THE USE OF A SCORING CARD SYSTEM TO ASSESS THE SUITABILITY OF UNDERGROUND AND SURFACE WATER FOR THE FARMING OF WARM WATER FISH SPECIES IN FIVE DISTRICTS IN LIMPOPO PROVINCE

By

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DECLARATION

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GLOSSARY

ADB: Asian Development Bank

Aquaculture: The propagation, improvement, trade or rearing of aquatic organisms (plants and animals) in controlled or selected aquatic environments (fresh, sea or brackish waters) for any commercial, subsistence, recreational or other public or private purpose.

Algae: A primitive, chiefly aquatic and nonflowering plant that lacks true stems, roots, and leaves, but usually contain chlorophyll. Algae converts carbon dioxide and inorganic nutrients, such as nitrogen and phosphorus, into organic matter through photosynthesis and this forms the basis of the marine food chain. Common algae include dinoflagellates, diatoms, seaweeds and kelp.

Alkalinity: The capacity of water to neutralize an acidic solution.

Coldwater fish: Fish, such as trout and salmon, which prefer a water temperature range of 7 to 18°C.

DEEDI: Development of Employment, Economic Development and Innovation.

Freshwater: Water that contains less than 1000 milligrams per litre (mg/L) of dissolved solids. More than 500 mg/L of dissolved solids is generally undesirable for drinking and many industrial purposes.

Groundwater: Refers to water found within subsurface geological formations.

Groundwater availability: The amount of groundwater that exists at any given time and location, and which could be extracted for human use.

mg/L: Milligram per litre.

pH: A measure of the relative acidity or alkalinity of a substance. Water with a pH of 7 is neutral, while lower pH levels indicate acidic solutions and pH levels higher than 7 indicate basic solutions.

Surface waters: Includes streams, rivers, canals, ponds, lakes, seas, and oceans.

Seepage: The slow movement of water through small cracks, pores, interstices, etc. of a material into or out of a body of surface or subsurface water. (2) The loss of water by infiltration into the soil from a canal, ditches, laterals, watercourses, a reservoir, storage facilities, or other bodies of water, or from a field.

Turbidity: The amount of solid particles suspended in water and causes light rays shining through the water to scatter. Turbidity thus makes the water cloudy or even opaque in extreme cases. Turbidity is measured in nephelometric turbidity units (NTU's).

PPM: parts per million.

Water quality: A term used to describe the chemical, physical and biological characteristics of water; usually regarding its suitability for a particular purpose.

Withdrawal: Water removed from a ground- or surface water source for use.

SUMMARY

The development of aquaculture to meet the local and global market demand for fish as an affordable protein source, has created the need for the screening of alternative water sources (i.e. underground and surface water) for its physicochemical properties to assess whether it is suitable for fish production. With wild stocks being characterized by over-utilisation, aquaculture presents a solution to meet the protein needs of rural communities in many countries and to overcome the problems experienced in wild capture fisheries such as over-exploitation and shortages in supply. This study aimed to assess the quality of underground and surface water for aquaculture production in five districts in the Limpopo Province of South Africa, i.e. the Vhembe, Mopani, Capricorn, Sekhukhune and Waterberg. A scorecard, based on guidelines on suitable water quality standards as published by different authors, was developed and used to collect data from the study areas. Ten physicochemical parameters, including dissolved oxygen (DO) (mg/L), temperature (°C), pH, turbidity (NTU), total dissolved solids (TDS) (mg/L), phosphorus as phosphate (PO_4, mg/L), and salinity (ppm) were analysed in order to determine the suitability of the water for aquaculture development. The mean and standard deviation of results were calculated for the physicochemical parameters, whereby averages were determined for sampling sites from a single type of water body, i.e. for both underground and surface water bodies used in each district. Water samples were collected at scheduled times (i.e. 10h00, 12h00 and 15h00) from randomly selected earthen ponds, stagnant concrete ponds and water stored in Jojo tanks, respectively. Samples were then analysed according to standard methods. Results obtained showed that with the exception of dissolved oxygen and phosphorus in Mopani, Sekhukhune and Capricorn districts, all other parameters considered were within the recommended suitable ranges for fish farming of the candidate species.

