	**0.030**	**0.027**	**0.030**	**0.029**	**0.030**	**0.030**	**0.011**	**0.029**	0.380	**0.027**	0.426	0.577	0.639	**0.030**
Phosphate	0.569	0.865	0.543	0.548	0.423	0.644	**0**	0.780	0.877	0.699	0.965	0.400	0.379	0.448	0.443	0.450	0.444	0.446	0.444	0.444	0.540	0.448	**0.047**	0.441	0.656	0.276	0.588	0.444
Chlorophy	**0.034**	**0.008**	0.122	0.352	0.392	0.130	0.780	**0**	0.920	0.750	0.862	0.254	0.285	0.216	0.222	0.213	0.221	0.219	0.222	0.224	0.196	0.219	0.548	0.188	0.720	0.987	0.277	0.222
Temp	0.915	0.998	0.642	0.410	0.341	0.498	0.877	0.920	**0**	0.188	**0.013**	0.517	0.506	0.516	0.512	0.518	0.513	0.514	0.512	0.510	0.466	0.511	0.921	0.563	0.064	0.450	0.779	0.512
Rain	0.722	0.635	0.525	0.974	0.430	0.741	0.699	0.750	0.188	**0**	0.145	0.580	0.546	0.620	0.612	0.625	0.614	0.616	0.612	0.610	0.630	0.615	0.641	0.671	0.446	0.127	0.276	0.612
Rad	0.996	0.957	0.732	0.460	0.441	0.421	0.965	0.862	**0.013**	0.145	**0**	0.405	0.392	0.411	0.406	0.413	0.407	0.408	0.406	0.404	0.374	0.406	0.764	0.456	0.106	0.338	0.733	0.406
Al	0.245	0.346	0.419	0.563	0.666	**0.047**	0.400	0.254	0.517	0.580	0.405	**0**	**0.001**	**0.002**	**0.002**	**0.003**	**0.002**	**0.002**	**0.002**	**0.002**	**0.014**	**0.002**	0.187	**0.006**	0.550	0.347	0.904	**0.002**
Ti	0.271	0.380	0.445	0.592	0.683	0.060	0.379	0.285	0.506	0.546	0.392	**0.001**	**0**	**0.006**	**0.005**	**0.007**	**0.006**	**0.006**	**0.005**	**0.005**	**0.021**	**0.006**	0.173	**0.011**	0.555	0.313	0.950	**0.005**
V	0.220	0.302	0.397	0.508	0.662	**0.028**	0.448	0.216	0.516	0.620	0.411	**0.002**	**0.006**	**0**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**< 0.0001**	0.222	**0.002**	0.524	0.397	0.839	**< 0.0001**
Cr	0.225	0.309	0.403	0.513	0.667	**0.030**	0.443	0.222	0.512	0.612	0.406	**0.002**	**0.005**	**< 0.0001**	**0**	**0.000**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**< 0.0001**	0.219	**0.002**	0.524	0.389	0.849	**< 0.0001**
Mn	0.217	0.298	0.394	0.505	0.660	**0.027**	0.450	0.213	0.518	0.625	0.413	**0.003**	**0.007**	**< 0.0001**	**0.000**	**0**	**< 0.0001**	**< 0.0001**	**0.000**	**0.000**	**0.005**	**< 0.0001**	0.224	**0.001**	0.524	0.401	0.834	**0.000**
Fe	0.224	0.307	0.402	0.512	0.665	**0.030**	0.444	0.221	0.513	0.614	0.407	**0.002**	**0.006**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**< 0.0001**	0.220	**0.002**	0.524	0.391	0.847	**< 0.0001**
Co	0.223	0.305	0.400	0.511	0.664	**0.029**	0.446	0.219	0.514	0.616	0.408	**0.002**	**0.006**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	**< 0.0001**	**< 0.0001**	**0.006**	**< 0.0001**	0.220	**0.002**	0.524	0.393	0.844	**< 0.0001**
Ni	0.225	0.309	0.403	0.513	0.667	**0.030**	0.444	0.222	0.512	0.612	0.406	**0.002**	**0.005**	**< 0.0001**	**< 0.0001**	**0.000**	**< 0.0001**	**< 0.0001**	**0**	**< 0.0001**	**0.006**	**< 0.0001**	0.219	**0.002**	0.523	0.389	0.849	**< 0.0001**
Cu	0.227	0.310	0.405	0.513	0.669	**0.030**	0.444	0.224	0.510	0.610	0.404	**0.002**	**0.005**	**< 0.0001**	**< 0.0001**	**0.000**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0**	**0.006**	**< 0.0001**	0.219	**0.002**	0.522	0.388	0.850	**< 0.0001**
Zn	0.227	0.276	0.420	0.418	0.718	**0.011**	0.540	0.196	0.466	0.630	0.374	**0.014**	**0.021**	**0.006**	**0.006**	**0.005**	**0.006**	**0.006**	**0.006**	**0.006**	**0**	**0.006**	0.294	**0.009**	0.447	0.448	0.779	**0.006**
As	0.224	0.305	0.402	0.508	0.667	**0.029**	0.448	0.219	0.511	0.615	0.406	**0.002**	**0.006**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**0**	0.223	**0.002**	0.521	0.394	0.843	**< 0.0001**
Se	0.390	0.643	0.434	0.838	0.439	0.380	**0.047**	0.548	0.921	0.641	0.764	0.187	0.173	0.222	0.219	0.224	0.220	0.220	0.219	0.219	0.294	0.223	**0**	0.217	0.910	0.240	0.752	0.219
Mo	0.186	0.269	0.353	0.513	0.612	**0.027**	0.441	0.188	0.563	0.671	0.456	**0.006**	**0.011**	**0.002**	**0.002**	**0.001**	**0.002**	**0.002**	**0.002**	**0.002**	**0.009**	**0.002**	0.217	**0**	0.560	0.430	0.801	**0.002**
Cd	0.937	0.769	0.792	0.170	0.417	0.426	0.656	0.720	0.064	0.446	0.106	0.550	0.555	0.524	0.524	0.524	0.524	0.524	0.523	0.522	0.447	0.521	0.910	0.560	**0**	0.736	0.872	0.524
Sb	0.934	0.860	0.927	0.843	0.896	0.577	0.276	0.987	0.450	0.127	0.338	0.347	0.313	0.397	0.389	0.401	0.391	0.393	0.389	0.388	0.448	0.394	0.240	0.430	0.736	**0**	0.310	0.389
Ba	0.385	0.198	0.378	0.343	0.587	0.639	0.588	0.277	0.779	0.276	0.733	0.904	0.950	0.839	0.849	0.834	0.847	0.844	0.849	0.850	0.779	0.843	0.752	0.801	0.872	0.310	**0**	0.849
Hg	0.225	0.309	0.403	0.513	0.667	**0.030**	0.444	0.222	0.512	0.612	0.406	**0.002**	**0.005**	**< 0.0001**	**< 0.0001**	**0.000**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**< 0.0001**	**0.006**	**< 0.0001**	0.219	**0.002**	0.524	0.389	0.849	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.15The physico-chemical quality of aquaculture water: Mrs. Mahwasane

The fish ponds (Figure 18) of Mrs. Mahwasane shows that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values (Figure 17). The pH of the water was ranging from 6.82 to 8.37 (Figure 17A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming.

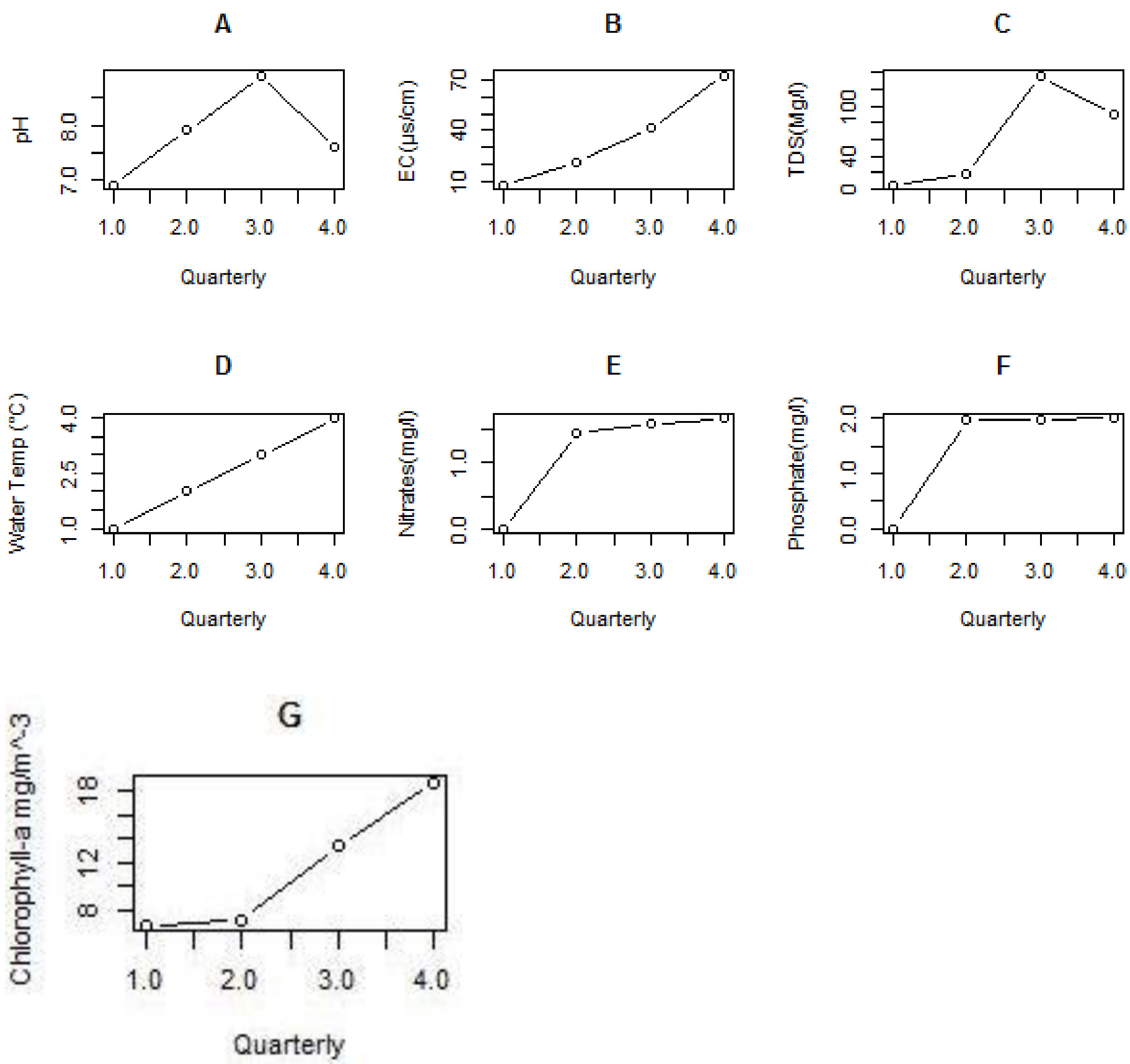


Figure 17: showing the quarterly physico-chemical parameters Mrs Mahwasane fish pond.

The study showed that nitrates ranged from 1.457 to 1.678 ppm (Figure 17E), which is lower than DWAF (1996) guideline value of 300 ppm. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.962 to 1.99 mg/l (Figure 17F), which was above the DWAF (1996) guideline value of 0.1 ppm, meaning that the water has a high phosphate content. Nitrates positively correlates with phosphate, with 0.978 and $p = 0.0005$. The relationship between nitrates and phosphates is expected since nitrates can be found from unconsumed fish feeds, fish waste or dead plants in water which decompose or breakdown to form building blocks of phosphate.

Water temperature ranged from 20.9 – 27.9 ^{0}C (Figure 17D). Keremah et al. (2014) said that water temperature must be 20 to 30 ^{0}C, water temperature of Mrs. Mahwasane is still normal. Temperature positively correlated with radiation, rain and Zn, with 0.974 and $p = 0.026$. This is expected since temperature depends on solar radiation which is the heat from the sun, when radiation emits back to the atmosphere it forms clouds for rainfall and since Zn is natural geological occurrence it may be washed from the soil to the fish dams during rainfall.

EC ranged from 7.07 to 73.1µS/cm (Figure 17B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. EC positively correlates with chlorophyll, with 0.978 and $p = 0.021$. The relationship between EC and chlorophyll is expected since chlorophyll allow plant to absorb energy from the sun and EC uses the very same energy to transport electrical charge. TDS of the water ranged from 4.53 to 32.5 mg/l (Figure 17C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore, the TDS is good for the fish.

3.5.16The presence metal species in aquaculture water: Mrs. Mahwasane

Al, Fe, Ni and Zn were high in the earthen dams (Figure 18) and they have exceeded water guidelines for aquaculture (DWAF, 1996) (Table 22). Most of the trace elements show positive correlation coefficient greater than 0.5, which means there is strong correlation of trace elements Al correlated with Ti, V and Fe.

Figure 18: The earthen fish dam for Mrs. Mahwasane

This was expected since Ti, Al, V and Fe are found in the geological material Hemloite with the formula $(Ti,V^{3+},Fe^{3+},Al)_{12}As_2^{3+}O_{23}(OH)$(https://www.mindat.org/min-1845.html) and Cr correlated with Ni, Cu, As, Se and Mo correlated with Cd (Table 23 & 24) and this was expected since Cr and Ni are found in the geological material Yarlongitewith the formula $Cr_4Fe_4NiC_4$ and Se and Mo are found in the geological material Drysdallite with the formula $MoSe_2$, Ni, As and Se are found in the geological material Jolliffeite with the formula NiAsSe(https://www.mindat.org/min-1845.html).The presence of Al, Ni, V and Se were expected since those elements are found in the Arenite group which is found in the study area (Figure 4).

Table 22: The presence of metal species in the aquaculture pond for Mrs Mahwasane

Ppb	Mahwasane				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	82.44±0.82	139.39±8.94	461.94±29.62	9.60±0.54	**30**	**70**	**105**	1500
Ti	3.68±0.31	4.86±0.40	20.55±0.01	0.22±0.07				
V	0.70±0.00	0.73±0.01	1.60±0.03	0.52±0.04				
Cr	5.23±0.00	0.48±0.00	1.19±0.00	0.07±0.00	**20000**			
Mn	0.78±0.00	0.24±0.00	0.73±0.01	0.15±0.07	**100**	**500**	**600**	
Fe	108.33±0.96	103.85±2.12	334.95±6.82	4.50±0.64	**10**	**1750**		
Co	0.08±0.00	0.04±0.00	0.11±0.00	0.02±0.00				
Ni	14.33±0.66	0.42±0.00	1.03±0.00	0.43±0.00				
Cu	3.53±0.18	0.31±0.00	1.56±0.00	3.06±0.06	**5**			
Zn	9.68±0.40	2.95±0.01	6.18±0.02	10.18±0.06	**30**			
As	0.63±0.01	0.08±0.00	0.09±0.00	0.09±0.01		**50**		
Se	2.00±0.04	0.45±0.00	0.45±0.00	0.08±0.00	**300**	**460**		
Mo	3.32±0.11	0.09±0.00	0.14±0.00	0.01±0.00				
Cd	0.03±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.26±0.01	0.27±0.01	0.30±0.01	0.32±0.01				
Ba	10.12±0.12	22.84±0.19	24.92±0.20	25.79±0.02				
Hg	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.31±0.01	0.03±0.00	0.20±0.00	0.03±0.00	**10**	**30**	**2150**	