Where certain low and high scores are observed for parameters, water treatment is recommended to improve the water quality, as this may otherwise have potential negative effects on the sustainability of productivity of aquaculture in the long term. Water treatment can optimise the application of underground and surface water for fish farming, and with continuous monitoring of all parameters, successful aquaculture development can be maintained. The scorecard system provided a user-friendly, basic tool to rapidly assess the suitability of warm water resources for fish farming of candidate species, such as Mozambique tilapia (*Oreochromis mossambicus*), African catfish (*Clarias gariepinus)* and Common carp (*Cyprinus carpio*) in the Limpopo Province of South Africa.

OPSOMMING

Die ontwikkeling van akwakultuur om die plaaslike en wêreldwye markvraag na vis as 'n bekostigbare proteïenbron te voorsien, het die behoefte geskep vir die ondersoek van alternatiewe waterbronne (bv. ondergrondse- en oppervlakwater) vir fisies-chemiese eienskappe om te bepaal of dit geskik is vir visproduksie. Met natuurlike visbronne wat gekenmerk word deur oorbenutting, bied akwakultuur 'n oplossing om die proteïenbehoeftes van landelike gemeenskappe in baie lande te bevredig en om die probleme wat ondervind word in wildvangste-visserye soos oorontgining en tekorte aan voorsiening te oorkom. Hierdie studie het ten doel om die gehalte van ondergrondse- en oppervlakwater vir akwakultuurproduksie in vyf distrikte in die Limpopo Provinsie van Suid-Afrika, insluitende, Vhembe, Mopani, Capricorn, Sekhukhune en Waterberg te evalueer. 'n Telkaart gebaseer op riglyne oor geskikte watergehaltestandaarde soos deur verskillende skrywers gepubliseer, is ontwikkel en gebruik om data vanuit die studiegebiede te versamel. Tien fisies-chemiese parameters, insluitende opgeloste suurstof (DO) (mg/L), temperatuur (°C), pH, troebelheid (NTU), totale opgeloste vastestowwe (mg/L), fosfor as fosfaat (PO_4, mg/L) en saliniteit (ppm) is ontleed om die geskiktheid van die water vir die ontwikkeling van akwakultuur te bepaal. Die gemiddelde en standaardafwyking van resultate is bereken vir die fisies-chemiese parameters, waardeur gemiddeldes vir steekproefpersele vir enkele soort waterbron bepaal is, d.w.s. vir beide ondergrondse- en oppervlakwaterliggame wat in elke distrik gebruik word. Watermonsters is geneem op geskeduleerde tye (o.a. 10h00, 12h00 en 15h00) van lukraak geselekteerde gronddamme, stagnante betondamme en water gestoor in Jojo tenks, onderskeidelik. Monsters is dan volgens standaardmetodes ontleed. Uitslae het getoon dat met uitsondering van opgeloste suurstof en fosfor in Mopani-, Sekhukhune- en Capricorn

distrikte alle ander parameters oorweeg was binne die aanbevole geskikte reekse vir visboerdery van kandidaatspesies. In gevalle waar sekere lae en hoë tellings vir parameters waargeneem word, word waterbehandeling aanbeveel om die gehalte te verbeter aangesien dit op die lang termyn moontlike negatiewe uitwerking op die volhoubaarheid van die produktiwiteit van akwakultuur kan hê. Waterbehandeling kan die aanwending van ondergrondse en oppervlakwater vir visboerdery optimaliseer, en met volgehoue monitering van alle parameters kan suksesvolle akwakultuurontwikkeling gehandhaaf word. Die telkaart stelsel bied 'n gebruikersvriendelike basiese instrument om die geskiktheid van warmwaterhulpbronne vir visboerdery van kandidaatspesies, soos Mosambiek tilapia (*Oreochromis mossambicus*), Afrika-katvis (*Clarias gariepinus*) en gewone karper (*Cyprinus carpio*) in die Limpopo Provinsie van Suid-Afrika te bepaal.

CHAPTER 1

GENERAL INTRODUCTION

In aquaculture there is a wide range of production systems, from small ponds to large commercial systems. Successful pond fish farming depends on the water's physical, chemical and biological characteristics, as well as on the nutrition management of the species being cultured. In pond fish farming, all these factors are interrelated and require careful and constant monitoring to prevent contamination and/or degradation of the aquaculture system (Sapkota *et al.,* 2008).

Aquaculture is acknowledged worldwide as a major contributor to food security. The increasing demand for fish and fish products as sources of affordable animal protein, has created a gap between the demand and supply chain, and this in turn has necessitated an increase in demand from aquaculture production (Oboh & Egun, 2017). Different authors have defined aquaculture in different ways. For example, Swann (1992) has defined aquaculture as a form of agriculture that involves the propagation, cultivation, and marketing of aquatic plants and animals in a more-or-less controlled environment. According to Hinrichsen (2007), aquaculture is defined as "the propagation, improvement, trade or rearing of aquatic organisms (plant and animal) in controlled or selected aquatic environments (fresh, sea or brackish waters) for any commercial, subsistence, recreational or other public or private purpose".

Based on the definitions above, it is clear that without an adequate regular supply of quality water, aquaculture development will not be successful. Fish are totally dependent on water and information on water quality and the availability of source water for production is essential to ensure successful production and animal wellbeing

(Zweig *et al*., 1999; Oboh & Egun, 2017). Aquaculture is regarded as an environmentally sound practice, as it can utilise farm resources (i.e. farm waters), and then generate food and income (Pemetsa *et al.*, 2013).

Farmers are growing warm water fish species such as Mozambique tilapia (*Oreochromis mossambicus*), African catfish (*Clarias gariepinus)* and Common carp (*Cyprinus carpio*) in earthen and stagnant ponds. Ehiagbonare and Ogunride (2010) defined a pond as a manmade or natural water body, which is between 1 m^2 and 2 ha (20 000 m^2) in area, and holds water for four months of the year or more, for the production of fish. The Turfloop Breeding Station, managed by the Department of Agriculture and Rural Development (LARD), has taken the responsibility of producing quality fingerlings of warm water fish species suitable for production in the Limpopo Province of South Africa (Phosa, 2013). Fish is a favoured source of animal protein compared to pork, poultry, beef, or mutton in Limpopo Province, and therefore necessitates its importance to be investigate and promoted.

1.1. STUDY OBJECTIVES

The objectives of this study was to develop a scorecard system which could be used to establish the suitability of different water resources and compare these results with set water quality standards that are recommended for the development of sustainable warm water aquaculture production. This study was conducted in five districts in the Limpopo Province.

The scorecard is an important tool in data collection and quality assessment and there are case studies where scorecard systems have been developed for such purposes.

As an example, Zaza *et al.* (2000) and ADB (2005) have developed a descriptive abstraction form and procedure to provide consistency, reduce bias, and improve validity and reliability in data collection (Guide to Community Preventive Services: Systematic Reviews and Evidence Based Recommendation). Furthermore, after completion, such a form could provide information on the intervention under study, the evaluation setting, and the study population with reference to outcomes, results, and importantly study quality. According to Kpadeh (2011), it is important to develop suitable criteria for assessing the potential of pond aquaculture in different regions (such as Liberia as a test country) and to use the criteria as a tool. The tool developed should include criteria which can be interpreted as, for example: very suitable, more suitable, suitable, or unsuitable.

CHAPTER 2

LITERATURE REVIEW

2.1. GLOBAL VIEW ON AQUACULTURE

Aquaculture remains a growing, vibrant and important production sector for high protein foods (FAO, 2018). The global production from the aquaculture of finfish, crustaceans, molluscs and other aquatic animals for human consumption, reached 52.5 million tonnes in 2008 (Companhia, 2012). The total global aquaculture production increased by 4.5 percent from 105.46 million tons (live weight equivalent) in 2015, to a new high of 110.21 million tons in 2016, with the total production valued at US$ 243.26 billion (FAO, 2018).

It is often seen as an important primary production sector from a food security, poverty alleviation, socio-economic and industrial view point, however, further growth and development of this sector in the new millennium will be necessary within a different socio-economic setting (De Silva, 2001). Although aquaculture is growing rapidly, the world demand for fish protein cannot be met, due to the limited availability of running fresh water. This means that water is the limiting factor in most countries where the demand for fish is very high. Another 2.9 billion people must be fed in the world by 2050, while the rising middle class in developing countries is also creating new demand for animal protein (Lockwood, 2018).

Freshwater fish culture is severely limited by the supply of suitable water in areas where rainfall is concentrated in summer only, with the farming of warm water fish species limited by cold winters. Besides good feed and feeding practices, water quality is one of the critical factors in fish production and it varies with culture systems and growth media, amongst other factors (Davies & Ansa, 2010). It is important in that it provides useful aquaculture data that can be used by farmers when culturing their warm water fish in underground and/or surface water. Improving water quality subsequently improves fish production, and this in turn contributes to rural economic development and the value chain, which is necessary in order to establish developmental opportunities within the sector.