Table 23: Spearman correlation matrix of the physico-chemical & climate data parameters at Mutshenzheni (Mahwasane fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.473	**0.984**	0.777	-0.646	0.842	0.784	**0.956**	0.180	0.216	0.136	0.067	0.074	0.067	-0.805	-0.590	-0.073	-0.352	-0.773	-0.681	0.177	-0.778	-0.751	-0.138	-0.103	**0.951**	0.867	-0.775
pH	0.473	1	0.311	0.785	-0.776	0.733	0.744	0.306	-0.730	-0.546	-0.667	0.858	0.838	0.825	-0.607	0.057	0.761	0.416	-0.723	-0.471	-0.545	-0.742	-0.610	0.791	0.828	0.532	0.737	-0.750
EC (µS/cm	**0.984**	0.311	1	0.697	-0.520	0.746	0.680	**0.979**	0.352	0.366	0.300	-0.086	-0.072	-0.075	-0.726	-0.619	-0.213	-0.436	-0.671	-0.613	0.326	-0.674	-0.665	-0.314	-0.275	0.930	0.775	-0.668
TDS (mg/l	0.777	0.785	0.697	1	-0.530	0.676	0.623	0.764	-0.159	0.084	-0.064	0.638	0.657	0.657	-0.526	0.017	0.547	0.314	-0.592	-0.315	0.079	-0.615	-0.475	0.275	0.392	0.905	0.712	-0.619
Water To(	-0.646	-0.776	-0.520	-0.530	1	**-0.956**	**-0.980**	-0.398	0.562	0.604	0.651	-0.358	-0.313	-0.289	0.949	0.565	-0.204	0.235	**0.982**	0.919	0.636	**0.982**	**0.963**	-0.534	-0.465	-0.504	-0.939	**0.983**
Nitrates (r	0.842	0.733	0.746	0.676	**-0.956**	1	**0.995**	0.650	-0.330	-0.344	-0.409	0.281	0.253	0.233	**-0.980**	-0.625	0.119	-0.299	**-0.992**	-0.911	-0.382	**-0.994**	**-0.970**	0.326	0.291	0.723	**0.998**	**-0.993**
Phosphate	0.784	0.744	0.680	0.623	**-0.980**	**0.995**	1	0.571	-0.403	-0.433	-0.491	0.294	0.260	0.238	**-0.983**	-0.624	0.133	-0.297	**-0.999**	-0.929	-0.470	**-1.000**	**-0.981**	0.389	0.340	0.652	**0.988**	**-1.000**
Chlorophy	**0.956**	0.306	**0.979**	0.764	-0.398	0.650	0.571	1	0.406	0.483	0.397	-0.010	0.017	0.019	-0.599	-0.456	-0.117	-0.287	-0.556	-0.452	0.451	-0.563	-0.528	-0.339	-0.263	**0.965**	0.688	-0.559
Temp	0.180	-0.730	0.352	-0.159	0.562	-0.330	-0.403	0.406	1	0.935	**0.974**	-0.739	-0.692	-0.674	0.273	-0.218	-0.704	-0.451	0.400	0.274	0.920	0.408	0.332	**-0.987**	-0.938	0.183	-0.299	0.418
Rain	0.216	-0.546	0.366	0.084	0.604	-0.344	-0.433	0.483	0.935	1	**0.987**	-0.456	-0.395	-0.371	0.358	0.049	-0.407	-0.137	0.444	0.435	**0.998**	0.441	0.431	-0.867	-0.754	0.325	-0.299	0.447
Rad	0.136	-0.667	0.300	-0.064	0.651	-0.409	-0.491	0.397	**0.974**	**0.987**	1	-0.584	-0.526	-0.504	0.394	-0.010	-0.528	-0.237	0.495	0.434	**0.983**	0.497	0.459	-0.928	-0.839	0.210	-0.370	0.505
Al	0.067	0.858	-0.086	0.638	-0.358	0.281	0.294	-0.010	-0.739	-0.456	-0.584	1	**0.998**	**0.995**	-0.111	0.561	**0.986**	0.823	-0.265	0.039	-0.426	-0.292	-0.118	0.837	0.926	0.252	0.292	-0.303
Ti	0.074	0.838	-0.072	0.657	-0.313	0.253	0.260	0.017	-0.692	-0.395	-0.526	**0.998**	1	**1.000**	-0.076	0.592	**0.989**	0.845	-0.229	0.084	-0.363	-0.257	-0.078	0.799	0.899	0.275	0.267	-0.268
V	0.067	0.825	-0.075	0.657	-0.289	0.233	0.238	0.019	-0.674	-0.371	-0.504	**0.995**	**1.000**	1	-0.054	0.610	**0.990**	0.857	-0.206	0.109	-0.339	-0.235	-0.055	0.784	0.888	0.276	0.249	-0.246
Cr	-0.805	-0.607	-0.726	-0.526	0.949	**-0.980**	**-0.983**	-0.599	0.273	0.358	0.394	-0.111	-0.076	-0.054	1	0.758	0.054	0.468	**0.987**	**0.973**	0.403	**0.983**	**0.996**	-0.239	-0.172	-0.632	**-0.971**	**0.981**
Mn	-0.590	0.057	-0.619	0.017	0.565	-0.625	-0.624	-0.456	-0.218	0.049	-0.010	0.561	0.592	0.610	0.758	1	0.689	0.931	0.649	0.844	0.106	0.626	0.755	0.317	0.440	-0.315	-0.607	0.617
Fe	-0.073	0.761	-0.213	0.547	-0.204	0.119	0.133	-0.117	-0.704	-0.407	-0.528	**0.986**	**0.989**	**0.990**	0.054	0.689	1	0.904	-0.102	0.199	-0.370	-0.130	0.046	0.807	0.905	0.141	0.130	-0.142
Co	-0.352	0.416	-0.436	0.314	0.235	-0.299	-0.297	-0.287	-0.451	-0.137	-0.237	0.823	0.845	0.857	0.468	0.931	0.904	1	0.327	0.600	-0.086	0.300	0.467	0.566	0.694	-0.077	-0.281	0.289
Ni	-0.773	-0.723	-0.671	-0.592	**0.982**	**-0.992**	**-0.999**	-0.556	0.400	0.444	0.495	-0.265	-0.229	-0.206	**0.987**	0.649	-0.102	0.327	1	0.943	0.482	**0.999**	**0.987**	-0.379	-0.323	-0.630	**-0.983**	**0.999**
Cu	-0.681	-0.471	-0.613	-0.315	0.919	-0.911	-0.929	-0.452	0.274	0.435	0.434	0.039	0.084	0.109	**0.973**	0.844	0.199	0.600	0.943	1	0.483	0.931	**0.983**	-0.206	-0.098	-0.454	-0.890	0.928
Zn	0.177	-0.545	0.326	0.079	0.636	-0.382	-0.470	0.451	0.920	**0.998**	**0.983**	-0.426	-0.363	-0.339	0.403	0.106	-0.370	-0.086	0.482	0.483	1	0.478	0.475	-0.847	-0.728	0.301	-0.336	0.484
As	-0.778	-0.742	-0.674	-0.615	**0.982**	**-0.994**	**-1.000**	-0.563	0.408	0.441	0.497	-0.292	-0.257	-0.235	**0.983**	0.626	-0.130	0.300	**0.999**	0.931	0.478	1	**0.982**	-0.393	-0.342	-0.644	**-0.986**	**1.000**
Se	-0.751	-0.610	-0.665	-0.475	**0.963**	**-0.970**	**-0.981**	-0.528	0.332	0.431	0.459	-0.118	-0.078	-0.055	**0.996**	0.755	0.046	0.467	**0.987**	**0.983**	0.475	**0.982**	1	-0.289	-0.210	-0.567	**-0.956**	**0.980**
Mo	-0.138	0.791	-0.314	0.275	-0.534	0.326	0.389	-0.339	**-0.987**	-0.867	-0.928	0.837	0.799	0.784	-0.239	0.317	0.807	0.566	-0.379	-0.206	-0.847	-0.393	-0.289	1	**0.981**	-0.096	0.303	-0.403
Cd	-0.103	0.828	-0.275	0.392	-0.465	0.291	0.340	-0.263	-0.938	-0.754	-0.839	0.926	0.899	0.888	-0.172	0.440	0.905	0.694	-0.323	-0.098	-0.728	-0.342	-0.210	**0.981**	1	-0.004	0.279	-0.353
Sb	**0.951**	0.532	0.930	0.905	-0.504	0.723	0.652	**0.965**	0.183	0.325	0.210	0.252	0.275	0.276	-0.632	-0.315	0.141	-0.077	-0.630	-0.454	0.301	-0.644	-0.567	-0.096	-0.004	1	0.762	-0.643
Ba	0.867	0.737	0.775	0.712	-0.939	**0.998**	**0.988**	0.688	-0.299	-0.299	-0.370	0.292	0.267	0.249	**-0.971**	-0.607	0.130	-0.281	**-0.983**	-0.890	-0.336	**-0.986**	**-0.956**	0.303	0.279	0.762	1	**-0.986**
Hg	-0.775	-0.750	-0.668	-0.619	**0.983**	**-0.993**	**-1.000**	-0.559	0.418	0.447	0.505	-0.303	-0.268	-0.246	**0.981**	0.617	-0.142	0.289	**0.999**	0.928	0.484	**1.000**	**0.980**	-0.403	-0.353	-0.643	**-0.986**	1

Values in bold are different from 0 with a significance level alpha=0.05

Table 24: p- value of the physico-chemical & climate data parameters at Mutshenzheni (Mahwasane fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.527	**0.016**	0.223	0.354	0.158	0.216	**0.044**	0.820	0.784	0.864	0.933	0.926	0.933	0.195	0.410	0.927	0.648	0.227	0.319	0.823	0.222	0.249	0.862	0.897	**0.049**	0.133	0.225
pH	0.527	**0**	0.689	0.215	0.224	0.267	0.256	0.694	0.270	0.454	0.333	0.142	0.162	0.175	0.393	0.943	0.239	0.584	0.277	0.529	0.455	0.258	0.390	0.209	0.172	0.468	0.263	0.250
EC (µS/cm	**0.016**	0.689	**0**	0.303	0.480	0.254	0.320	**0.021**	0.648	0.634	0.700	0.914	0.928	0.925	0.274	0.381	0.787	0.564	0.329	0.387	0.674	0.326	0.335	0.686	0.725	0.070	0.225	0.332
TDS (mg/l	0.223	0.215	0.303	**0**	0.470	0.324	0.377	0.236	0.841	0.916	0.936	0.362	0.343	0.343	0.474	0.983	0.453	0.686	0.408	0.685	0.921	0.385	0.525	0.725	0.608	0.095	0.288	0.381
Water To(	0.354	0.224	0.480	0.470	**0**	**0.044**	**0.020**	0.602	0.438	0.396	0.349	0.642	0.687	0.711	0.051	0.435	0.796	0.765	**0.018**	0.081	0.364	**0.018**	**0.037**	0.466	0.535	0.496	0.061	**0.017**
Nitrates (r	0.158	0.267	0.254	0.324	**0.044**	**0**	**0.005**	0.350	0.670	0.656	0.591	0.719	0.747	0.767	**0.020**	0.375	0.881	0.701	**0.008**	0.089	0.618	**0.006**	**0.030**	0.674	0.709	0.277	**0.002**	**0.007**
Phosphate	0.216	0.256	0.320	0.377	**0.020**	**0.005**	**0**	0.429	0.597	0.567	0.509	0.706	0.740	0.762	**0.017**	0.376	0.867	0.703	**0.001**	0.071	0.530	**< 0.0001**	**0.019**	0.611	0.660	0.348	**0.012**	**0.000**
Chlorophy	**0.044**	0.694	**0.021**	0.236	0.602	0.350	0.429	**0**	0.594	0.517	0.603	0.990	0.983	0.981	0.401	0.544	0.883	0.713	0.444	0.548	0.549	0.437	0.472	0.661	0.737	**0.035**	0.312	0.441
Temp	0.820	0.270	0.648	0.841	0.438	0.670	0.597	0.594	**0**	0.065	**0.026**	0.261	0.308	0.326	0.727	0.782	0.296	0.549	0.600	0.726	0.080	0.592	0.668	**0.013**	0.062	0.817	0.701	0.582
Rain	0.784	0.454	0.634	0.916	0.396	0.656	0.567	0.517	0.065	**0**	**0.013**	0.544	0.605	0.629	0.642	0.951	0.593	0.863	0.556	0.565	**0.002**	0.559	0.569	0.133	0.246	0.675	0.701	0.553
Rad	0.864	0.333	0.700	0.936	0.349	0.591	0.509	0.603	**0.026**	**0.013**	**0**	0.416	0.474	0.496	0.606	0.990	0.472	0.763	0.505	0.566	**0.017**	0.503	0.541	0.072	0.161	0.790	0.630	0.495
Al	0.933	0.142	0.914	0.362	0.642	0.719	0.706	0.990	0.261	0.544	0.416	**0**	**0.002**	**0.005**	0.889	0.439	**0.014**	0.177	0.735	0.961	0.574	0.708	0.882	0.163	0.074	0.748	0.708	0.697
Ti	0.926	0.162	0.928	0.343	0.687	0.747	0.740	0.983	0.308	0.605	0.474	**0.002**	**0**	**0.000**	0.924	0.408	**0.011**	0.155	0.771	0.916	0.637	0.743	0.922	0.201	0.101	0.725	0.733	0.732
V	0.933	0.175	0.925	0.343	0.711	0.767	0.762	0.981	0.326	0.629	0.496	**0.005**	**0.000**	**0**	0.946	0.390	**0.010**	0.143	0.794	0.891	0.661	0.765	0.945	0.216	0.112	0.724	0.751	0.754
Cr	0.195	0.393	0.274	0.474	0.051	**0.020**	**0.017**	0.401	0.727	0.642	0.606	0.889	0.924	0.946	**0**	0.242	0.946	0.532	**0.013**	**0.027**	0.597	**0.017**	**0.004**	0.761	0.828	0.368	**0.029**	**0.019**
Mn	0.410	0.943	0.381	0.983	0.435	0.375	0.376	0.544	0.782	0.951	0.990	0.439	0.408	0.390	0.242	**0**	0.311	0.069	0.351	0.156	0.894	0.374	0.245	0.683	0.560	0.685	0.393	0.383
Fe	0.927	0.239	0.787	0.453	0.796	0.881	0.867	0.883	0.296	0.593	0.472	**0.014**	**0.011**	**0.010**	0.946	0.311	**0**	0.096	0.898	0.801	0.630	0.870	0.954	0.193	0.095	0.859	0.870	0.858
Co	0.648	0.584	0.564	0.686	0.765	0.701	0.703	0.713	0.549	0.863	0.763	0.177	0.155	0.143	0.532	0.069	0.096	**0**	0.673	0.400	0.914	0.700	0.533	0.434	0.306	0.923	0.719	0.711
Ni	0.227	0.277	0.329	0.408	**0.018**	**0.008**	**0.001**	0.444	0.600	0.556	0.505	0.735	0.771	0.794	**0.013**	0.351	0.898	0.673	**0**	0.057	0.518	**0.001**	**0.013**	0.621	0.677	0.370	**0.017**	**0.001**
Cu	0.319	0.529	0.387	0.685	0.081	0.089	0.071	0.548	0.726	0.565	0.566	0.961	0.916	0.891	**0.027**	0.156	0.801	0.400	0.057	**0**	0.517	0.069	**0.017**	0.794	0.902	0.546	0.110	0.072
Zn	0.823	0.455	0.674	0.921	0.364	0.618	0.530	0.549	0.080	**0.002**	**0.017**	0.574	0.637	0.661	0.597	0.894	0.630	0.914	0.518	0.517	**0**	0.522	0.525	0.153	0.272	0.699	0.664	0.516
As	0.222	0.258	0.326	0.385	**0.018**	**0.006**	**< 0.0001**	0.437	0.592	0.559	0.503	0.708	0.743	0.765	**0.017**	0.374	0.870	0.700	**0.001**	0.069	0.522	**0**	**0.018**	0.607	0.658	0.356	**0.014**	**< 0.0001**
Se	0.249	0.390	0.335	0.525	**0.037**	**0.030**	**0.019**	0.472	0.668	0.569	0.541	0.882	0.922	0.945	**0.004**	0.245	0.954	0.533	**0.013**	**0.017**	0.525	**0.018**	**0**	0.711	0.790	0.433	**0.044**	**0.020**
Mo	0.862	0.209	0.686	0.725	0.466	0.674	0.611	0.661	**0.013**	0.133	0.072	0.163	0.201	0.216	0.761	0.683	0.193	0.434	0.621	0.794	0.153	0.607	0.711	**0**	**0.019**	0.904	0.697	0.597
Cd	0.897	0.172	0.725	0.608	0.535	0.709	0.660	0.737	0.062	0.246	0.161	0.074	0.101	0.112	0.828	0.560	0.095	0.306	0.677	0.902	0.272	0.658	0.790	**0.019**	**0**	0.996	0.721	0.647
Sb	**0.049**	0.468	0.070	0.095	0.496	0.277	0.348	**0.035**	0.817	0.675	0.790	0.748	0.725	0.724	0.368	0.685	0.859	0.923	0.370	0.546	0.699	0.356	0.433	0.904	0.996	**0**	0.238	0.357
Ba	0.133	0.263	0.225	0.288	0.061	**0.002**	**0.012**	0.312	0.701	0.701	0.630	0.708	0.733	0.751	**0.029**	0.393	0.870	0.719	**0.017**	0.110	0.664	**0.014**	**0.044**	0.697	0.721	0.238	**0**	**0.014**
Hg	0.225	0.250	0.332	0.381	**0.017**	**0.007**	**0.000**	0.441	0.582	0.553	0.495	0.697	0.732	0.754	**0.019**	0.383	0.858	0.711	**0.001**	0.072	0.516	**< 0.0001**	**0.020**	0.597	0.647	0.357	**0.014**	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.17The physico-chemical quality of aquaculture water: Mr. Mufunwaini (Zwavhavhili)

The fish ponds of Mr. Mufunwaini (Figure 20) show that the pH of the water was ranging from 8.69 to 9.36 (Figure 19A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming. The pH positively correlated with EC and chlorophyll, with Spearman coefficient 0.956 and p = 0.018. EC is the current carried by ions which are positively charged (cat ions) such as H+ ions move differently according to the conductivity, and since the pH is a measure of concentration of hydrogen, the higher the H+, the higher the EC (Leveling, 2002).

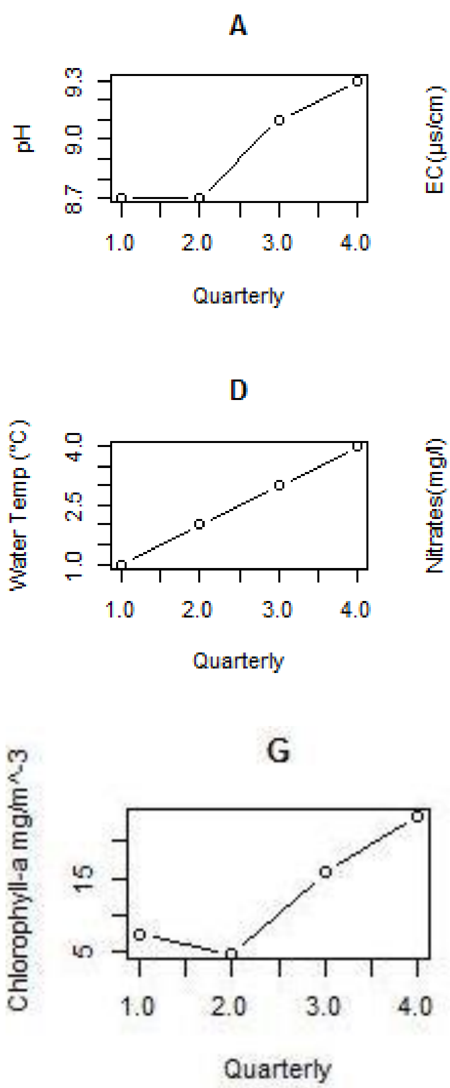


Figure 19:showing the quarterly physico-chemical parameters for Mr Mufunwaini fish pond from Zwavhavhili.

The study showed that nitrates ranged from 1 to 1.654 ppm (Figure 19E), which is lower than DWAF (1996) guideline value of 300 ppm. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.087 to 1.834 mg/l (Figure 19F), which was seventeen times above the DWAF (1996) guideline value of 0.1 ppm, meaning that the water has a high phosphate content. Nitrates positively correlated with phosphate, with 0.982 and $p = 0.018$. The relationship between nitrates and phosphates is expected since nitrates can be found from unconsumed fish feeds, fish waste or dead plants in water which decompose or breakdown to form building blocks of phosphate.

Water temperature ranged from 25 to 30.3 ^{0}C (Figure 19D), because the fish ponds are under the shadow of a tree. Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mr. Mufunwaini is still normal. EC ranged from 21.33 to 266.66 µS/cm (Figure 19B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 13.53 to 170.01 mg/l (Figure 19C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore the TDS is good for the fish. TDS positively correlate with rain, and V, with 0.967 and $p = 0.019$. This relationship is expected since V naturally occur in the environment, and during rainfall it erodes to the fish dams and the minerals will dissolve and increases TDS in water.

3.5.18The presence metal species in aquaculture water: Mr. Mufunwaini (Zwavhavhili)

Most of the trace elements in the earthen dams (Figure 20) were high, such as Al, Cr, Mn, Fe, Ni, and Mo (DWAF,1996) (Table 25). Cr positively correlated with Co, Ni, Hg, As.

Figure 20: The concrete and plastic fish dam for Mr. Mufunwaini

This was expected since Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$ and Cr, Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$, Cr and As are found in the geological material Bellite with the formula $Pb_5(AsO_4,CrO_4,SiO_4)_3Cl$ (https://www.mindat.org/min-1845.html) .Mn correlated with Fe This was expected since Mn and Fe are found in the geological material Earlshannonite with the formula $Mn^{2+}Fe_2^{3+}(PO_4)_2(OH)_2 \cdot 4H_2O$ (https://www.mindat.org/min-1845.html) (Table 26 &27). The presence of Co, Ni, Cr, Fe, Mn were expected since those elements are found in the Basalt group which is found in the study area (Figure 4).