There are countries such as China, India, Indonesia and Thailand, which are the global production leaders in aquaculture (Hinrichsen, 2007). According to the LADP (2010), “In 1997, farmed fish, crustaceans and molluscs contributed 1.9% of the total world fish supplies and this figure had increased to 27.3% by 2000”. Aquaculture contributed 43% of aquatic animal food for human consumption in 2007 (e.g. fish, crustaceans and molluscs, but excluding mammals, reptiles and aquatic plants) and is expected to grow further to meet the future demand (Bostock, 2010). China dominated global aquaculture production at 63.72 million tons or 57.8% of total global production in 2016 and remains the largest global producer of fish, crustaceans, molluscs and aquatic plants (FAO, 2018). There is a clear indication that aquaculture is no longer stagnant. Aquaculture is of growing importance to world food resources and trade commodities (Moji & Brink, 2005). Figure 1 shows the increase in aquaculture production from 1950 to 2003.

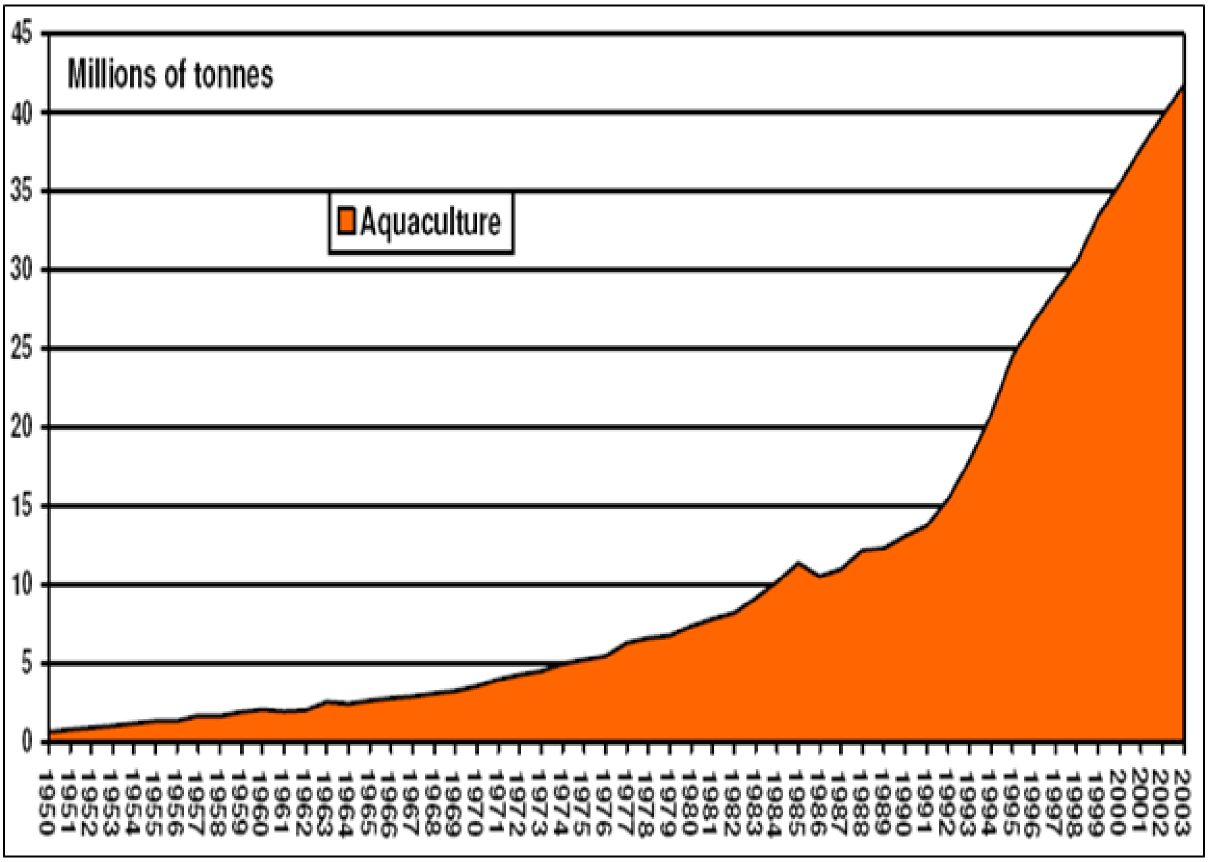

Figure 1 The increase in aquaculture production 1950 – 2003 (adapted from Hinrichsen, 2007).

2.2. STATUS OF AQUACULTURE IN AFRICA

In Africa, aquaculture productions has increased by 56% in volume and more than 100% in value between 2003 and 2007 (Companhia, 2012). This growth was driven partly by increasing prices for aquatic products, but also by the emergence and spread of small and medium scale aquaculture enterprises; and by significant investments into cage culture and the expansion of larger commercial ventures, some producing high value commodities for overseas markets (Companhia, 2012). Almost 98% of the world's small-scale fish farmers are in developing countries which are also mostly in rural areas (Bhujel, 2012).

In many African countries fish consumption is an important source of animal protein, contributing 22% of overall protein intake (Van der Waal, 2000). Interest into aquaculture across the region continues to grow and there is increasing activity in both the private and public sector (Moehl, 1999). Aquaculture in Africa, particularly Sub - Saharan Africa (SSA), has been viewed with renewed interest in recent years as a means of alleviating the supply gap which is currently filled by imports (Cocker, 2014). The focus of this study is on the freshwater aquaculture producers who are culturing warm water fish such Mozambique tilapia (*Oreochromis mossambicus*), African catfish (*Clarias gariepinus)* and Common carp (*Cyprinus carpio*), as the climatic conditions in Limpopo Province are more suitable for these species.

Africa contributes 1% of the world market share and South Africa accounts for about 1% of the contribution to African aquaculture; whereas China and Chile have become huge producers and exporters (Feike, 2008). Many African countries are also turning to aquaculture or fish farming in order to increase food security and job creation and reduce poverty. Nambia and Mozambique have chosen to invest strongly in aquaculture as per their respective habitat; with Namibia having invested in abalone and oysters, and Mozambique in shrimp (Feike, 2008). Ghana is fortunate to have good natural resources, with regards to land and water (rivers, lakes and the sea) which can support aquaculture, however, aquaculture in Ghana is still in the developing stage even though it started about 50 years ago (Amankwaah *et al.*, 2014).

More than half of the region’s population consumes fish products on a daily basis and for some countries (i.e. Benin, Gambia, Ghana, Mali, Mauritania and Senegal) it accounts for up to 3-5% of the total GDP (FAO, 2006; 2010). Fish consumption in

Africa is of crucial importance as at least a million people eat fish as their regular source of animal protein (Cocker, 2014).

2.3. STATUS OF AQUACULTURE IN SOUTH AFRICA

Due to its warm climatic conditions, South Africa can be regarded as suitable for the development of aquaculture. The South African government has been encouraging fish farming as part of the development of the country’s aquaculture sector, as well as to protect fish species from overfishing due to Asian market demand. They have also worked with the Department of Trade and Industry; the fisheries unit of the Department of Agriculture; and Fisheries and Forestry; to establish the Aquaculture Development and Enhancement Programme, which is a funding incentive aimed at attracting new entrants into the fish farming business so as to improve competitiveness in the sector (Radebe, 2013). As an example, climatically, the Northern Cape coastline is suitable for farming a variety of marine fish species (Feike, 2008).

Initially, there was little capacity of the public sector to support the growth of aquaculture in South Africa, however, due to the sprouting of aquaculture everywhere, especially in rural areas, public support began to emerge. The public sector have demonstrated support to people in rural areas by supplying fish tanks, free fish feed, scoop nets, fowl nets and tilapia fingerlings. The public sector have also made information available, with regards to aquaculture, which means that future aquaculture development is less likely to be hampered by a lack of access to necessary information. A prominent form of government intervention was demonstrated through the establishment of fish stations (Moehl, 1999). It has also been suggested by Bhujel (2012), that cage culture in reservoirs, trout farming in hilly areas and backyard fish farming in integration with agriculture in rural areas, should be promoted and supported by government, donor assistance and international collaborations.

Successful aquaculture experiments have been demonstrated at Kleinzee (abalone and oysters), at Port Nolloth (abalone) and at Hondelklipbaai (abalone), which show future potential for expansion and experimentation with these species in aquaculture (Feike, 2008).These aquaculture initiatives bring about social benefits in the communities in terms of potential job creation and the empowerment of marginalized people and communities. As aquaculture sites are largely rural and subsistence based, they play a major role as providers of direct and indirect employment to the poorer rural communities and thereby help to alleviate poverty (De Silva, 2001). Fish consumption also has profound health benefits, especially where other animal protein sources are lacking. It promotes maternal health, child development, resistance to infectious diseases and improves the efficacy of antiretroviral therapies for the treatment of AIDS (Cocker, 2014).