Table 25: The presence of metal species in the aquaculture pond for Mr. Mufunwaini

Ppb	Mufunwaini				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	**2nd QTR**	**3rd QTR**	**4th QTR**	No adverse effect	toxic to	toxic to	lethal
Al		2.39±0.15	12.84±0.82	2.56±0.19	**30**	**70**	**105**	1500
Ti		0.07±0.01	0.08±0.01	0.02±0.03				
V		13.57±0.23	3.33±0.06	5.16±1.17				
Cr		0.15±0.00	0.12±0.00	0.04±0.00	**20000**			
Mn		0.06±0.00	0.05±0.00	0.16±0.03	**100**	**500**	**600**	
Fe		1.90±0.04	2.94±0.06	1.08±0.18	**10**	**1750**		
Co		0.27±0.00	0.07±0.00	0.13±0.00				
Ni		0.65±0.00	0.51±0.00	0.56±0.01				
Cu		2.02±0.00	1.12±0.00	1.88±0.03	**5**			
Zn		4.37±0.01	3.37±0.01	6.92±2.68	**30**			
As		0.06±0.00	0.05±0.00	0.06±0.00		**50**		
Se		0.45±0.00	0.45±0.00	0.08±0.00	**300**	**460**		
Mo		0.15±0.00	0.05±0.00	0.23±0.07				
Cd		0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb		0.27±0.01	0.27±0.01	0.27±0.00				
Ba		22.01±0.18	61.45±0.49	86.82±0.73				
Hg		0.00±0.00	0.001±0.00	0.00±0.00	**1000**			
Pb		0.01±0.00	0.02±0.00	0.01±0.00	**10**	**30**	**2150**	

The farmer participated in the second to fourth quarters of the study

Table 26: Spearman correlation matrix of the physico-chemical & climate data parameters at Zwavhavhili (Mufunwaini fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**1**	**0.956**	0.898	0.272	-0.075	0.685	0.810	0.898	0.107	0.037	0.021	-0.452	**-0.956**	-0.063	-0.777	-0.571	-0.631	-0.789	-0.773	-0.495	-0.019	-0.750	-0.919	-0.178	-0.192	-0.414	0.155	-0.775
pH	**0.956**	**1**	**0.982**	0.516	0.117	0.456	0.616	**0.983**	0.274	0.311	0.223	-0.278	-0.828	0.199	-0.579	-0.782	-0.825	-0.603	-0.574	-0.243	-0.229	-0.545	-0.855	-0.349	-0.427	-0.136	-0.140	-0.576
EC (µS/cm	0.898	**0.982**	**1**	0.563	0.110	0.361	0.526	**0.971**	0.246	0.390	0.224	-0.095	-0.734	0.260	-0.497	-0.872	-0.907	-0.532	-0.492	-0.158	-0.406	-0.463	-0.743	-0.321	-0.458	-0.023	-0.279	-0.494
TDS (mg/l	0.272	0.516	0.563	**1**	0.850	-0.513	-0.343	0.663	0.868	**0.967**	0.904	0.048	-0.009	0.942	0.393	-0.797	-0.766	0.371	0.400	0.701	-0.353	0.431	-0.335	-0.893	**-0.989**	0.743	-0.813	0.397
Water ToC	-0.075	0.117	0.110	0.850	**1**	-0.690	-0.578	0.296	**0.981**	0.857	**0.993**	-0.172	0.251	0.926	0.636	-0.360	-0.314	0.644	0.641	0.823	0.065	0.664	-0.173	**-0.967**	-0.919	0.755	-0.635	0.640
Nitrates (r	0.685	0.456	0.361	-0.513	-0.690	**1**	**0.982**	0.295	-0.539	-0.702	-0.648	-0.479	-0.851	-0.766	**-0.989**	0.116	0.038	**-0.979**	**-0.989**	**-0.971**	0.293	**-0.993**	-0.582	0.495	0.571	-0.940	0.773	**-0.989**
Phosphate	0.810	0.616	0.526	-0.343	-0.578	**0.982**	**1**	0.470	-0.410	-0.555	-0.520	-0.496	-0.931	-0.633	**-0.997**	-0.058	-0.136	**-0.993**	**-0.997**	-0.910	0.224	**-0.994**	-0.703	0.356	0.411	-0.862	0.659	**-0.997**
Chlorophy	0.898	**0.983**	**0.971**	0.663	0.296	0.295	0.470	**1**	0.440	0.473	0.399	-0.265	-0.735	0.374	-0.426	-0.837	-0.869	-0.450	-0.420	-0.067	-0.242	-0.388	-0.835	-0.509	-0.587	0.029	-0.279	-0.422
Temp	0.107	0.274	0.246	0.868	**0.981**	-0.539	-0.410	0.440	**1**	0.826	**0.987**	-0.311	0.061	0.884	0.476	-0.413	-0.381	0.486	0.482	0.705	0.128	0.508	-0.359	**-0.997**	-0.929	0.640	-0.553	0.480
Rain	0.037	0.311	0.390	**0.967**	0.857	-0.702	-0.555	0.473	0.826	**1**	0.896	0.243	0.237	**0.985**	0.594	-0.730	-0.682	0.568	0.600	0.846	-0.449	0.627	-0.086	-0.837	**-0.964**	0.888	-0.919	0.597
Rad	0.021	0.223	0.224	0.904	**0.993**	-0.648	-0.520	0.399	**0.987**	0.896	**1**	-0.156	0.176	0.946	0.579	-0.463	-0.421	0.581	0.584	0.801	-0.005	0.610	-0.240	**-0.982**	**-0.957**	0.753	-0.673	0.583
Al	-0.452	-0.278	-0.095	0.048	-0.172	-0.479	-0.496	-0.265	-0.311	0.243	-0.156	**1**	0.597	0.166	0.445	-0.279	-0.234	0.394	0.442	0.378	-0.870	0.436	0.736	0.314	0.023	0.514	-0.605	0.441
Ti	**-0.956**	-0.828	-0.734	-0.009	0.251	-0.851	-0.931	-0.735	0.061	0.237	0.176	0.597	**1**	0.314	0.904	0.307	0.379	0.902	0.901	0.700	-0.202	0.886	0.907	0.002	-0.053	0.654	-0.438	0.902
V	-0.063	0.199	0.260	0.942	0.926	-0.766	-0.633	0.374	0.884	**0.985**	0.946	0.166	0.314	**1**	0.677	-0.607	-0.555	0.660	0.682	0.897	-0.318	0.707	-0.048	-0.884	**-0.964**	0.904	-0.877	0.680
Cr	-0.777	-0.579	-0.497	0.393	0.636	**-0.989**	**-0.997**	-0.426	0.476	0.594	0.579	0.445	0.904	0.677	**1**	0.035	0.113	**0.998**	**1.000**	0.931	-0.193	**0.999**	0.650	-0.423	-0.465	0.877	-0.670	**1.000**
Mn	-0.571	-0.782	-0.872	-0.797	-0.360	0.116	-0.058	-0.837	-0.413	-0.730	-0.463	-0.279	0.307	-0.607	0.035	**1**	**0.997**	0.084	0.030	-0.296	0.699	-0.001	0.399	0.473	0.699	-0.449	0.711	0.033
Fe	-0.631	-0.825	-0.907	-0.766	-0.314	0.038	-0.136	-0.869	-0.381	-0.682	-0.421	-0.234	0.379	-0.555	0.113	**0.997**	**1**	0.161	0.108	-0.223	0.673	0.077	0.454	0.445	0.663	-0.378	0.653	0.110
Co	-0.789	-0.603	-0.532	0.371	0.644	**-0.979**	**-0.993**	-0.450	0.486	0.568	0.581	0.394	0.902	0.660	**0.998**	0.084	0.161	**1**	**0.998**	0.920	-0.129	**0.996**	0.639	-0.430	-0.451	0.853	-0.628	**0.998**
Ni	-0.773	-0.574	-0.492	0.400	0.641	**-0.989**	**-0.997**	-0.420	0.482	0.600	0.584	0.442	0.901	0.682	**1.000**	0.030	0.108	**0.998**	**1**	0.934	-0.193	**0.999**	0.645	-0.429	-0.472	0.880	-0.674	**1.000**
Cu	-0.495	-0.243	-0.158	0.701	0.823	**-0.971**	-0.910	-0.067	0.705	0.846	0.801	0.378	0.700	0.897	0.931	-0.296	-0.223	0.920	0.934	**1**	-0.305	0.946	0.378	-0.674	-0.750	**0.978**	-0.849	0.933
Zn	-0.019	-0.229	-0.406	-0.353	0.065	0.293	0.224	-0.242	0.128	-0.449	-0.005	-0.870	-0.202	-0.318	-0.193	0.699	0.673	-0.129	-0.193	-0.305	**1**	-0.203	-0.310	-0.094	0.239	-0.493	0.720	-0.191
As	-0.750	-0.545	-0.463	0.431	0.664	**-0.993**	**-0.994**	-0.388	0.508	0.627	0.610	0.436	0.886	0.707	**0.999**	-0.001	0.077	**0.996**	**0.999**	0.946	-0.203	**1**	0.621	-0.457	-0.502	0.894	-0.694	**0.999**
Se	-0.919	-0.855	-0.743	-0.335	-0.173	-0.582	-0.703	-0.835	-0.359	-0.086	-0.240	0.736	0.907	-0.048	0.650	0.399	0.454	0.639	0.645	0.378	-0.310	0.621	**1**	0.413	0.311	0.376	-0.230	0.646
Mo	-0.178	-0.349	-0.321	-0.893	**-0.967**	0.495	0.356	-0.509	**-0.997**	-0.837	**-0.982**	0.314	0.002	-0.884	-0.423	0.473	0.445	-0.430	-0.429	-0.674	-0.094	-0.457	0.413	**1**	0.944	-0.621	0.561	-0.427
Cd	-0.192	-0.427	-0.458	**-0.989**	-0.919	0.571	0.411	-0.587	-0.929	**-0.964**	**-0.957**	0.023	-0.053	**-0.964**	-0.465	0.699	0.663	-0.451	-0.472	-0.750	0.239	-0.502	0.311	0.944	**1**	-0.762	0.781	-0.469
Sb	-0.414	-0.136	-0.023	0.743	0.755	-0.940	-0.862	0.029	0.640	0.888	0.753	0.514	0.654	0.904	0.877	-0.449	-0.378	0.853	0.880	**0.978**	-0.493	0.894	0.376	-0.621	-0.762	**1**	-0.938	0.878
Ba	0.155	-0.140	-0.279	-0.813	-0.635	0.773	0.659	-0.279	-0.553	-0.919	-0.673	-0.605	-0.438	-0.877	-0.670	0.711	0.653	-0.628	-0.674	-0.849	0.720	-0.694	-0.230	0.561	0.781	-0.938	**1**	-0.672
Hg	-0.775	-0.576	-0.494	0.397	0.640	**-0.989**	**-0.997**	-0.422	0.480	0.597	0.583	0.441	0.902	0.680	**1.000**	0.033	0.110	**0.998**	**1.000**	0.933	-0.191	**0.999**	0.646	-0.427	-0.469	0.878	-0.672	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 27: p-value of the physico-chemical & climate data parameters at Zwavhavhili (Mufunwaini fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	**0.044**	0.102	0.728	0.925	0.315	0.190	0.102	0.893	0.963	0.979	0.548	**0.044**	0.937	0.223	0.429	0.369	0.211	0.227	0.505	0.981	0.250	0.081	0.822	0.808	0.586	0.845	0.225
pH	**0.044**	**0**	**0.018**	0.484	0.883	0.544	0.384	**0.017**	0.726	0.689	0.777	0.722	0.172	0.801	0.421	0.218	0.175	0.397	0.426	0.757	0.771	0.455	0.145	0.651	0.573	0.864	0.860	0.424
EC (µS/cm	0.102	**0.018**	**0**	0.437	0.890	0.639	0.474	**0.029**	0.754	0.610	0.776	0.905	0.266	0.740	0.503	0.128	0.093	0.468	0.508	0.842	0.594	0.537	0.257	0.679	0.542	0.977	0.721	0.506
TDS (mg/l	0.728	0.484	0.437	**0**	0.150	0.487	0.657	0.337	0.132	**0.033**	0.096	0.952	0.991	0.058	0.607	0.203	0.234	0.629	0.600	0.299	0.647	0.569	0.665	0.107	**0.011**	0.257	0.187	0.603
Water To(	0.925	0.883	0.890	0.150	**0**	0.310	0.422	0.704	**0.019**	0.143	**0.007**	0.828	0.749	0.074	0.364	0.640	0.686	0.356	0.359	0.177	0.935	0.336	0.827	**0.033**	0.081	0.245	0.365	0.360
Nitrates (r	0.315	0.544	0.639	0.487	0.310	**0**	**0.018**	0.705	0.461	0.298	0.352	0.521	0.149	0.234	**0.011**	0.884	0.962	**0.021**	**0.011**	**0.029**	0.707	**0.007**	0.418	0.505	0.429	0.060	0.227	**0.011**
Phosphate	0.190	0.384	0.474	0.657	0.422	**0.018**	**0**	0.530	0.590	0.445	0.480	0.504	0.069	0.367	**0.003**	0.942	0.864	**0.007**	**0.003**	0.090	0.776	**0.006**	0.297	0.644	0.589	0.138	0.341	**0.003**
Chlorophy	0.102	**0.017**	**0.029**	0.337	0.704	0.705	0.530	**0**	0.560	0.527	0.601	0.735	0.265	0.626	0.574	0.163	0.131	0.550	0.580	0.933	0.758	0.612	0.165	0.491	0.413	0.971	0.721	0.578
Temp	0.893	0.726	0.754	0.132	**0.019**	0.461	0.590	0.560	**0**	0.174	**0.013**	0.689	0.939	0.116	0.524	0.587	0.619	0.514	0.518	0.295	0.872	0.492	0.641	**0.003**	0.071	0.360	0.447	0.520
Rain	0.963	0.689	0.610	**0.033**	0.143	0.298	0.445	0.527	0.174	**0**	0.104	0.757	0.763	**0.015**	0.406	0.270	0.318	0.432	0.400	0.154	0.551	0.373	0.914	0.163	**0.036**	0.112	0.081	0.403
Rad	0.979	0.777	0.776	0.096	**0.007**	0.352	0.480	0.601	**0.013**	0.104	**0**	0.844	0.824	0.054	0.421	0.537	0.579	0.419	0.416	0.199	0.995	0.390	0.760	**0.018**	**0.043**	0.247	0.327	0.417
Al	0.548	0.722	0.905	0.952	0.828	0.521	0.504	0.735	0.689	0.757	0.844	**0**	0.403	0.834	0.555	0.721	0.766	0.606	0.558	0.622	0.130	0.564	0.264	0.686	0.977	0.486	0.395	0.559
Ti	**0.044**	0.172	0.266	0.991	0.749	0.149	0.069	0.265	0.939	0.763	0.824	0.403	**0**	0.686	0.096	0.693	0.621	0.098	0.099	0.300	0.798	0.114	0.093	0.998	0.947	0.346	0.562	0.098
V	0.937	0.801	0.740	0.058	0.074	0.234	0.367	0.626	0.116	**0.015**	0.054	0.834	0.686	**0**	0.323	0.393	0.445	0.340	0.318	0.103	0.682	0.293	0.952	0.116	**0.036**	0.096	0.123	0.320
Cr	0.223	0.421	0.503	0.607	0.364	**0.011**	**0.003**	0.574	0.524	0.406	0.421	0.555	0.096	0.323	**0**	0.965	0.887	**0.002**	**< 0.0001**	0.069	0.807	**0.001**	0.350	0.577	0.535	0.123	0.330	**< 0.0001**
Mn	0.429	0.218	0.128	0.203	0.640	0.884	0.942	0.163	0.587	0.270	0.537	0.721	0.693	0.393	0.965	**0**	**0.003**	0.916	0.970	0.704	0.301	0.999	0.601	0.527	0.301	0.551	0.289	0.967
Fe	0.369	0.175	0.093	0.234	0.686	0.962	0.864	0.131	0.619	0.318	0.579	0.766	0.621	0.445	0.887	**0.003**	**0**	0.839	0.892	0.777	0.327	0.923	0.546	0.555	0.337	0.622	0.347	0.890
Co	0.211	0.397	0.468	0.629	0.356	**0.021**	**0.007**	0.550	0.514	0.432	0.419	0.606	0.098	0.340	**0.002**	0.916	0.839	**0**	**0.002**	0.080	0.871	**0.004**	0.361	0.570	0.549	0.147	0.372	**0.002**
Ni	0.227	0.426	0.508	0.600	0.359	**0.011**	**0.003**	0.580	0.518	0.400	0.416	0.558	0.099	0.318	**< 0.0001**	0.970	0.892	**0.002**	**0**	0.066	0.807	**0.001**	0.355	0.571	0.528	0.120	0.326	**< 0.0001**
Cu	0.505	0.757	0.842	0.299	0.177	**0.029**	0.090	0.933	0.295	0.154	0.199	0.622	0.300	0.103	0.069	0.704	0.777	0.080	0.066	**0**	0.695	0.054	0.622	0.326	0.250	**0.022**	0.151	0.067
Zn	0.981	0.771	0.594	0.647	0.935	0.707	0.776	0.758	0.872	0.551	0.995	0.130	0.798	0.682	0.807	0.301	0.327	0.871	0.807	0.695	**0**	0.797	0.690	0.906	0.761	0.507	0.280	0.809
As	0.250	0.455	0.537	0.569	0.336	**0.007**	**0.006**	0.612	0.492	0.373	0.390	0.564	0.114	0.293	**0.001**	0.999	0.923	**0.004**	**0.001**	0.054	0.797	**0**	0.379	0.543	0.498	0.106	0.306	**0.001**
Se	0.081	0.145	0.257	0.665	0.827	0.418	0.297	0.165	0.641	0.914	0.760	0.264	0.093	0.952	0.350	0.601	0.546	0.361	0.355	0.622	0.690	0.379	**0**	0.587	0.689	0.624	0.770	0.354
Mo	0.822	0.651	0.679	0.107	**0.033**	0.505	0.644	0.491	**0.003**	0.163	**0.018**	0.686	0.998	0.116	0.577	0.527	0.555	0.570	0.571	0.326	0.906	0.543	0.587	**0**	0.056	0.379	0.439	0.573
Cd	0.808	0.573	0.542	**0.011**	0.081	0.429	0.589	0.413	0.071	**0.036**	**0.043**	0.977	0.947	**0.036**	0.535	0.301	0.337	0.549	0.528	0.250	0.761	0.498	0.689	0.056	**0**	0.238	0.219	0.531
Sb	0.586	0.864	0.977	0.257	0.245	0.060	0.138	0.971	0.360	0.112	0.247	0.486	0.346	0.096	0.123	0.551	0.622	0.147	0.120	**0.022**	0.507	0.106	0.624	0.379	0.238	**0**	0.062	0.122
Ba	0.845	0.860	0.721	0.187	0.365	0.227	0.341	0.721	0.447	0.081	0.327	0.395	0.562	0.123	0.330	0.289	0.347	0.372	0.326	0.151	0.280	0.306	0.770	0.439	0.219	0.062	**0**	0.328
Hg	0.225	0.424	0.506	0.603	0.360	**0.011**	**0.003**	0.578	0.520	0.403	0.417	0.559	0.098	0.320	**< 0.0001**	0.967	0.890	**0.002**	**< 0.0001**	0.067	0.809	**0.001**	0.354	0.573	0.531	0.122	0.328	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.19The physico-chemical quality of aquaculture water: Mr. Mufunwaini (Lwamondo garage)

The fish ponds of Mr. Mufunwaini show that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values. The pH of the water was alkaline ranging from 8.11 to 9.56(Figure 21A). According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming.

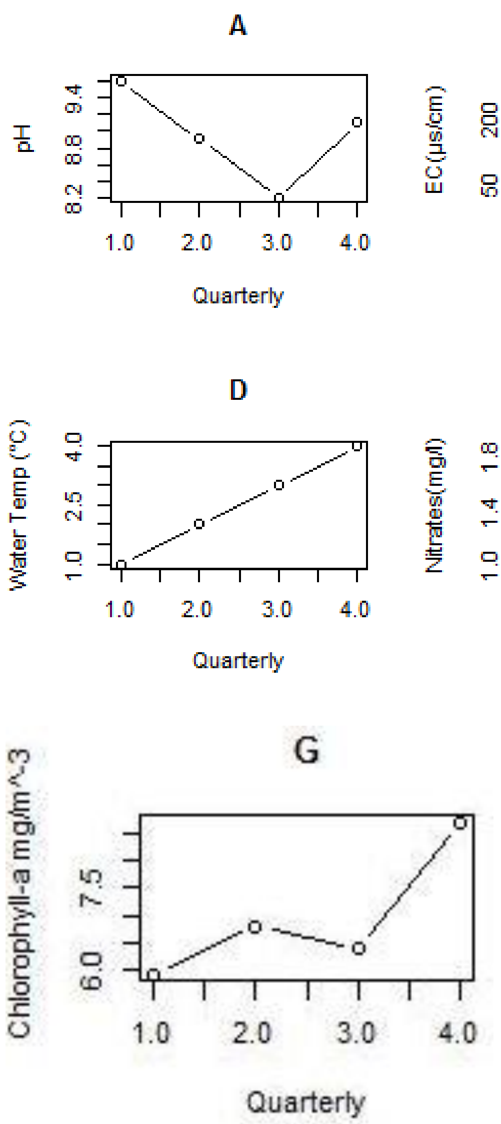


Figure 21: showing the quarterly physico-chemical parameters for Mr. Mufunwaini from Lwamondo garage fish pond.

The study showed that nitrates ranged from 1 to 1.876 ppm (Figure 21E), which is lower than DWAF (1996) guideline value of 300 ppm. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.05 to 2 mg/l which was above the DWAF (1996) guideline value of 0.1 ppm, meaning that the water has a high phosphate content.

Water temperature ranged from 24.3 to 31.4 ^{0}C (Figure 21D), water temperature increased because of weather conditions. Keremah et al. (2014) water temperature must be 20 to 30 ^{0}C. Water temperature positively correlated with Ti, with spearman coefficient of 0.953 and $p = 0.044$. EC ranged from 19.23 to 287.66 µS/cm (Figure 21B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 13.1 to 182.66 mg/l (Figure 21C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore the TDS is good for the fish. TDS positively correlated with EC, with 0.973 and $p = 0.027$. TDS and the electrical conductivity are related because the more salts are dissolved in the water the higher dissolved ions transport electric current.

3.5.20The presence metal species in aquaculture water: Mr. Mufunwaini (Lwamondo garage)

Most of the trace elements were detected such as Al, V, Cr, Mn, Fe and Ni (Table 28). The As shows positive correlation with Al, Cr, Ti, Mn, Co, Ni and Sb, with 0.988 and <0,012 (Table 29 &30) This was expected since Ti, Mn and Sb are found in the geological material Hiärneite with the formula $(Ca,Mn^{2+},Na)_2(Zr,Mn^{3+})_5(Sb,Ti,Fe)_2O_{16}$**,** Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$**,** As and Cr are found in the geological material Bellitewith the formula $Pb_5(AsO_4,CrO_4,SiO_4)_3Cl$, As and Al are found in the geological material Alarsite with the formula $AlAsO_4$ (https://www.mindat.org/min-1845.html). Hg positively correlated with Al, Cr (Table 10), this was expected since Cr and Hg are found in the geological material Wattersite with the formula $Hg_4^{1+}Hg^{2+}O_2(CrO_4)$ and As and Al are found in the geological material Alarsite with the formula $AlAsO_4$ (https://www.mindat.org/min-

1845.html).The presence of Co, Ni, Cr, Fe, Mn, Ti, Ca were expected since those elements are found in the Basalt group which is found in the study area (Figure 4).

Table 28: The presence of heavy metals in the aquaculture pond for Mr. Mufunwaini (Lwamondo garage)

Ppb	Mufunwaini garage				DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	11.03±0.11	2.39±0.15	2.12±0.14	1.02±0.42	**30**	**70**	**105**	1500
Ti	0.16±0.01	0.07±0.01	0.06±0.00	0.09±0.07				
V	7.33±0.03	13.57±0.23	8.86±0.15	10.93±0.98				
Cr	15.59±0.01	0.15±0.00	0.11±0.00	0.01±0.01	**20000**			
Mn	5.02±0.01	0.06±0.00	0.27±0.01	0.07±0.04	**100**	**500**	**600**	
Fe	137.48±1.21	1.90±0.04	3.78±0.08	1.17±0.06	**10**	**1750**		
Co	1.45±0.08	0.27±0.00	0.15±0.00	0.14±0.00				
Ni	53.48±2.46	0.65±0.00	0.61±0.00	0.50±0.00				
Cu	3.32±0.17	2.02±0.00	1.80±0.00	1.92±0.02	**5**			
Zn	4.31±0.18	4.37±0.01	8.16±0.02	4.99±0.12	**30**			
As	0.81±0.01	0.06±0.00	0.07±0.00	0.13±0.00		**50**		
Se	0.63±0.01	0.45±0.00	0.45±0.00	0.21±0.03	**300**	**460**		
Mo	15.04±0.48	0.15±0.00	0.17±0.01	0.08±0.01				
Cd	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.37±0.01	0.27±0.01	0.26±0.00	0.28±0.01				
Ba	8.22±0.10	22.01±0.18	45.31±0.36	24.93±0.36				
Hg	0.01±0.00	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.17±0.01	0.01±0.00	0.02±0.00	0.10±0.00	**10**	**30**	**2150**	

Table 29:Spearman correlation matrix of the physico-chemical & climate data parameters at Lwamondo Garage (Mufunwaini fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**1**	-0.483	0.911	0.834	-0.258	0.561	0.782	0.841	0.107	0.037	0.021	-0.857	-0.531	0.194	-0.779	-0.776	-0.777	-0.801	-0.776	0.200	0.392	-0.720	-0.456	-0.116	0.014	-0.700	0.613	-0.775
pH	-0.483	**1**	-0.131	0.072	0.831	-0.540	-0.744	0.014	0.759	0.476	0.754	0.678	0.883	-0.224	0.743	0.717	0.735	0.778	0.745	0.734	-0.875	0.778	0.209	-0.804	-0.837	0.848	**-0.975**	0.745
EC (µS/cm	0.911	-0.131	**1**	**0.973**	0.163	0.240	0.467	0.884	0.501	0.408	0.430	-0.586	-0.135	-0.080	-0.463	-0.464	-0.463	-0.487	-0.459	0.569	0.181	-0.379	-0.233	-0.484	-0.389	-0.345	0.315	-0.457
TDS (mg/l	0.834	0.072	**0.973**	**1**	0.275	0.226	0.380	0.938	0.627	0.419	0.539	-0.510	-0.010	-0.014	-0.377	-0.387	-0.379	-0.387	-0.372	0.705	-0.051	-0.286	-0.300	-0.644	-0.534	-0.228	0.105	-0.370
Water ToC	-0.258	0.831	0.163	0.275	**1**	-0.801	-0.785	0.039	0.913	0.884	**0.958**	0.687	**0.956**	-0.685	0.787	0.778	0.785	0.779	0.790	0.845	-0.478	0.843	0.579	-0.841	-0.937	0.870	-0.704	0.791
Nitrates (	0.561	-0.540	0.240	0.226	-0.801	**1**	0.922	0.515	-0.504	-0.786	-0.631	-0.895	-0.867	0.900	-0.924	-0.936	-0.929	-0.894	-0.925	-0.368	0.090	-0.931	-0.936	0.350	0.542	-0.889	0.467	-0.925
Phosphate	0.782	-0.744	0.467	0.380	-0.785	0.922	**1**	0.571	-0.472	-0.588	-0.574	**-0.989**	-0.924	0.663	**-1.000**	**-0.999**	**-1.000**	**-0.997**	**-1.000**	-0.354	0.411	**-0.995**	-0.762	0.389	0.554	**-0.982**	0.734	**-1.000**
Chlorophy	0.841	0.014	0.884	0.938	0.039	0.515	0.571	**1**	0.444	0.098	0.316	-0.679	-0.216	0.333	-0.570	-0.588	-0.575	-0.558	-0.566	0.563	-0.167	-0.491	-0.611	-0.533	-0.365	-0.412	0.105	-0.565
Temp	0.107	0.759	0.501	0.627	0.913	-0.504	-0.472	0.444	**1**	0.826	**0.987**	0.340	0.771	-0.469	0.474	0.459	0.470	0.473	0.478	**0.989**	-0.509	0.556	0.262	**-0.975**	**-0.991**	0.614	-0.599	0.480
Rain	0.037	0.476	0.408	0.419	0.884	-0.786	-0.588	0.098	0.826	**1**	0.896	0.483	0.759	-0.876	0.592	0.600	0.596	0.552	0.596	0.746	-0.031	0.655	0.709	-0.681	-0.796	0.644	-0.292	0.597
Rad	0.021	0.754	0.430	0.539	**0.958**	-0.631	-0.574	0.316	**0.987**	0.896	**1**	0.450	0.835	-0.598	0.577	0.566	0.574	0.568	0.581	**0.952**	-0.441	0.653	0.412	-0.932	**-0.982**	0.695	-0.592	0.583
Al	-0.857	0.678	-0.586	-0.510	0.687	-0.895	**-0.989**	-0.679	0.340	0.483	0.450	**1**	0.861	-0.617	**0.989**	**0.990**	**0.989**	**0.988**	**0.988**	0.218	-0.371	**0.970**	0.759	-0.259	-0.431	0.949	-0.696	**0.988**
Ti	-0.531	0.883	-0.135	-0.010	**0.956**	-0.867	-0.924	-0.216	0.771	0.759	0.835	0.861	**1**	-0.650	0.925	0.916	0.923	0.926	0.927	0.684	-0.549	**0.956**	0.637	-0.708	-0.830	**0.976**	-0.812	0.928
V	0.194	-0.224	-0.080	-0.014	-0.685	0.900	0.663	0.333	-0.469	-0.876	-0.598	-0.617	-0.650	**1**	-0.666	-0.690	-0.675	-0.610	-0.668	-0.340	-0.275	-0.688	-0.950	0.267	0.450	-0.624	0.089	-0.669
Cr	-0.779	0.743	-0.463	-0.377	0.787	-0.924	**-1.000**	-0.570	0.474	0.592	0.577	**0.989**	0.925	-0.666	**1**	**0.999**	**1.000**	**0.997**	**1.000**	0.356	-0.408	**0.995**	0.765	-0.390	-0.556	**0.982**	-0.732	**1.000**
Mn	-0.776	0.717	-0.464	-0.387	0.778	-0.936	**-0.999**	-0.588	0.459	0.600	0.566	**0.990**	0.916	-0.690	**0.999**	**1**	**1.000**	**0.994**	**0.999**	0.337	-0.371	**0.993**	0.790	-0.367	-0.538	**0.975**	-0.704	**0.999**
Fe	-0.777	0.735	-0.463	-0.379	0.785	-0.929	**-1.000**	-0.575	0.470	0.596	0.574	**0.989**	0.923	-0.675	**1.000**	**1.000**	**1**	**0.996**	**1.000**	0.351	-0.396	**0.995**	0.773	-0.383	-0.551	**0.980**	-0.723	**1.000**
Co	-0.801	0.778	-0.487	-0.387	0.779	-0.894	**-0.997**	-0.558	0.473	0.552	0.568	**0.988**	0.926	-0.610	**0.997**	**0.994**	**0.996**	**1**	**0.997**	0.362	-0.470	**0.992**	0.715	-0.405	-0.561	**0.986**	-0.777	**0.997**
Ni	-0.776	0.745	-0.459	-0.372	0.790	-0.925	**-1.000**	-0.566	0.478	0.596	0.581	**0.988**	0.927	-0.668	**1.000**	**0.999**	**1.000**	**0.997**	**1**	0.361	-0.409	**0.996**	0.765	-0.394	-0.560	**0.983**	-0.733	**1.000**
Cu	0.200	0.734	0.569	0.705	0.845	-0.368	-0.354	0.563	**0.989**	0.746	**0.952**	0.218	0.684	-0.340	0.356	0.337	0.351	0.362	0.361	**1**	-0.547	0.443	0.115	**-0.991**	**-0.975**	0.514	-0.577	0.363
Zn	0.392	-0.875	0.181	-0.051	-0.478	0.090	0.411	-0.167	-0.509	-0.031	-0.441	-0.371	-0.549	-0.275	-0.408	-0.371	-0.396	-0.470	-0.409	-0.547	**1**	-0.431	0.261	0.653	0.597	-0.531	0.920	-0.409
As	-0.720	0.778	-0.379	-0.286	0.843	-0.931	**-0.995**	-0.491	0.556	0.655	0.653	**0.970**	**0.956**	-0.688	**0.995**	**0.993**	**0.995**	**0.992**	**0.996**	0.443	-0.431	**1**	0.758	-0.472	-0.632	**0.993**	-0.749	**0.996**
Se	-0.456	0.209	-0.233	-0.300	0.579	-0.936	-0.762	-0.611	0.262	0.709	0.412	0.759	0.637	-0.950	0.765	0.790	0.773	0.715	0.765	0.115	0.261	0.758	**1**	-0.065	-0.275	0.679	-0.135	0.765
Mo	-0.116	-0.804	-0.484	-0.644	-0.841	0.350	0.389	-0.533	**-0.975**	-0.681	-0.932	-0.259	-0.708	0.267	-0.390	-0.367	-0.383	-0.405	-0.394	**-0.991**	0.653	-0.472	-0.065	**1**	**0.977**	-0.552	0.669	-0.396
Cd	0.014	-0.837	-0.389	-0.534	-0.937	0.542	0.554	-0.365	**-0.991**	-0.796	**-0.982**	-0.431	-0.830	0.450	-0.556	-0.538	-0.551	-0.561	-0.560	**-0.975**	0.597	-0.632	-0.275	**0.977**	**1**	-0.693	0.697	-0.561
Sb	-0.700	0.848	-0.345	-0.228	0.870	-0.889	**-0.982**	-0.412	0.614	0.644	0.695	0.949	**0.976**	-0.624	**0.982**	**0.975**	**0.980**	**0.986**	**0.983**	0.514	-0.531	**0.993**	0.679	-0.552	-0.693	**1**	-0.819	**0.983**
Ba	0.613	**-0.975**	0.315	0.105	-0.704	0.467	0.734	0.105	-0.599	-0.292	-0.592	-0.696	-0.812	0.089	-0.732	-0.704	-0.723	-0.777	-0.733	-0.577	0.920	-0.749	-0.135	0.669	0.697	-0.819	**1**	-0.733
Hg	-0.775	0.745	-0.457	-0.370	0.791	-0.925	**-1.000**	-0.565	0.480	0.597	0.583	**0.988**	0.928	-0.669	**1.000**	**0.999**	**1.000**	**0.997**	**1.000**	0.363	-0.409	**0.996**	0.765	-0.396	-0.561	**0.983**	-0.733	**1**

Values in bold are different from 0 with a significance level alpha=0.05

Table 30: p-value of the physico-chemical & climate data parameters at Lwamondo Garage (Mufunwaini fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To(	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	**0**	0.517	0.089	0.166	0.742	0.439	0.218	0.159	0.893	0.963	0.979	0.143	0.469	0.806	0.221	0.224	0.223	0.199	0.224	0.800	0.608	0.280	0.544	0.884	0.986	0.300	0.387	0.225
pH	0.517	**0**	0.869	0.928	0.169	0.460	0.256	0.986	0.241	0.524	0.246	0.322	0.117	0.776	0.257	0.283	0.265	0.222	0.255	0.266	0.125	0.222	0.791	0.196	0.163	0.152	**0.025**	0.255
EC (µS/cm	0.089	0.869	**0**	**0.027**	0.837	0.760	0.533	0.116	0.499	0.592	0.570	0.414	0.865	0.920	0.537	0.536	0.537	0.513	0.541	0.431	0.819	0.621	0.767	0.516	0.611	0.655	0.685	0.543
TDS (mg/l	0.166	0.928	**0.027**	**0**	0.725	0.774	0.620	0.062	0.373	0.581	0.461	0.490	0.990	0.986	0.623	0.613	0.621	0.613	0.628	0.295	0.949	0.714	0.700	0.356	0.466	0.772	0.895	0.630
Water To(	0.742	0.169	0.837	0.725	**0**	0.199	0.215	0.961	0.087	0.116	**0.042**	0.313	**0.044**	0.315	0.213	0.222	0.215	0.221	0.210	0.155	0.522	0.157	0.421	0.159	0.063	0.130	0.296	0.209
Nitrates (r	0.439	0.460	0.760	0.774	0.199	**0**	0.078	0.485	0.496	0.214	0.369	0.105	0.133	0.100	0.076	0.064	0.071	0.106	0.075	0.632	0.910	0.069	0.064	0.650	0.458	0.111	0.533	0.075
Phosphat(	0.218	0.256	0.533	0.620	0.215	0.078	**0**	0.429	0.528	0.412	0.426	**0.011**	0.076	0.337	**< 0.0001**	**0.001**	**0.000**	**0.003**	**< 0.0001**	0.646	0.589	**0.005**	0.238	0.611	0.446	**0.018**	0.266	**< 0.0001**
Chlorophy	0.159	0.986	0.116	0.062	0.961	0.485	0.429	**0**	0.556	0.902	0.684	0.321	0.784	0.667	0.430	0.412	0.425	0.442	0.434	0.437	0.833	0.509	0.389	0.467	0.635	0.588	0.895	0.435
Temp	0.893	0.241	0.499	0.373	0.087	0.496	0.528	0.556	**0**	0.174	**0.013**	0.660	0.229	0.531	0.526	0.541	0.530	0.527	0.522	**0.011**	0.491	0.444	0.738	**0.025**	**0.009**	0.386	0.401	0.520
Rain	0.963	0.524	0.592	0.581	0.116	0.214	0.412	0.902	0.174	**0**	0.104	0.517	0.241	0.124	0.408	0.400	0.404	0.448	0.404	0.254	0.969	0.345	0.291	0.319	0.204	0.356	0.708	0.403
Rad	0.979	0.246	0.570	0.461	**0.042**	0.369	0.426	0.684	**0.013**	0.104	**0**	0.550	0.165	0.402	0.423	0.434	0.426	0.432	0.419	**0.048**	0.559	0.347	0.588	0.068	**0.018**	0.305	0.408	0.417
Al	0.143	0.322	0.414	0.490	0.313	0.105	**0.011**	0.321	0.660	0.517	0.550	**0**	0.139	0.383	**0.011**	**0.010**	**0.011**	**0.012**	**0.012**	0.782	0.629	**0.030**	0.241	0.741	0.569	0.051	0.304	**0.012**
Ti	0.469	0.117	0.865	0.990	**0.044**	0.133	0.076	0.784	0.229	0.241	0.165	0.139	**0**	0.350	0.075	0.084	0.077	0.074	0.073	0.316	0.451	**0.044**	0.363	0.292	0.170	**0.024**	0.188	0.072
V	0.806	0.776	0.920	0.986	0.315	0.100	0.337	0.667	0.531	0.124	0.402	0.383	0.350	**0**	0.334	0.310	0.325	0.390	0.332	0.660	0.725	0.312	0.050	0.733	0.550	0.376	0.911	0.331
Cr	0.221	0.257	0.537	0.623	0.213	0.076	**< 0.0001**	0.430	0.526	0.408	0.423	**0.011**	0.075	0.334	**0**	**0.001**	**< 0.0001**	**0.003**	**< 0.0001**	0.644	0.592	**0.005**	0.235	0.610	0.444	**0.018**	0.268	**< 0.0001**
Mn	0.224	0.283	0.536	0.613	0.222	0.064	**0.001**	0.412	0.541	0.400	0.434	**0.010**	0.084	0.310	**0.001**	**0**	**0.000**	**0.006**	**0.001**	0.663	0.629	**0.007**	0.210	0.633	0.462	**0.025**	0.296	**0.001**
Fe	0.223	0.265	0.537	0.621	0.215	0.071	**0.000**	0.425	0.530	0.404	0.426	**0.011**	0.077	0.325	**< 0.0001**	**0.000**	**0**	**0.004**	**0.000**	0.649	0.604	**0.005**	0.227	0.617	0.449	**0.020**	0.277	**0.000**
Co	0.199	0.222	0.513	0.613	0.221	0.106	**0.003**	0.442	0.527	0.448	0.432	**0.012**	0.074	0.390	**0.003**	**0.006**	**0.004**	**0**	**0.003**	0.638	0.530	**0.008**	0.285	0.595	0.439	**0.014**	0.223	**0.003**
Ni	0.224	0.255	0.541	0.628	0.210	0.075	**< 0.0001**	0.434	0.522	0.404	0.419	**0.012**	0.073	0.332	**< 0.0001**	**0.001**	**0.000**	**0.003**	**0**	0.639	0.591	**0.004**	0.235	0.606	0.440	**0.017**	0.267	**< 0.0001**
Cu	0.800	0.266	0.431	0.295	0.155	0.632	0.646	0.437	**0.011**	0.254	**0.048**	0.782	0.316	0.660	0.644	0.663	0.649	0.638	0.639	**0**	0.453	0.557	0.885	**0.009**	**0.025**	0.486	0.423	0.637
Zn	0.608	0.125	0.819	0.949	0.522	0.910	0.589	0.833	0.491	0.969	0.559	0.629	0.451	0.725	0.592	0.629	0.604	0.530	0.591	0.453	**0**	0.569	0.739	0.347	0.403	0.469	0.080	0.591
As	0.280	0.222	0.621	0.714	0.157	0.069	**0.005**	0.509	0.444	0.345	0.347	**0.030**	**0.044**	0.312	**0.005**	**0.007**	**0.005**	**0.008**	**0.004**	0.557	0.569	**0**	0.242	0.528	0.368	**0.007**	0.251	**0.004**
Se	0.544	0.791	0.767	0.700	0.421	0.064	0.238	0.389	0.738	0.291	0.588	0.241	0.363	0.050	0.235	0.210	0.227	0.285	0.235	0.885	0.739	0.242	**0**	0.935	0.725	0.321	0.865	0.235
Mo	0.884	0.196	0.516	0.356	0.159	0.650	0.611	0.467	**0.025**	0.319	0.068	0.741	0.292	0.733	0.610	0.633	0.617	0.595	0.606	**0.009**	0.347	0.528	0.935	**0**	**0.023**	0.448	0.331	0.604
Cd	0.986	0.163	0.611	0.466	0.063	0.458	0.446	0.635	**0.009**	0.204	**0.018**	0.569	0.170	0.550	0.444	0.462	0.449	0.439	0.440	**0.025**	0.403	0.368	0.725	**0.023**	**0**	0.307	0.303	0.439
Sb	0.300	0.152	0.655	0.772	0.130	0.111	**0.018**	0.588	0.386	0.356	0.305	0.051	**0.024**	0.376	**0.018**	**0.025**	**0.020**	**0.014**	**0.017**	0.486	0.469	**0.007**	0.321	0.448	0.307	**0**	0.181	**0.017**
Ba	0.387	**0.025**	0.685	0.895	0.296	0.533	0.266	0.895	0.401	0.708	0.408	0.304	0.188	0.911	0.268	0.296	0.277	0.223	0.267	0.423	0.080	0.251	0.865	0.331	0.303	0.181	**0**	0.267
Hg	0.225	0.255	0.543	0.630	0.209	0.075	**< 0.0001**	0.435	0.520	0.403	0.417	**0.012**	0.072	0.331	**< 0.0001**	**0.001**	**0.000**	**0.003**	**< 0.0001**	0.637	0.591	**0.004**	0.235	0.604	0.439	**0.017**	0.267	**0**

Values in bold are different from 0 with a significance level alpha=0.05

3.5.21The physico-chemical quality of aquaculture water: Mrs. Mushiana

The fish ponds (Figure 23) of Mrs. Mushiana show that the physico-chemical parameters were within the DWAF (1996) aquaculture guideline values. The pH of the water was ranging from 5.53 to 7.89. According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9(Figure 22A). Therefore the pH of the water is normal and suitable for fish farming.