South African aquaculture consists mainly of freshwater species, such as trout (*Oncorhynchus mykiss*), crocodiles (*Crocodylus niloticus*), ornamental fish, catfish (*Clarias gariepinus*), tilapia (*Oreochromis mossambicus*); and marine species, such as abalone (*Haliotis midae*), prawns (*Fenneropenaeus indicus*), oysters (*Crassostrea gigas*) and mussels (*Mytilus galloprovincialis* and *Choromytilus meridionalis)* (Moji & Brink, 2005). South African abalone species are rated among the best in export markets and as a result, abalone producers have developed their own niche markets in countries such as China, Hong Kong, Japan, Thailand, Taiwan, Singapore and

Malaysia. In addition, there is a freshwater aquaculture development programme which includes species such as trout, catfish, tilapia, carp, Atlantic salmon, marron crayfish and largemouth bass (Radebe, 2013).

2.4. STATUS OF AQUACULTURE IN LIMPOPO PROVINCE

Limpopo Province has huge potential for the development of warm water aquaculture due to the warm climatic conditions and if set-up successfully can improve rural livelihoods and create decent jobs through the integration of aquaculture with existing agricultural development projects and irrigation schemes (Phosa, 2013). Aquaculture in Limpopo Province has expansion potential like any other agricultural commodity due to its possible contribution to rural livelihoods. Due to its subtropical climate and warm water resources, it is suitable for warm, freshwater aquaculture species such as Mozambique tilapia (*Oreochromis mossambicus*), African catfish (*Clarias gariepinus)* and Common carp (*Cyprinus carpio*). The Integrated Aquaculture Strategy of Limpopo Province has identified promising dams for aquaculture, such as Flag Boshielo and Buffelsdoring, which have the capacity to store water and grow fish. Both dams are currently being used in irrigation schemes, with crop farming being a core business, however, the same water can also be used for fish production and to develop the aquaculture sector (Phosa, 2013).

The Limpopo Department of Agriculture and Rural Development (LDARD) has budgeted for funds which will assist fish farmers in complying with food, health and safety regulations, as well as aid in the construction of a fish processing facility at Tompi Seleka College of Agriculture (LDARD, 2016). The LDARD is in support of and has been encouraging aquaculture practices. Successful setups will assist in the development of the country's aquaculture sector, as well as alleviate the pressures on local fish species due to overfishing.

Initially, limited capabilities prevented the public sector from supporting the growth of aquaculture in Limpopo Province, but gradually as more small-scale aquaculture systems emerged, especially in rural areas, the public support began to grow. The LDARD demonstrated its support by supplying people in rural areas with aquaculture starter packs, which consisted of a 3.0 m diameter x 1.2 m height plastic fish pond (aqua dam), a hand net, 100 fingerlings, a 3.0 m x 4.5 m bird net and six bags of 50 kg fish feed to farmers who expressed interest and with the purpose of reducing poverty and promoting food security (Britz *et al*., 2015). Information regarding aquaculture was also made available to the public, so that aquaculture development would no longer be hampered by a lack of access to necessary information.

Prominent support was demonstrated by the LDARD through the establishment of Fish Breeding Stations in Turfloop in the East of the University of Limpopo. The Turfloop campus is a government facility managed by the LDARD, which supplies quality fish fingerlings for production. As surface water is less available in the province, fish farmers expand their production through the use of groundwater in plastic tanks and earthen ponds, where they produce fish for human consumption.

Other governmental hatcheries also exist, such as the Dzindi Nature Reserve located in the Vhembe district and Tompi Seleka located in the Sekhukhune district. These hatcheries also supply quality fingerlings to farmers in an effort to establish and support aquaculture projects. Bhujel (2012) indicated that the development of aquaculture systems, (i.e. cage culture in reservoirs, trout farming in hilly areas, and backyard fish farming that is integrated with agriculture in rural areas) needs government support, donor assistance and international collaborations. Fish production is important to the provincial and national economy and contributes significantly to employment, income and food production. The LDARD, fish producers, universities and colleges have developed training manuals for the benefit of extension officers and farmers.