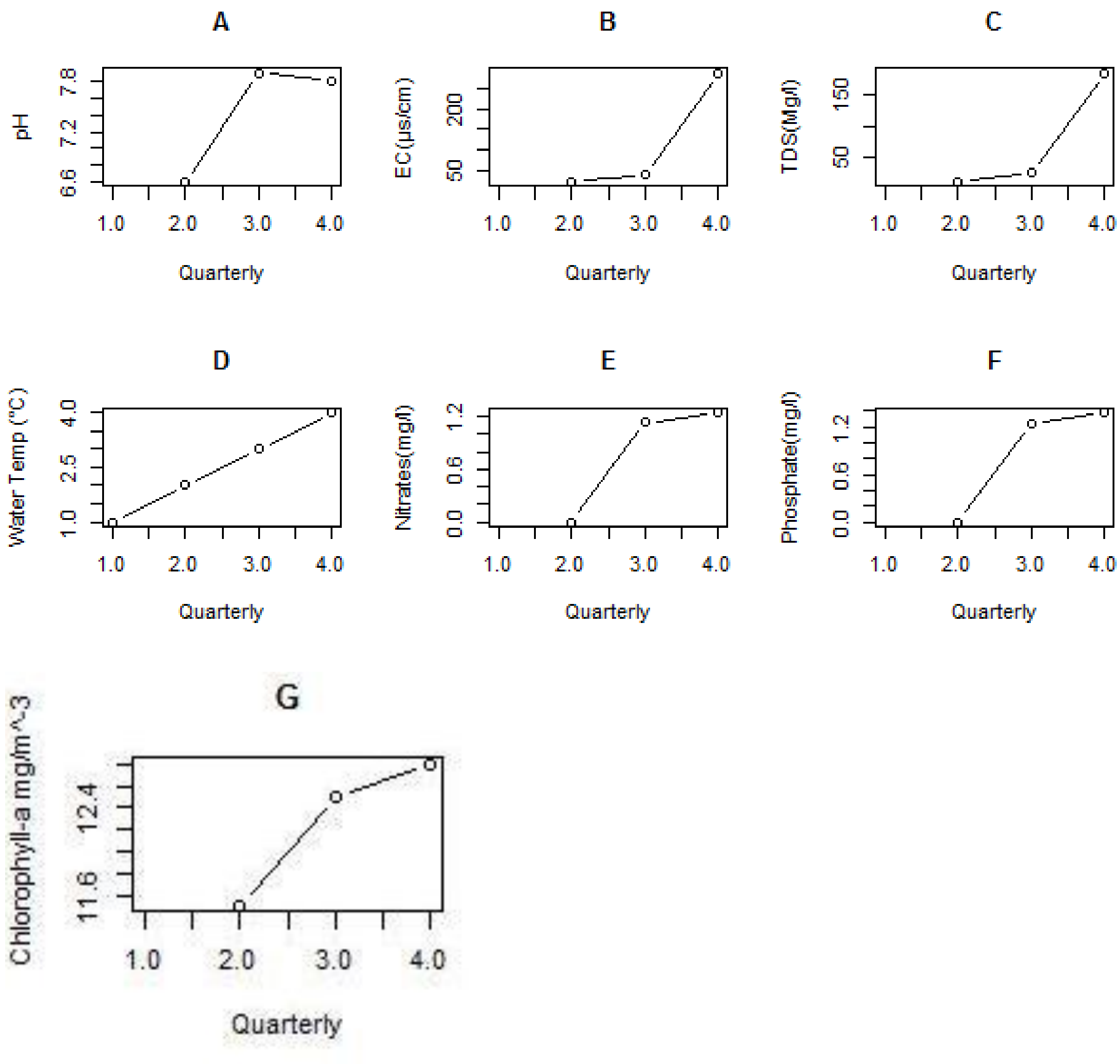


Figure 22: showing the quarterly physico-chemical parameters for Mrs. Mushiana fish pond.

The study showed that nitrates ranged from 1.0 to 1.8 ppm(Figure 22E), which is lower than DWAF (1996) guideline value of 300 ppm. It means that water has low nitrate content and good for fish. Phosphate ranged from 1.046 to 1.784 mg/l(Figure 22F), which was seventeen times above the DWAF (1996) guideline value of 0.1 ppm, meaning that the water has a high phosphate content. Nitrates positively correlated with phosphate, As, Sb, with 1.000 and p = < 0.0001. The relationship between nitrates and phosphates is expected since nitrates can be found from unconsumed fish feeds, fish waste or dead plants and minerals in water which decompose or breakdown to form building blocks of phosphate.

Water temperature ranged from 23.62 to 27.55 ^{0}C(Figure 22D), because the fish ponds are under the shadow of a tree. Keremah et al. (2014) water temperature must be 20 – 30 ^{0}C, water temperature of Mrs. Mushiana is still normal. EC ranged from 2.95 to 30.3µS/cm(Figure 22B), while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 2.44 to 19.77 mg/l(Figure 22C), while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore, the TDS is good for the fish. EC positively correlates with TDS, Water temperature, temperature and solar radiation, with 0.998 and p = 0.012.water temperature depends on radiation which is the heat from the sun and high temperature affects the electric conductivity because the higher the temperature the higher the energy which ions uses to transport the electrical current.

3.5.22The presence metal species in aquaculture water: Mrs. Mushiana

Al, Fe, Ni and Mo exceeded water guidelines for aquaculture (DWAF, 1996) (Table 31). Ti shows positive correlation coefficient greater than 0.5 with Cr, Fe, Co, Ni, with 1,000 and p= < 0.0001 (Table 32 & 33).

Figure 23: The earthen fish dam for Mrs. Mushiana

This was expected since Ti and Fe are found in the geological material Schreibersite with the formula $(Fe,Ni,Cr)_3P$, Co and Ni are found in the geological material Siegenite with the formula $CoNi_2S_4$, Ti and Cr are found in the geological material Carmichaelite with the formula $Ti,Cr,Fe)(O,OH)_2$ (https://www.mindat.org/min-1845.html). Mn shows positive correlation with V, Cr, Fe and Co, with 0.999 and p = 0.002 (Table 11) This was expected since Mn, V, Cr and Fe are found in the geological material Dessauite-(Y) with the formula $Sr(Y,U,Mn)Fe_2(Ti,Fe,Cr,V)_{18}(O,OH)_{38}$ and Co and Fe are found in the geological material Glaucodot with the formula $Co_{0.5}Fe_{0.5}AsS$(https://www.mindat.org/min-1845.html). The presence of Co, Ni, Cr, Fe, Mn were expected since these elements are found in the Basalt group which is found in the study area (Figure 4).

Table 31: The presence of metal species in the aquaculture pond for Mrs. Mushiana

Ppb	Mushiana			DWAF (1996) Aquaculture guidelines, ppb			
	2nd QTR	3rd QTR	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	1297.80±83.21	125.10±8.01	2842.78±110.92	**30**	**70**	**105**	1500
Ti	21.34±13.21	159.13±1.77	27.60±0.63				
V	1.25±0.02	6.64±0.11	1.97±0.06				
Cr	5.11±0.00	35.72±0.00	6.87±0.20	**20000**			
Mn	1.00±0.02	4.44±0.08	1.42±0.08	**100**	**500**	**600**	
Fe	765.62±15.60	3819.08±76.38	1048. 43±0.48	**10**	**1750**		
Co	0.29±0.01	1.91±0.03	0.37±0.01				
Ni	6.84±0.01	36.32±0.07	8.12±0.12				
Cu	3.25±0.00	6.73±0.01	0.06±0.00	**5**			
Zn	9.92±0.03	13.08±0.04	5.58±0.12	**30**			
As	0.04±0.00	0.12±0.00	0.13±0.01		**50**		
Se	0.45±0.00	0.45±0.00	0.14±0.08	**300**	**460**		
Mo	0.20±0.01	0.10±0.00	0.01±0.00				
Cd	0.01±0.00	0.00±0.00	0.00±0.00	**200**			
Sb	0.14±0.00	0.34±0.01	0.38±0.01				
Ba	68.41±0.56	49.8±0.40	60.35±0.05				
Hg	0.00±0.00	0.00±0.00	0.00±0.00	**1000**			
Pb	0.39±0.00	1.52±0.00	0.58±0.00	**10**	**30**	**2150**	

Table 32: Spearman correlation matrix of the physico-chemical & climate data parameters at Khumbe (Mushiana fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water ToC	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba	Hg
Qtr	1	0.845	0.893	0.901	0.866	0.904	0.907	0.962	0.862	0.986	0.918	0.578	0.043	0.130	0.055	0.127	0.084	0.045	0.041	-0.271	-0.572	0.929	-0.866	-0.985	**-1.000**	0.925	-0.434	
pH	0.845	1	0.513	0.529	0.464	0.992	0.992	0.959	0.457	0.922	0.564	0.052	0.571	0.641	0.581	0.638	0.604	0.573	0.569	0.286	-0.044	0.983	-0.464	-0.740	-0.839	0.985	-0.849	
EC (µS/cm	0.893	0.513	1	**1.000**	**0.998**	0.614	0.620	0.736	**0.998**	0.806	**0.998**	0.884	-0.411	-0.330	-0.400	-0.333	-0.374	-0.410	-0.414	-0.676	-0.880	0.662	**-0.998**	-0.957	-0.898	0.654	0.019	
TDS (mg/l	0.901	0.529	**1.000**	1	**0.997**	0.629	0.634	0.749	0.997	0.817	**0.999**	0.875	-0.394	-0.313	-0.383	-0.315	-0.357	-0.393	-0.397	-0.662	-0.871	0.676	**-0.997**	-0.962	-0.906	0.668	0.000	
Water ToC	0.866	0.464	**0.998**	**0.997**	1	0.569	0.575	0.697	**1.000**	0.771	0.993	0.909	-0.462	-0.383	-0.451	-0.386	-0.426	-0.460	-0.464	-0.716	-0.905	0.619	**-1.000**	-0.939	-0.871	0.610	0.075	
Nitrates (	0.904	0.992	0.614	0.629	0.569	1	**1.000**	0.986	0.563	0.962	0.661	0.173	0.466	0.542	0.477	0.539	0.502	0.468	0.464	0.167	-0.166	**0.998**	-0.569	-0.816	-0.899	**0.999**	-0.778	
Phosphate	0.907	0.992	0.620	0.634	0.575	**1.000**	1	0.987	0.569	0.964	0.666	0.180	0.460	0.536	0.471	0.534	0.496	0.462	0.458	0.160	-0.173	**0.998**	-0.575	-0.820	-0.902	**0.999**	-0.773	
Chlorophy	0.962	0.959	0.736	0.749	0.697	0.986	0.987	1	0.692	0.994	0.776	0.334	0.314	0.395	0.325	0.393	0.352	0.316	0.311	0.001	-0.327	0.995	-0.697	-0.901	-0.959	0.993	-0.663	
Temp	0.862	0.457	**0.998**	0.997	**1.000**	0.563	0.569	0.692	1	0.766	0.992	0.912	-0.469	-0.390	-0.458	-0.392	-0.432	-0.467	-0.471	-0.721	-0.909	0.613	**-1.000**	-0.937	-0.868	0.604	0.082	
Rain	0.986	0.922	0.806	0.817	0.771	0.962	0.964	0.994	0.766	1	0.840	0.435	0.208	0.293	0.220	0.290	0.248	0.210	0.206	-0.108	-0.428	0.977	-0.771	-0.943	-0.984	0.975	-0.577	
Rad	0.918	0.564	**0.998**	**0.999**	0.993	0.661	0.666	0.776	0.992	0.840	1	0.854	-0.356	-0.273	-0.344	-0.276	-0.317	-0.354	-0.358	-0.630	-0.850	0.706	-0.993	-0.973	-0.922	0.698	-0.042	
Al	0.578	0.052	0.884	0.875	0.909	0.173	0.180	0.334	0.912	0.435	0.854	1	-0.790	-0.734	-0.783	-0.736	-0.765	-0.789	-0.792	-0.942	**-1.000**	0.234	-0.909	-0.710	-0.587	0.223	0.484	
Ti	0.043	0.571	-0.411	-0.394	-0.462	0.466	0.460	0.314	-0.469	0.208	-0.356	-0.790	1	0.996	**1.000**	0.996	**0.999**	**1.000**	**1.000**	0.950	0.795	0.411	0.462	0.130	-0.033	0.421	-0.919	
V	0.130	0.641	-0.330	-0.313	-0.383	0.542	0.536	0.395	-0.390	0.293	-0.273	-0.734	0.996	1	**0.997**	**1.000**	**0.999**	0.996	0.996	0.919	0.739	0.489	0.383	0.043	-0.120	0.498	-0.950	
Cr	0.055	0.581	-0.400	-0.383	-0.451	0.477	0.471	0.325	-0.458	0.220	-0.344	-0.783	**1.000**	**0.997**	1	**0.997**	**1.000**	**1.000**	**1.000**	0.946	0.787	0.422	0.451	0.118	-0.045	0.432	-0.924	
Mn	0.127	0.638	-0.333	-0.315	-0.386	0.539	0.534	0.393	-0.392	0.290	-0.276	-0.736	0.996	**1.000**	**0.997**	1	**0.999**	0.997	0.996	0.920	0.741	0.486	0.386	0.046	-0.117	0.496	-0.949	
Fe	0.084	0.604	-0.374	-0.357	-0.426	0.502	0.496	0.352	-0.432	0.248	-0.317	-0.765	**0.999**	**0.999**	**1.000**	**0.999**	1	**0.999**	**0.999**	0.936	0.769	0.448	0.426	0.089	-0.073	0.457	-0.934	
Co	0.045	0.573	-0.410	-0.393	-0.460	0.468	0.462	0.316	-0.467	0.210	-0.354	-0.789	**1.000**	0.996	**1.000**	0.997	**0.999**	1	**1.000**	0.949	0.794	0.413	0.460	0.128	-0.035	0.423	-0.920	
Ni	0.041	0.569	-0.414	-0.397	-0.464	0.464	0.458	0.311	-0.471	0.206	-0.358	-0.792	**1.000**	0.996	**1.000**	0.996	**0.999**	**1.000**	1	0.951	0.796	0.409	0.464	0.132	-0.030	0.419	-0.918	
Cu	-0.271	0.286	-0.676	-0.662	-0.716	0.167	0.160	0.001	-0.721	-0.108	-0.630	-0.942	0.950	0.919	0.946	0.920	0.936	0.949	0.951	1	0.945	0.105	0.716	0.433	0.282	0.116	-0.749	
Zn	-0.572	-0.044	-0.880	-0.871	-0.905	-0.166	-0.173	-0.327	-0.909	-0.428	-0.850	**-1.000**	0.795	0.739	0.787	0.741	0.769	0.794	0.796	0.945	1	-0.227	0.905	0.705	0.581	-0.216	-0.491	
As	0.929	0.983	0.662	0.676	0.619	**0.998**	**0.998**	0.995	0.613	0.977	0.706	0.234	0.411	0.489	0.422	0.486	0.448	0.413	0.409	0.105	-0.227	1	-0.619	-0.851	-0.925	**1.000**	-0.737	
Se	-0.866	-0.464	**-0.998**	**-0.997**	**-1.000**	-0.569	-0.575	-0.697	**-1.000**	-0.771	-0.993	-0.909	0.462	0.383	0.451	0.386	0.426	0.460	0.464	0.716	0.905	-0.619	1	0.939	0.871	-0.610	-0.075	
Mo	-0.985	-0.740	-0.957	-0.962	-0.939	-0.816	-0.820	-0.901	-0.937	-0.943	-0.973	-0.710	0.130	0.043	0.118	0.046	0.089	0.128	0.132	0.433	0.705	-0.851	0.939	1	0.987	-0.845	0.272	
Cd	**-1.000**	-0.839	-0.898	-0.906	-0.871	-0.899	-0.902	-0.959	-0.868	-0.984	-0.922	-0.587	-0.033	-0.120	-0.045	-0.117	-0.073	-0.035	-0.030	0.282	0.581	-0.925	0.871	0.987	1	-0.920	0.424	
Sb	0.925	0.985	0.654	0.668	0.610	**0.999**	**0.999**	0.993	0.604	0.975	0.698	0.223	0.421	0.498	0.432	0.496	0.457	0.423	0.419	0.116	-0.216	**1.000**	-0.610	-0.845	-0.920	1	-0.744	
Ba	-0.434	-0.849	0.019	0.000	0.075	-0.778	-0.773	-0.663	0.082	-0.577	-0.042	0.484	-0.919	-0.950	-0.924	-0.949	-0.934	-0.920	-0.918	-0.749	-0.491	-0.737	-0.075	0.272	0.424	-0.744	1	
Hg																												

Table 33: p- value of the physico-chemical & climate data parameters at Khumbe (Mushiana fish farm)

Variables	Qtr	pH	EC (µS/cm)	TDS (mg/l)	Water To	trates (mg	sphates (m	hyll-a mg/	Temp	Rain	Rad	Al	Ti	V	Cr	Mn	Fe	Co	Ni	Cu	Zn	As	Se	Mo	Cd	Sb	Ba
Qtr	**0**	0.360	0.297	0.286	0.333	0.281	0.277	0.176	0.338	0.106	0.259	0.608	0.973	0.917	0.965	0.919	0.947	0.971	0.974	0.825	0.612	0.242	0.333	0.110	**0.007**	0.249	0.714
pH	0.360	**0**	0.657	0.645	0.693	0.078	0.083	0.184	0.698	0.253	0.619	0.967	0.613	0.557	0.605	0.559	0.587	0.612	0.614	0.815	0.972	0.117	0.693	0.470	0.366	0.111	0.355
EC (µS/cm	0.297	0.657	**0**	**0.012**	**0.036**	0.579	0.574	0.473	**0.041**	0.403	**0.038**	0.310	0.730	0.786	0.738	0.784	0.756	0.731	0.729	0.528	0.315	0.540	**0.036**	0.187	0.291	0.546	0.988
TDS (mg/l	0.286	0.645	**0.012**	**0**	**0.048**	0.567	0.563	0.461	0.052	0.392	**0.027**	0.322	0.742	0.798	0.750	0.796	0.768	0.743	0.740	0.539	0.327	0.528	**0.048**	0.175	0.279	0.535	1.000
Water To(	0.333	0.693	**0.036**	**0.048**	**0**	0.615	0.610	0.509	**0.005**	0.439	0.074	0.274	0.694	0.750	0.702	0.748	0.720	0.695	0.693	0.492	0.279	0.575	**< 0.0001**	0.223	0.327	0.582	0.952
Nitrates (	0.281	0.078	0.579	0.567	0.615	**0**	**0.004**	0.106	0.619	0.175	0.540	0.889	0.691	0.635	0.683	0.637	0.665	0.690	0.693	0.894	0.894	**0.039**	0.615	0.392	0.288	**0.033**	0.433
Phosphate	0.277	0.083	0.574	0.563	0.610	**0.004**	**0**	0.101	0.615	0.171	0.536	0.885	0.695	0.640	0.688	0.642	0.669	0.694	0.697	0.898	0.889	**0.035**	0.610	0.387	0.284	**0.028**	0.437
Chlorophy	0.176	0.184	0.473	0.461	0.509	0.106	0.101	**0**	0.514	0.070	0.435	0.783	0.797	0.741	0.789	0.743	0.771	0.796	0.798	0.999	0.788	0.066	0.509	0.286	0.182	0.073	0.539
Temp	0.338	0.698	**0.041**	0.052	**0.005**	0.619	0.615	0.514	**0**	0.444	0.079	0.270	0.690	0.745	0.697	0.743	0.716	0.691	0.688	0.487	0.274	0.580	**0.005**	0.227	0.331	0.587	0.948
Rain	0.106	0.253	0.403	0.392	0.439	0.175	0.171	0.070	0.444	**0**	0.365	0.714	0.866	0.811	0.859	0.813	0.840	0.865	0.868	0.931	0.718	0.136	0.439	0.217	0.113	0.143	0.608
Rad	0.259	0.619	**0.038**	**0.027**	0.074	0.540	0.536	0.435	0.079	0.365	**0**	0.349	0.768	0.824	0.776	0.822	0.794	0.770	0.767	0.566	0.353	0.501	0.074	0.149	0.252	0.508	0.973
Al	0.608	0.967	0.310	0.322	0.274	0.889	0.885	0.783	0.270	0.714	0.349	**0**	0.420	0.476	0.428	0.474	0.446	0.421	0.418	0.217	**0.005**	0.850	0.274	0.497	0.601	0.857	0.678
Ti	0.973	0.613	0.730	0.742	0.694	0.691	0.695	0.797	0.690	0.866	0.768	0.420	**0**	0.056	**0.008**	0.054	**0.026**	**0.001**	**0.002**	0.202	0.415	0.730	0.694	0.917	0.979	0.724	0.258
V	0.917	0.557	0.786	0.798	0.750	0.635	0.640	0.741	0.745	0.811	0.824	0.476	0.056	**0**	**0.048**	**0.002**	**0.030**	0.054	0.057	0.258	0.471	0.675	0.750	0.973	0.924	0.668	0.202
Cr	0.965	0.605	0.738	0.750	0.702	0.683	0.688	0.789	0.697	0.859	0.776	0.428	**0.008**	**0.048**	**0**	**0.046**	**0.018**	**0.006**	**0.009**	0.210	0.423	0.723	0.702	0.925	0.972	0.716	0.250
Mn	0.919	0.559	0.784	0.796	0.748	0.637	0.642	0.743	0.743	0.813	0.822	0.474	0.054	**0.002**	**0.046**	**0**	**0.028**	0.052	0.055	0.256	0.469	0.677	0.748	0.971	0.925	0.670	0.204
Fe	0.947	0.587	0.756	0.768	0.720	0.665	0.669	0.771	0.716	0.840	0.794	0.446	**0.026**	**0.030**	**0.018**	**0.028**	**0**	**0.025**	**0.028**	0.228	0.441	0.704	0.720	0.943	0.953	0.698	0.232
Co	0.971	0.612	0.731	0.743	0.695	0.690	0.694	0.796	0.691	0.865	0.770	0.421	**0.001**	0.054	**0.006**	0.052	**0.025**	**0**	**0.003**	0.204	0.416	0.729	0.695	0.918	0.978	0.722	0.257
Ni	0.974	0.614	0.729	0.740	0.693	0.693	0.697	0.798	0.688	0.868	0.767	0.418	**0.002**	0.057	**0.009**	0.055	**0.028**	**0.003**	**0**	0.201	0.414	0.732	0.693	0.915	0.981	0.725	0.260
Cu	0.825	0.815	0.528	0.539	0.492	0.894	0.898	0.999	0.487	0.931	0.566	0.217	0.202	0.258	0.210	0.256	0.228	0.204	0.201	**0**	0.213	0.933	0.492	0.715	0.818	0.926	0.461
Zn	0.612	0.972	0.315	0.327	0.279	0.894	0.889	0.788	0.274	0.718	0.353	**0.005**	0.415	0.471	0.423	0.469	0.441	0.416	0.414	0.213	**0**	0.854	0.279	0.502	0.606	0.861	0.673
As	0.242	0.117	0.540	0.528	0.575	**0.039**	**0.035**	0.066	0.580	0.136	0.501	0.850	0.730	0.675	0.723	0.677	0.704	0.729	0.732	0.933	0.854	**0**	0.575	0.353	0.249	**0.007**	0.472
Se	0.333	0.693	**0.036**	**0.048**	**< 0.0001**	0.615	0.610	0.509	**0.005**	0.439	0.074	0.274	0.694	0.750	0.702	0.748	0.720	0.695	0.693	0.492	0.279	0.575	**0**	0.223	0.327	0.582	0.952
Mo	0.110	0.470	0.187	0.175	0.223	0.392	0.387	0.286	0.227	0.217	0.149	0.497	0.917	0.973	0.925	0.971	0.943	0.918	0.915	0.715	0.502	0.353	0.223	**0**	0.104	0.359	0.825
Cd	**0.007**	0.366	0.291	0.279	0.327	0.288	0.284	0.182	0.331	0.113	0.252	0.601	0.979	0.924	0.972	0.925	0.953	0.978	0.981	0.818	0.606	0.249	0.327	0.104	**0**	0.256	0.721
Sb	0.249	0.111	0.546	0.535	0.582	**0.033**	**0.028**	0.073	0.587	0.143	0.508	0.857	0.724	0.668	0.716	0.670	0.698	0.722	0.725	0.926	0.861	**0.007**	0.582	0.359	0.256	**0**	0.465
Ba	0.714	0.355	0.988	1.000	0.952	0.433	0.437	0.539	0.948	0.608	0.973	0.678	0.258	0.202	0.250	0.204	0.232	0.257	0.260	0.461	0.673	0.472	0.952	0.825	0.721	0.465	**0**
Hg																											

3.5.23The physico-chemical quality of aquaculture water: Mr. Ramugumo

Water samples for Mr. Ramugumo were only collected first quarter and no water available during the second quarter probable due to prevailing drought conditions. The results of first quarter show that the pH of the water was slightly acidic ranging from 6.66 to 6.67. According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming.

The study showed that there were no nitrates in the fish pond which is lower than DWAF (1996) guideline value of 300 ppm. No Phosphate was found in the fish ponds whereas according to DWAF (1996) guideline value of 0.1 ppm. Water temperature was 25 ^{0}C. Keremah et al. (2014) water temperature must be 20 to 30 ^{0}C, water temperature of Mr. Ramugumo was normal. EC ranged from 16.01 to 14 µS/cm, while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 8.43 to 9.08 mg/l, while the TDS of the water should not be more than 500mg/l (Keremah et al., 2014). Therefore the TDS was good for the fish.

3.5.24The presence metal species in aquaculture water: Mr. Ramugumo

The presence of Co, Ni, Cr, Fe, Mn in the earthen fish dam (Figure 24) were expected since these elements are found in the Basalt group which is found in the study area (Figure 4). According to DWAF (1996) Fe levels were high and this may be caused by rock type found in the area (Table 34).

Figure 24: The earthen fish dam for Mr. Ramugumo

Table 34:The presence of heavy metals in the aquaculture pond for Mr. Ramugumo

Ppb	Ramugumo	DWAF (1996) Aquaculture guidelines, ppb			
	1ST QTR	No adverse effect	toxic to	toxic to	Lethal
Al	24.58±0.24	**30**	**70**	**105**	1500
Ti	0.72±0.00				
V	0.72±0.00				
Cr	7.86±0.00	**20000**			
Mn	6.31±0.01	**100**	**500**	**600**	
Fe	680.70±6.01	**10**	**1750**		
Co	1.53±0.08				
Ni	104.49±4.80				
Cu	4.23±0.22	**5**			
Zn	15.95±0.66	**30**			
As	0.47±0.01		**50**		
Se	0.52±0.01	**300**	**460**		
Mo	0.41±0.01				
Cd	0.02±0.00	**200**			
Sb	0.37±0.01				
Ba	30.87±0.38				
Hg	0.02±0.00	**1000**			
Pb	0.45±0.01	**10**	**30**	**2150**	

The water in aquaculture ponds dried in the second to fourth quarters due the prevailing drought conditions

3.5.25The physico-chemical quality of aquaculture water: Mr. Rambuda

Water samples of Mr. Rambuda were only collected fourth quarter as this was a new project that was starting. The results of fourth quarter show that the pH of the water was slightly alkaline ranging from 7.04 to 7.06. According to Bryan et al. (2011) suitable pH of the water should be between 6 and 9. Therefore the pH of the water is normal and suitable for fish farming.

The study showed that nitrates were 1 ppm which is lower than DWAF (1996) guideline value of 300 ppm. It means that water has low nitrate content and good for fish. Phosphate was 1.723

mg/l which is above DWAF (1996) guideline value of 0.1 ppm, meaning that the water has high phosphate content. Water temperature ranged from 26.7 to 27.5 ^{0}C. Keremah et al. (2014) water temperature must be 20 to 30 ^{0}C, water temperature of Mr. Mufunwaini is still normal. EC ranged from 5.93 to 599.66 µs/cm, while according to Stone et al. (2013), EC of the water for fish farming is between 30 and 5000 µS/cm and therefore the EC of the water was below the standard. TDS of the water ranged from 379 to 391 mg/l, while the TDS of the water should not be more than 500 mg/l (Keremah et al., 2014). Therefore, the TDS is good for the fish.

3.5.26The presence metal species in aquaculture water: Mr Rambuda

The study showed the presence of metal species (Table35) and their concentrations were within the DWAF (1996) aquaculture guideline values.

Table 35: The presence of metal species in the aquaculture pond for Mr. Rambuda

Ppb	Rambuda	DWAF (1996) Aquaculture guidelines, ppb			
	4th QTR	No adverse effect	toxic to	toxic to	lethal
Al	0.78±0.25	**30**	**70**	**105**	1500
Ti	0.08±0.01				
V	3.71±0.33				
Cr	0.32±0.04	**20000**			
Mn	0.14±0.02	**100**	**500**	**600**	
Fe	0.07±0.08	**10**	**1750**		
Co	0.02±0.01				
Ni	0.48±0.03				
Cu	0.02±0.11	**5**			
Zn	2.11±0.10	**30**			
As	0.35±0.02		**50**		
Se	0.17±0.10	**300**	**460**		
Mo	0.17±0.03				
Cd	0.00±0.00	**200**			
Sb	0.13±0.01				
Ba	29.32±2.54				
Hg	0.00±0.00	**1000**			
Pb	0.01±0.00	**10**	**30**	**2150**	

The fish farmer was found in the last Quarter.

3.6 Conclusion

The results of this study indicated that most of the physico-chemical parameters and trace elements were within the recommended water guidelines. The results also indicated that water samples contain concentration of Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg and Se. There was strong correlation between nutrients and trace element which could probably be explained by rainfall fish feeds, fish waste and present of trace element in the soil. Therefore, water quality is suitable for fish farming. However excess levels of nitrates and phosphates in some aquaculture ponds may encourage the growth of cyanobacteria on the long term with a negative impact on the fish health. There is a need to monitor the levels of nutrients in the aquaculture ponds.

CHAPTERFOUR: THE IDENTIFICATION OF CYANOBACTERIA IN THE AQUACULTURE PONDS

4.1 INTRODUCTION

The increases of the occurrence of cyanobacteria and harmful cyanotoxins have been reported together with their effects on human, mammals and the environment. The main objective of the study was to identify the cyanobacteria species using the FlowCAM and scanning electron microscopy.

4.2 Materials and methods

4.2.1 Determining the composition of algal (cyanobacteria) species in the fish ponds using FlowCam

A Benchtop FlowCAM (Model VS IV) was used to determine the composition of cyanobacteria species. The FlowCAM is equipped with a blue (488 nm) laser for florescent and particle detection. For the analysis of algal composition in natural field samples, a flow cell (FC300) was used with 4X objective and a cell size range of 20 to 300 µm. The water samples were transferred to the funnel with a pipette. The fluorescent particle/cell was digitally-acquired and archived by the FlowCAM for latter processing.

A scanning electron microscope was used for confirmatory tests for the identified cyanobacteria species as per procedure by Gumbo and Cloete (2011).

4.2.2 Identification of cyanobacteria using SEM

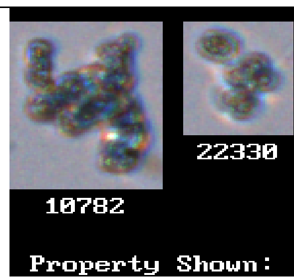
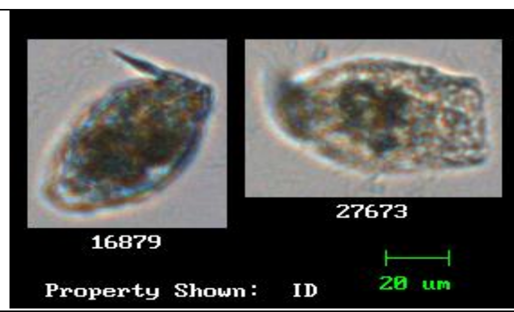
The samples were sent to University Pretoria for Scanning Electron Microscope (SEM) analysis. The samples were centrifuged after mixing with 2.5% v/v gluteraldehyde in 0.075 M phosphate buffer (30 min). The pellet in centrifuge tube was washed three times with 0.075 M phosphate buffer (15 min); dehydrated with 50% ethanol (15 min); 70% ethanol (15 min); 90% ethanol (15 min) and three times with 100% ethanol (15 min). This was followed by critical point drying (Bio-Rad E3000) and gold coating process (Polaron E5200C). The material was examined in a Zeiss ultra plus FEG-SEM scanning electron microscope operating at 1KV, 2.5mm (working distance), Gemini in lens detector system (Germany, Orbervch). The captured images were identified by comparison with published images from literature.

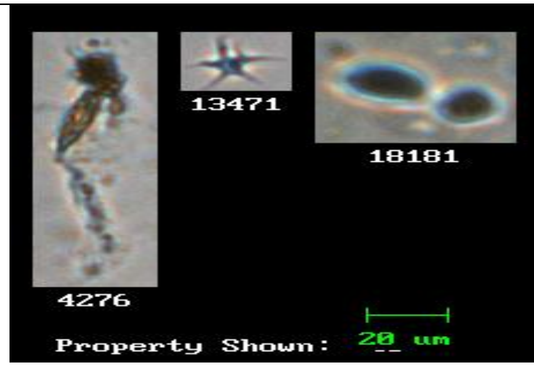
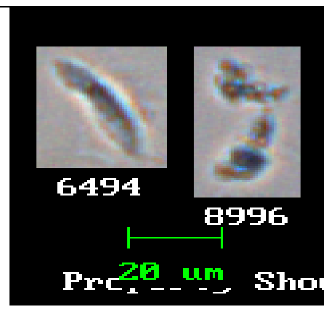
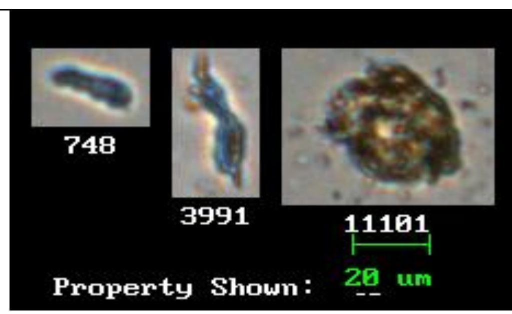
4.3 Results and discussion

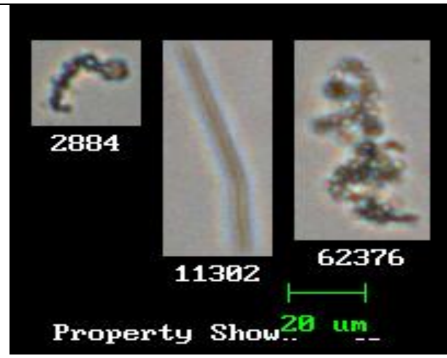
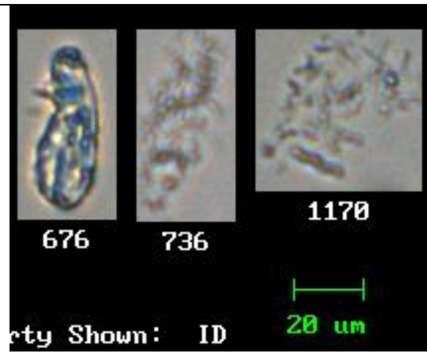
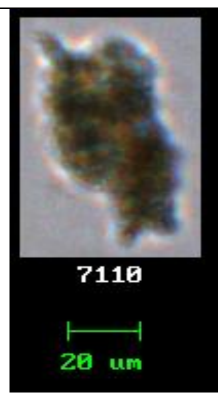
4.3.1 Composition of cyanobacteria species in the fish ponds

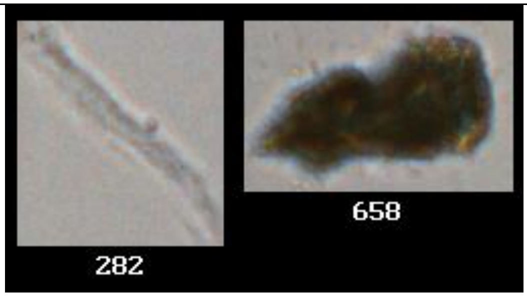
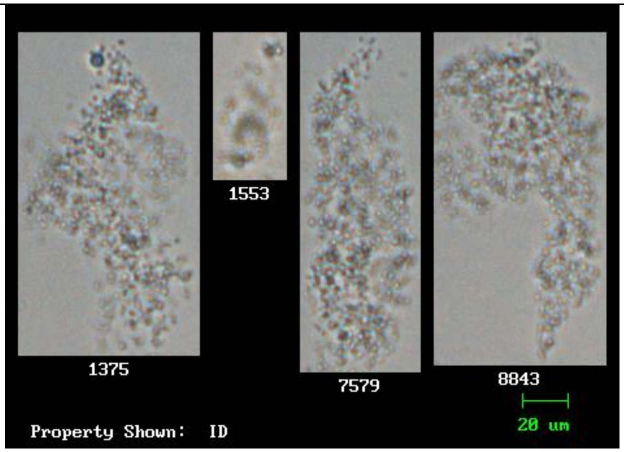
The presence of cyanobacteria was detected. The following cynobacteria species was found: *Microcystis*, *Cocconeis Ehrenberg*, *Cryptomonads*, *Pediastrum*, *Cyclotella*, *Cryptomonads*, *Pediastrum, Cyclotella, Oscillatoria, Cryptomonads, Tetraspora, RhodomonasKarsten, Dictyosphaerium, RhodomonasKarsten, Dictyosphaerium, Dinoflagellates, Nostoc, Anabaena,Volvox, Cryptomonas, Ehrenberg, ClosteriumNitzsch ex Ralfs, Cryptomonas, synedra, Stephanodiscus Ehrenberg, chlamydomonas,Synedra,Rhodomonas, Dinobryon Ehrenberg, Euglena, chlamydomonas, spirogyra, StrombomonasDeflandre, Coelastrum*(Table 36).*Microcystis, Anabaena and Nostoc* cause danger to human and fish and sometimes fish kill, this cyanobacteria were mostly detected in the first and second quarter which may also indicate that water in the first and second quarter were not suitable for fish farming (Huynh and Serediak, 2006). According to Van Vureen et al.(2006),*Microcystis*and *Chlamydomonas* usually occur during summer and high temperature this was expected since it was summer in the first quarter. *Chlamydomonas*was detected in Shanzha fish dams which was expected since the *Chlamydomonas* speciesoccur in "nutrient-rich water and nutrient may be from fish feed.

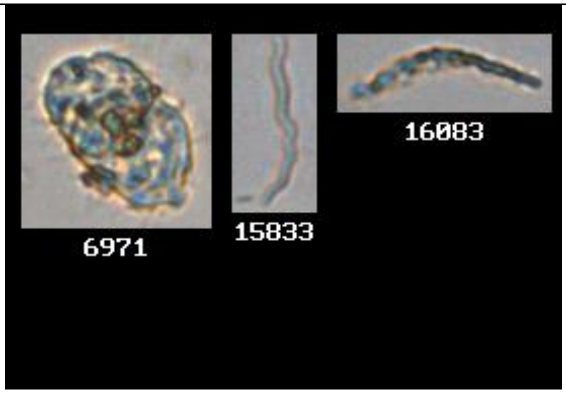
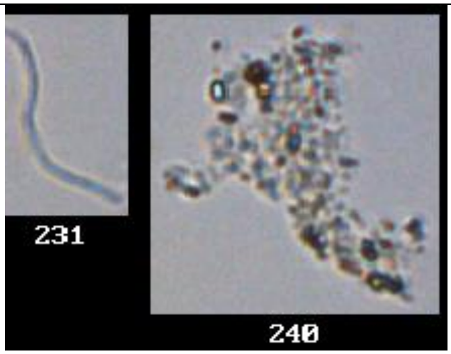
Table 36:The different cyanobacteria species in the fish ponds

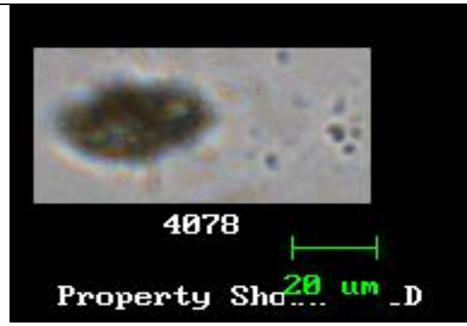
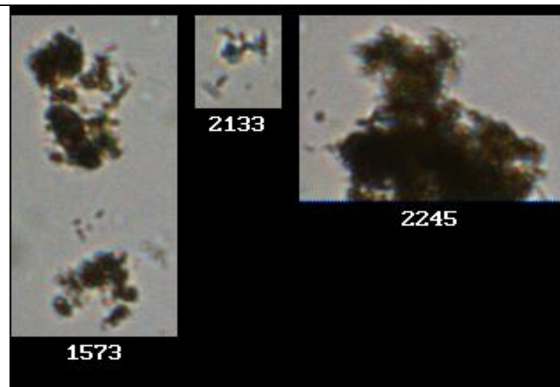
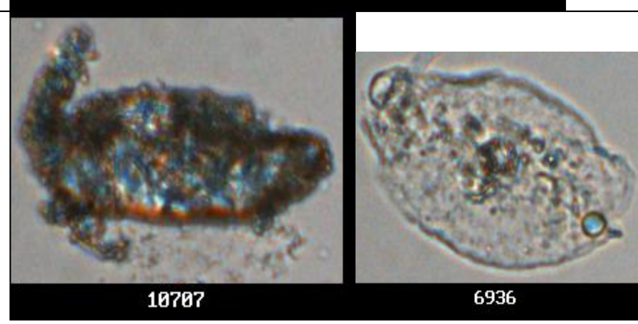
Area and fish farmer	Quarter	Images of cyanobacteria	Species	Reference
Lwamondo Nemaguvhuni	1st quarter		(18251) *Microcystis*	Huynh and Serediak, 2011
	2nd quarter		(10782 and 22330) *CocconeisEhrenberg*	Van Vureen et al, 2006
	4th quarter		(16879 and 27673) *Cryptomonads*	Van Vureen et al, 2006

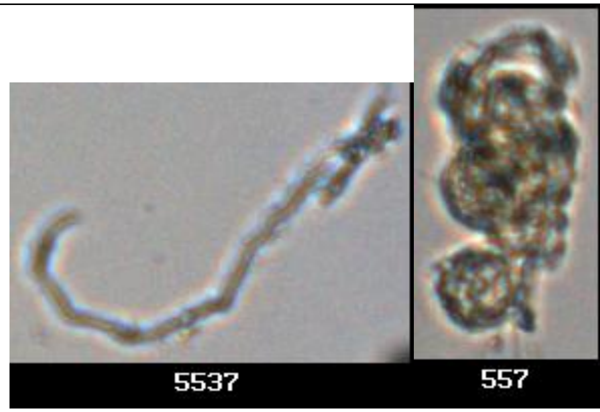
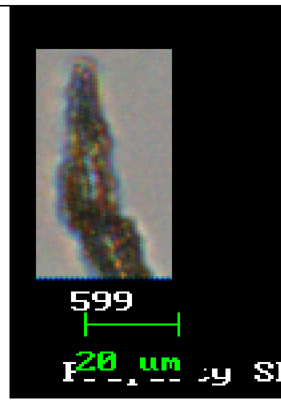
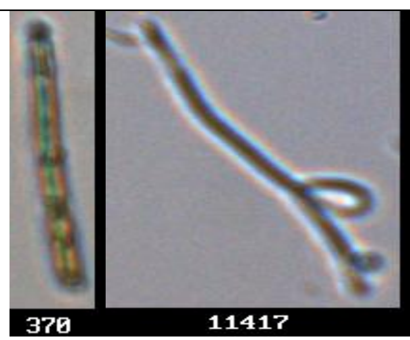
Lwamondo Mudau	No cyanobacteria were found			
Lwamondo Nemubvumoni	1st quarter		(4276)*Cryptomonads* (13471) *Pediastrum* (18181) *Cyclotella*	Van Vureen et al, 2006 Huynh and Serediak, 2011 Huynh and Serediak, 2011
	2nd quarter		(6494) *Oscillatoria* (8996)*Cryptomonads*	Huynh and Serediak, 2011 Van Vureen et al, 2006
	3rd quarter		(11101) *Tetraspora* (748 and 39991) *RhodomonasKarsten*	Huynh and Serediak, 2011 Van Vureen et al, 2006

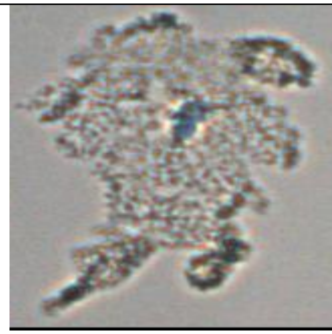
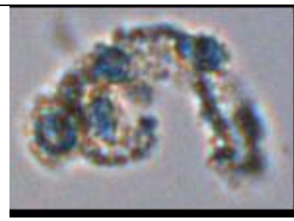
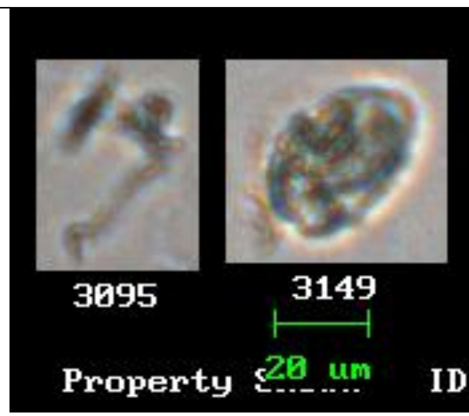
	4th quarter		(2884 and 62376) *Dictyosphaerium* (11302)*Oscillatoria*	Van Vureen et al, 2006 Van Vureen et al, 2006
Dzwerani Mathobo	1st quarter		(736 and 1170) *Microcystis* (676) *Dinoflagellates*	Huynh and Serediak, 2011 Kannan and Lenca, 2012
	2nd quarter		(7110) *Nostoc*	Huynh and Serediak, 2011

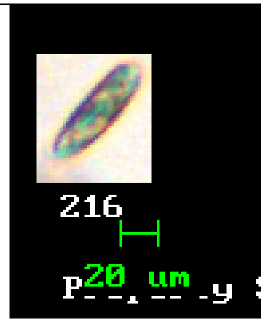
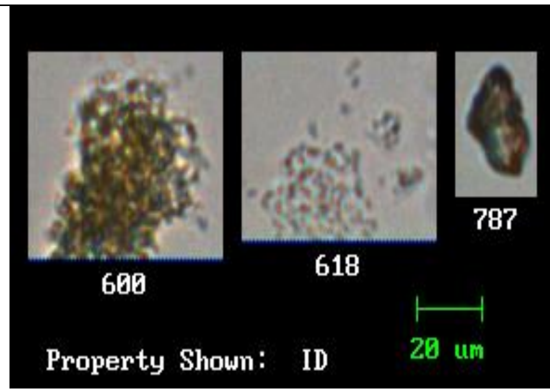
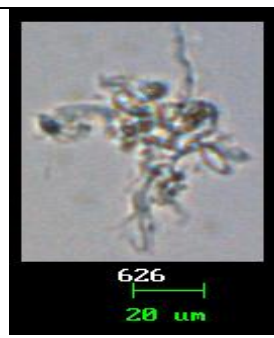
	3rd quarter		(658) *Nostoc* (282) *Anabaena*	Huynh and Serediak, 2011 Huynh and Serediak, 2011
	4th quarter		(1375, 1553, 7579,8843) *Volvox*	Huynh and Serediak, 2011

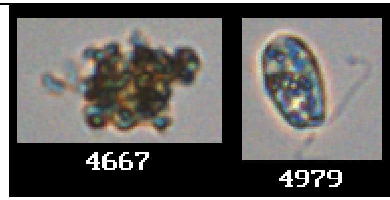
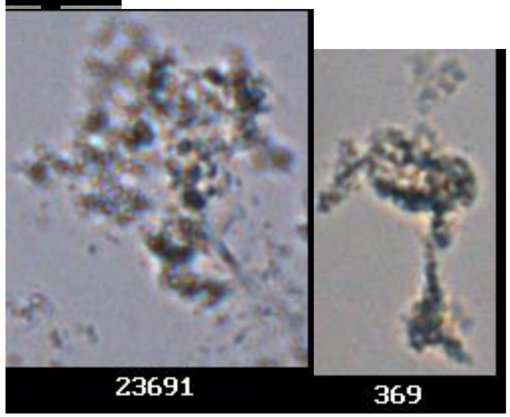
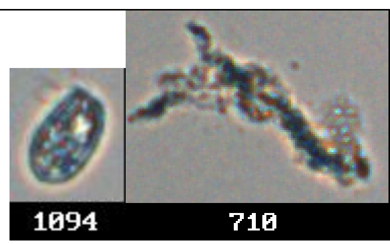
Phiphidi Tshivhase	1st quarter		(16083) *Anabaena* (6971) *Cryptomonas Ehrenberg* (15833)*Oscillatoria*	Huynh and Serediak, 2011 Van Vureen et al, 2006 Kannan and Lenca, 2012
	2nd quarter		(231) *ClosteriumNitzsch ex Ralfs* (240) *Microcystis*	Van Vureen et al, 2006 Van Vureen et al, 2006

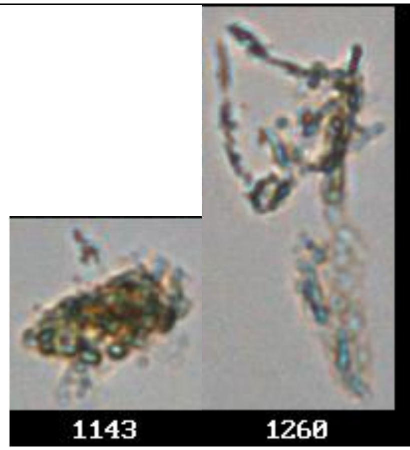
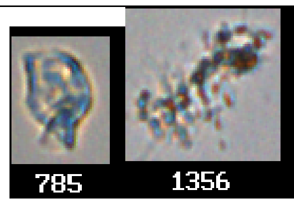
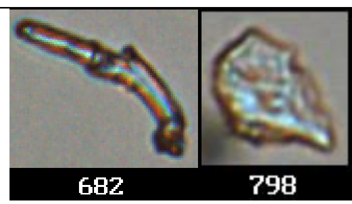
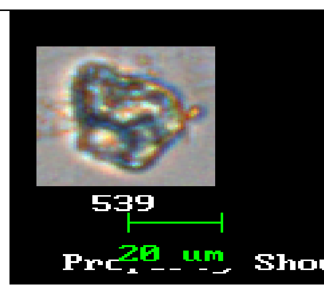
	3rd quarter		(4078) *Cryptomonas Ehrenberg*	Van Vureen et al, 2006
	4th quarter		(1573,2133 and 2245) *Microcystis aeruginosa*	Kannan and Lenca, 2012
Vondo Nevondo	1st quarter		(6936) *Peridinium Ehrenberg* (10707) *Cryptomonas*	Van Vureen et al, 2006 Belinger and Sigee, 2010

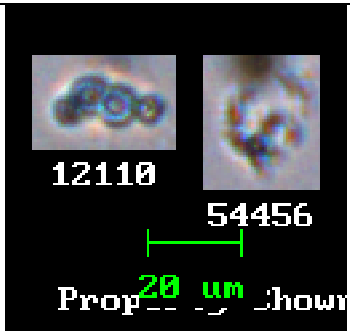
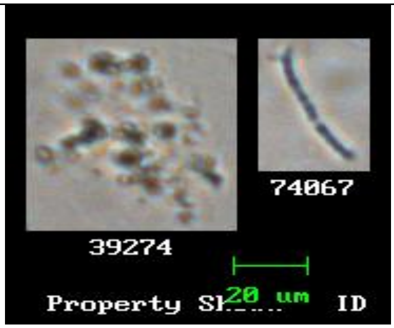
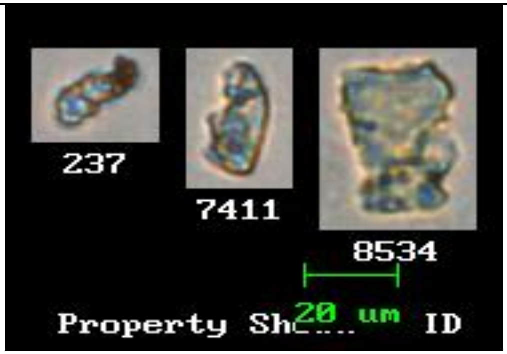
	2nd quarter		(5537) *Anabaena* (557) *Cryptomonas Ehrenberg*	Huynh and Serediak, 2011 Van Vureen et al, 2006
	3rd quarter		(599) *Synedra*	Huynh and Serediak, 2006
	4th quarter		(11417) *Oscillatoria* (370) *Eunotia Ehrenberg*	Huynh and Serediak, 2011 Van Vureen et al, 2006

Shanzha Shavhani	1st quarter		*Microcystis*	Huynh and Serediak, 2011
	3rd quarter		*Stephanodiscus Ehrenberg*	Van Vureen et al, 2006
	4th quarter		(3149) *Chlamydomonas* (3095) *Nostoc*	Huynh and Serediak, 2011 Kannan and Lenca, 2012

Mianzwi Ramugumo	1st quarter		(216) *Synedra*	Huynh and Serediak, 2011
Mutshenzheni Mahwasane	2nd quarter		(600 and 618) *Microcystis* (787) *Rhodomonas*	Huynh and Serediak, 2011 Belinger and Sigee, 2010
	3rd quarter		(626) *Dinobryon Ehrenberg*	Van Vureen et al, 2006

	4th quarter		(4979) *Chlamydomonas* (4667) *Microcystis*	Huynh and Serediak, 2011 Huynh and Serediak, 2011
Zwavhavhili Mufunwaini	1st quarter		(469) *Euglena*	Belinger and Sigee, 2010
	3rd quarter		(23691 and 369) *Microcystis*	Huynh and Serediak, 2011
	4th quarter		(710) *Microcystis* (1094)*Chlamydomonas*	Huynh and Serediak, 2011 Huynh and Serediak, 2011

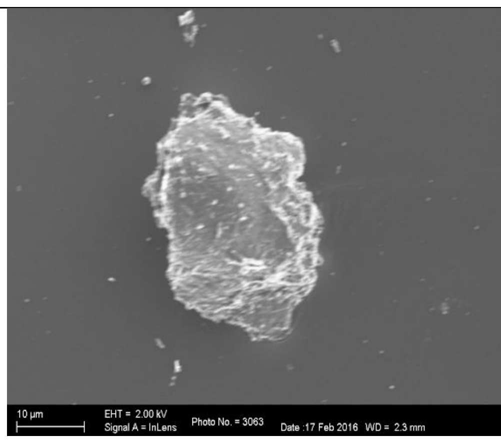
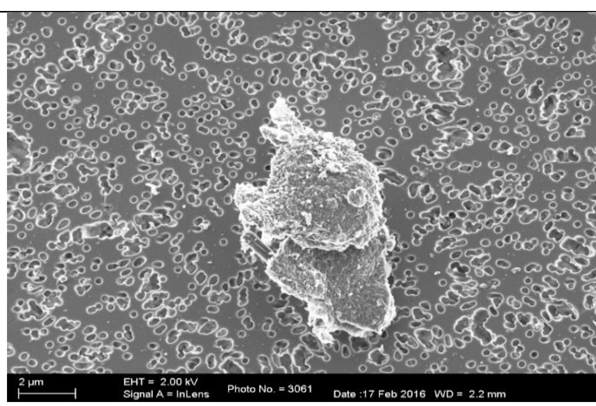
Lwamondo garage Mufunwaini	2nd quarter		(1143 and 1260) *Microcystis*	Huynh and Serediak, 2011
	3rd quarter		(1356) *Microcystis* (1356) *Cryptomonas Ehrenberg*	Huynh and Serediak, 2011 Van Vureen et al, 2006
	4th quarter		(682)*Spirogyra* (789)*Cryptomonas Ehrenberg*	Van Vureen et al, 2006 Van Vureen et al, 2006
Khumbe Mushiana	2nd quarter		(539)*Cryptomonas Ehrenberg*	Van Vureen et al, 2006

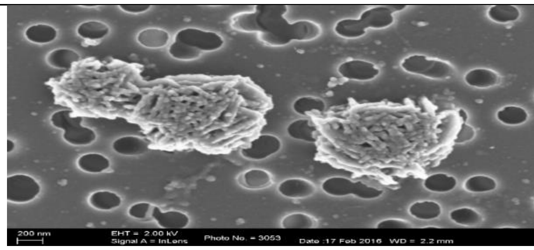
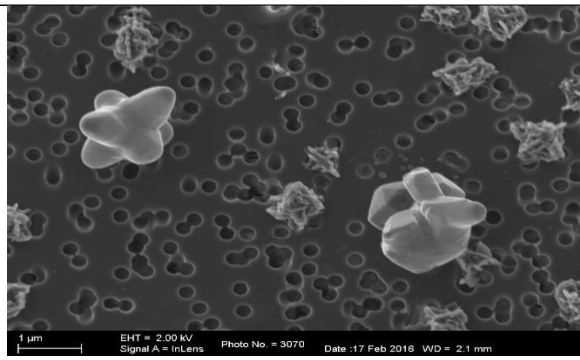
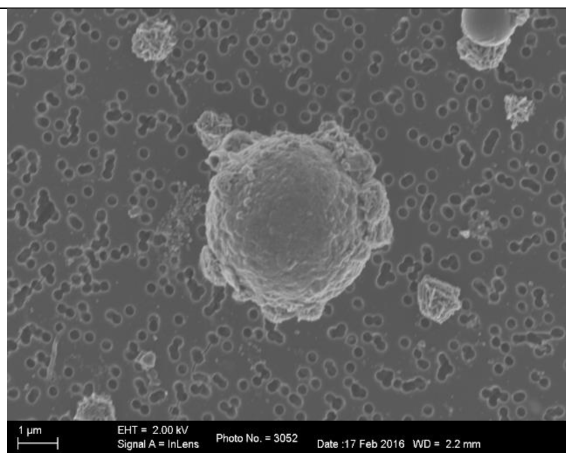
	3rd quarter		(12110 and 54456) *Coelastrum*	Van Vureen et al, 2006
	4th quarter		(39274)*Microcystis* (74067) *Anabaena*	Huynh and Serediak, 2011 Van Vureen et al, 2006
Mushuri Rambuda	4th quarter		(237, 7411 and 8534) *StrombomonasDefl andre*	Van Vureen et al, 2006

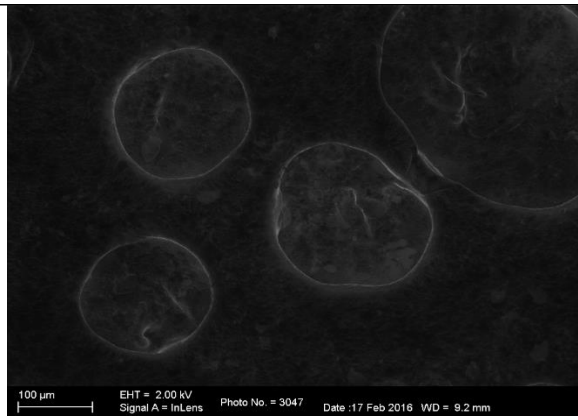
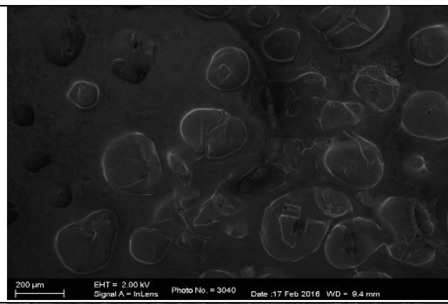
4.3.2 Identification of cyanobacteria using SEM

The following cyanobacteria were found in the fish ponds *Tetraspora*, *StrombomonasDeflandre*, *Nostoc*, *Oscillatoria*, *Pediastrum*, *Chroococcus*, *Chlorella* and *Anabaena.* In Nemubvumoni and Mudau fish ponds no cyanobacteria were detected (Table 37). *Anabaena* has been associated with causing respiratory problems, liver, gastro-intestinal damage and comparable with *Nostoc*(Van Vureen et al., 2006).

Table 37: The different cyanobacteria species found in the fish ponds using SEM

Area and fish farmer	Images of cyanobacteria	species	Reference
Lwamondo garage Mufunwaini		*Tetraspora*	Van Vureen et al., 2006
Zwavhavhili Mufunwaini		*Strombomonas Deflandre*	Van Vureen et al., 2006
		Nostoc	Huynh

Phiphidi Tshivhase			and Serediak, 2011
Shanzha Shavhani		*Oscillatoria*	Van Vureen et al., 2006
Vondo Nevondo		*Pediastrum*	Van Vureen et al., 2006
Lwamondo Nemubvumoni		*Chroococcus*	Huynh and Serediak, 2006

Khumbe Mushiana		*Chlorella*	Huynh and Serediak, 2011
Mutshenzheni Mahwasane		*Chlorella*	Huynh and Serediak, 2011
Dzwerani Mathobo		Anabaena	Huynh and Serediak, 2006

Mushuri Rambuda		Anabaena	Huynh and Serediak, 2006

4.4 Conclusion

Different species of cyanobacteria were detected in fish ponds and they may produce different toxins, *Microcystis, Anabaena, Dinoflagellates, Nostoc, Volvox, Cryptomonas, Cosmarium Cordaex Ralfs,ClosteriumNitzsch ex Ralfs, Euglena sanguine, Oscillatoria, Cryptomonas. Ehrenberg, Peridinium Ehrenberg, Synedra, Eunotia Ehrenberg, Stephanodiscus Ehrenberg, Rhodomonas, and Dinobryon Ehrenberg* were found in different fish ponds. Most of the cyanobacteria which were found in the fish ponds are harmful to human and fish. Some of the cyanobacteria are source of fish nutrition. However further tests are required using DNA and molecular techniques to differentiate toxic and non-toxic cyanobacteria species.

CHAPTER FIVE: MOLECULAR TECHNIQUES IN IDENTIFCATION OF TOXIC AND NON-TOXIC CYANOBACTERIA ANDTHEIR CYANOTOXINS

5.1 INTRODUCTION

Cyanobacteria detection using DNA from water samples is important because most of the cyanobacteria species are difficult to detect and DNA identification is more accurate than that obtained by phenotypic testing (Ficetola et al., 2008).

5.2 METERIALS AND METHODS

5.2.1 Cyanobacteria analysis using PCR

All the samples were filtered through 0.45µm membrane Sartorius filter and the suspended material were used for DNA extraction.

5.2.3 DNA extraction

Samples were stored in refrigerator at 4^0C and the DNA was extracted using DNA extraction kit (Bio-Rad, Johannesburg, South Africa) following the manufacture instruction.

5.2.4 Primers

The set of primers 27F, 809R and 740F, 1494R were used for amplification of 16S rRNA gene for cyanobacteria identification. The primers mcyA-Cd F, mcyA-Cd R and HEPF, HEPR were used for amplification of toxic genes (Table 38) (Frazao et al., 2010).

Table 38: showing PCR primers used for amplification of 16S rRNA gene for cyanobacteria identification and amplification of genes related to cyanotoxins production

Primer	Sequence (5´-3) ´	Size (bp)	Amplified gene	Reference
27F 809R	AGAGTTTGATCCTGGCTCAG GCTTCGGCACGGCTCGGGTCGATA	780	16S rRNA 16S rRNA	**Neilan et al., 1997 Jungblut et al., 2005**
740F 1494R	GGCYRWAWCTGACACTSAGGGA TACGGCTACCTTGTTACGAC	754	16S rRNA 16S rRNA	Neilan et al., 1997 Jungblut et al., 2005

mcyA-Cd F mcyA-Cd R	AAAATTAAAAGCCGTATCAAA AAAAGTGTTTTATTAGCGGCTCAT	297	Microcystin synthetase	Hisbergues et al., 2003
HEPF HEPR	TTTGGGGTTAACTTTTTTGGGCATAGTC AATTCTTGAGGCTGTAAATCGGGTTT	472	Microcystin synthetase	Jungblut et al., 2005
PKS M4 PKS M5	GAAGCTCTGGAATCCGGTAA AATCCTTACGGGATCCGGTGC	650	Cylindrospermopsin polyketide synthase	Schembri et al., 2001
M13 M14	GGCAAATTGTGATAGCCACGAGC GATGGAACATCGCTCACTGGTG	597	Cylindrospermopsin polyketide synthase	Schembri et al., 2001

5.2.5 Polymerase Chain Reaction (PCR) Amplification

PCR amplification for 16S rRNA was done according to with the exception of 1cycles at 95 ºC for 5 min, 35 cycles at 95 ºC for 30 s, 55.4 ºC for 30 s and 72 ºC for 60 s and 1 cycle at 72 ºC for 10 min. Reactions were carried out in 50 µL reaction volume that consisted of 0.5 pmol of each primer (10 pM/µL), 25 µL of Dream Taq master mix ,19 µl Nuclease-Free Waterand 5 µL of Template DNA.

The conditions of the PCR reactions were as those described for the amplification of the 16S rRNA gene. Concerning the cycling conditions, for mcyA-Cd genes the thermal cycling conditions were 1 cycle at 95 ºC for 2 min, 35 cycles at 95 ºC for 90 s, 56 ºC for 30 s and 72 ºC for 50 s and 1 cycle at 72 ºC for 7 min. For HEP, the thermal cycling conditions were as those for the amplification of the 16S rRNA with an exception for HEP gene annealing temperature of 58.15 ºC for 30 s.

5.2.6 Gel electrophoresis

All the PCR products were visualized by electrophoresis on 1.8% agarose gel with gene ruler. Agarose gel was stained with Ethidium bromide and run for 1hour in 1X TAE buffer

5.2.7 Toxins genes detection

The presence of toxins was determined using the selected primers, 27F & 809, 740F & 149R McyA-cd F & McyA-cd R, HEP F & HEP R, PKS M4 & PKS M5, M13 & M14 was used to detect and amplify the genes of Microcystins (MC), cylindrospermopsin (CYN), nodularins (NOD). The HEP primers set were used for detection of genes MC and NOD production. For the detection of other genes implied in the production of MC, primers *mcyA-C* were used to detect the *mcyA*, *mcyB* and *mcyC* genes, CYN were detected using production genes PKS, M4 & M5 primers and M13 & M14 (Table 38).

5.2.8 PCR Purification and sequencing

In order to confirm the identity of the amplified products, PCR products were purified and sequenced at Inqaba biotech and the sequence results obtained were compared against sequences in the GenBank nucleotide collection the Basic Local Alignment Search Tool (BLAST) available on the National Center for Biotechnology Information (NCBI) website (www.ncbi.nlm.nih.gov/).

5.3 RESULTS AND DISCUSSION

5.3.1 Identification of genes expressing cyanobacteria toxicity

Primers 27F/809R only amplify one sample (sample 2) from which was collected at Lwamondo garage fish farm, (Figure 25). Most of the samples were detected by primers M13/M14 from which amplify Cylindrospermopsin polyketide synthase, those samples were collected from Dzwerani, Zwavhavhili, and Lwamondo garage, Mushuri, Phiphidi and Lwamondo (Figure 26), where as the primers 740F/1494R, McyA-Cd, HEP and PKS M4/ PKS M5 did not amplify any DNA sample.

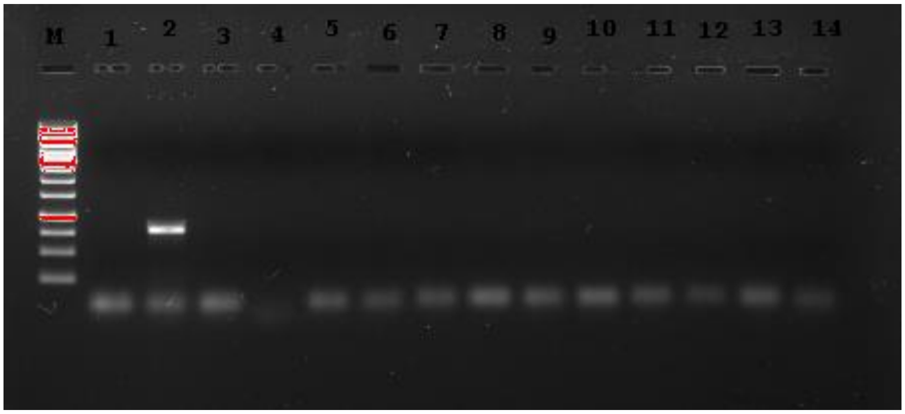


Figure 25:PCRproducts amplified with 27F/809R.M- GeneRuler DNA Ladder Mix, lane 1-Zwavhavhili Mufunwaini, lane 2-Lwamondo garage fish farm, lane 3-Mathobo, lane 4-Nevondo, lane 5-Tshivhase, lane 6-Nemaguvhuni, lane 7-Mudau, lane 8-Mahwasane, lane 9-Shavhani, lane 10-Mushiana, lane 11-Nemubvumoni, and lane 12-Rambuda.

Most of the samples were detected by primers M13/M14 from which was collected at Dzwerani, Zwavhavhili, and Lwamondo garage, Mushuri, Phiphidi and Lwamondo (Figure 26). This may indicate that there is presence of cylindrospermopsin in fish ponds since M13 & M14 were used to detect cylindrospermopsin. Cylindrospermopsin it has been reported that it increasing and causing fish mortality and human poisoning in Australia (Hawkins et al., 2001).

Figure 26:PCR products amplified with M13/M14 primers:(A) M- GeneRuler DNA Ladder Mix, lane 1- Mudau, lane2-, lane 3-Mathobo, lane 4-Nevondo, lane 5-Tshivhase, lane 6-Nemaguvhuni, lane 7-, lane 8-Mahwasane, lane 9-Shavhani, lane 10-Mushiana, lane 11-Nemubvumoni, lane 12-Rambuda, lane 13- Zwavhavhili Mufunwaini, lane 14-Lwamondo garage fish farm.(B) M- GeneRuler DNA Ladder Mix, lane 15-Zwavhavhili Mufunwaini, lane16-Lwamondo garage fish farm, lane 17-Mathobo, lane 18-Nevondo, lane 19-Tshivhase, lane 20-Nemaguvhuni, lane 21-Mudau, lane 22-Mahwasane, lane 23-Shavhani, lane 24-Mushiana, lane 25-Nemubvumoni, lane 26-Rambuda, 27- Zwavhavhili Mufunwaini, 28-Tshivhase, 29- Mathobo , 30- Nevondo, 31- Nemaguvhuni,32-Mudau, 33- Nemubvumoni

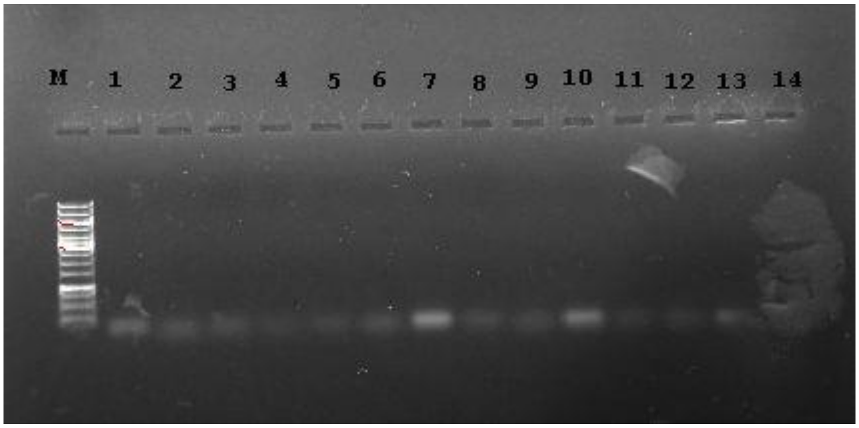


Figure 27:PCR products amplified with mcyA-Cd Primers: (A) M- Gene ruler DNA ladder mix, lane 1-Zwavhavhili Mufunwaini, lane 2-Lwamondo garage fish farm, lane 3-Mathobo, lane 4-Nevondo, lane 5-Tshivhase, lane 6-Nemaguvhuni, lane 7-Mudau, lane 8-Mahwasane, lane 9-Shavhani, lane 10-Mushiana, lane 11-Nemubvumoni, lane 12-Rambuda.

5.3.2 Identification of cyanobacteria species

Most of the samples did not amplify when using selected primers but only sample 2 (Lwamondo garage) were amplified with the 27F/809R primers. In order to confirm the species detected, PCR products were sequenced and blasted. Amplified PCR products were sequenced and all assembled sequences were aligned in BioEdit v7.0.9 (Hall, 1999).The results were blasted and only cyanobacteria with the highest similarity were selected. The species with the highest similarities *Uncultured Leptolyngbya*, *Pseudanabaena cyanobacterium*, *uncultured cyanobacterium clone* and *uncultured cyanobacterium partial* ith 99- 92% (Table 39).The production of algal toxins is normally associated with algal blooms, even though the toxins does not produce harmful toxins it can still poses danger to fish (Codd, 2000).

Table 39:Identification of cyanobacteria species using Primers 27F/809R primers of sequenced BLAST showing the similarity between GenBank sequences.

Sample No	**Similarity%**	**Species similar to**	**Accession No**
S2	99	*Uncultured cyanobacterium clone*	EU160364.1
S2	96	*Uncultured cyanobacterium partial*	FR687585.1
S2	93	*Pseudanabaena cyanobacterium*	KT731142.1
S2	92	*Uncultured Leptolyngbya sp*	KM 108695.1

Cylindrospermopsin toxin is produced by numerous cyanobacteria such as *Aphanizomenon, Aphanizomenon, Cylindrospermopsis raciborskii, Umezakia natans, Anabaena, Raphidiopsis curvata, Aphanizomenon and Leptolyngbya.*

5.4 Conclusion

Several primers were used in this study for amplification of 16S rDNA gene (27F & 809, 740F & 149R) McyA-cd F & McyA-cd R, HEP F & HEP R, PKS M4 & PKS M5, M13 & M14, *Uncultured Leptolyngbya*, *Pseudanabaena cyanobacterium*, *uncultured cyanobacterium clone* and *uncultured cyanobacterium partial* was found in Lwamondo garage fish farm with the 16S rDNA. It is concluded that there are toxic cyanobacteria species in Lwamondo fish farm. Further studies are required to identify the uncultured cyanobacteria species.

CHAPTER SIX: CONCLUSSION AND RECOMMENDATION

6.1 CONCLUSION

The results of this study indicated that most of the physico-chemical parameters and trace elements were within the recommended water quality guidelines for aquaculture. The results also indicated that water samples contain trace elements of Al, As, Cd, Cr, Cu, Fe, Pb, Mn, Hg and Se of geological origin. There was strong correlation between nutrients and trace element.

Different species of cyanobacteria were detected in fish ponds and they may produce different harmful toxins to human and aquatic life, *Microcystis, Anabaena, Dinoflagellates, Nostoc, Volvox, Cryptomonas, Cosmarium Cordaex Ralfs,ClosteriumNitzsch ex Ralfs, Euglena sanguine, Oscillatoria, Cryptomonas Ehrenberg, Peridinium Ehrenberg, synedra, Eunotia Ehrenberg, Stephanodiscus Ehrenberg, Rhodomonas, and Dinobryon Ehrenberg* were found in different fish ponds.

When using primers for amplification of 16S rDNA gene (27F & 809, 740F & 149R) McyA-cd F & McyA-cd R, HEP F & HEP R, PKS M4 & PKS M5, M13 & M14, *Leptolyngbya* was found in Lwamondo garage fish farm with the 16S RDNA which may also cause danger to human and fish.Therefore the study concluded that there are presence of cyanobacteria in the fish dams which some might cause danger to human and fish.

6.2 RECOMMENDATION

Water quality is very important to fish, therefore physico-chemical parameter should always be monitored. Water quality affects the production of fish and influence cyanobacteria. However it is recommended that water should be changed regularly, this may minimize cyanobacteria and cyanotoxins in water. It is also recommended that fish ponds should not be direct to the sunlight or should be covered because the higher the temperature the more cyanobacteria grow faster. Chemical methods of managing cyanobacteria are recommended but it is better to first check the impact of the chemical in aquatic organism because most of the chemicals there are harmful to aquatic life.

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