Existing fish farmers in the province who had their infrastructure ready, had no source from which to access quality fingerlings or feed for production (Britz *et al*., 2015). Warm water species are the major aquaculture species in the Limpopo Province. Turfloop Hatchery Station has warm water fish species available, which provides a possible solution to the lack of quality fingerlings, as it will potentially be a source of tilapia, catfish and/or carp fingerlings for the North West, Limpopo and Mpumalanga Provinces (Berold, 2005).

The major water supplies in Limpopo Province are underground water and surface water. All water beneath the land surface is referred to as underground water or sub-surface water (Alberta Environment, 2003). The underground water resources contribute largely to the total water supply, and it is used all year round in rural areas for drinking, irrigation and small-scale aquaculture. It becomes scarce during the dry season and rainfall is generally minimal in most rural areas during this time. This is one of the main reasons that aquaculture development is limited or done on a small scale in this area. Aquaculture is thus dependent on the ability to access an adequate, regular and constant supply of good quality water (Davies & Ansa, 2010).

Limpopo Province falls largely in the sub-tropical belt, with the northern portion in the tropics and the major portion in the Mopani District, which has a long hot summer season and short mild winters (Britz *et al*., 2015). Such climatic condition are very suitable for the culture of warm water fish, such as Mozambique tilapia, African catfish and Common carp, whereby the culture is seasonal. The advantages for culturing tilapia are that they have a high tolerance for poor water quality conditions, and they also have the ability to utilize planktonic organisms as food along with their commercially prepared feeds (Lewis, 1996). African catfish also have the same water tolerance. Aquaculture production in Limpopo Province under natural conditions is restricted to the rainy season and it cannot be carried out in drought-prone areas.

In Limpopo Province, it was concluded that from the 10 farms that were surveyed, a collective total of between 5 and 10 tons of fish were produced per year (tilapia, catfish and carp) (Rouhani & Britz, 2004). Fish production is important to the provincial and national economy and contributes significantly to employment, income and food production. In Limpopo Province it was seen that fish producers; universities that develop training manuals; training officials and farmers at colleges; government departments offering services and regulating the industry; and non-governmental organizations (NGO's) supporting the industry; are all operating in isolation. Existing fish farmers in the province who have their infrastructure set-up and ready, lack access to quality feed and/or fry or fingerlings for production (Britz *et al*., 2015).

Limpopo Province has limited fresh water resources available to execute fish farming activities optimally. According to Mustafa (2010), "the agriculture and fishery sectors are the largest water consumers, and can be highly vulnerable due to their direct dependence on climate parameters". Even though the province has experienced shortages of water for aquaculture, there are opportunities where aquaculture can be introduced by integrating aquaculture activities into the current irrigation schemes that are used to produce crops and where there is sufficient fresh water to produce fish. There are limited fish species that are suitable for the climatic conditions and for aquaculture production in Limpopo Province, however fish species that grow very well include tilapia, carp, and catfish due to the province's warm climatic conditions. A number of research studies have been conducted with various species including catfish, tilapia, butter catfish, common carp, chinese carp and even fresh water prawns (Nesamvuni & Dagada, 2003).

Most of the new emerging fish farmers' farm with two fish species that are recognized as indigenous for aquaculture in Limpopo, namely, the Mozambique tilapia *Oreochromis mossambicus* and African catfish (*Clarias gariepinus)*. Mozambique tilapia is the most common and well preferred freshwater fish and it has potential for producing cheap animal protein in rural aquaculture along with the African catfish. For optimum growth, they all require warm water temperatures of between 25 and 32°C, a pH of between 6.0 and 9.0, a dissolved oxygen range from 4mg/L, the water turbidity to be moderately green with an average Secchi disc reading of 30-45 NTU, the alkalinity of 20ppm, ammonia less than 0.1, and nitrite less than 0.3 (Companhia, 2012).

This limits the scope of farmers to produce and maximize production. In Limpopo Province fish production is predominantly done by women (Britz *et al.,* 2015). Women are suitable participants in aquaculture and play an important role in the fishery sector by ensuring household food security, attending to fish ponds, feeding and harvesting fish, and collecting fish fingerlings. Most of the rural women are unmarried and not working, with their plastic tanks close to the households so that they can take care of the pond and children at the same time. Aquaculture or fish farming thus contributes to food security, poverty alleviation and social well-being in Limpopo Province.

2.5. THE CONTRIBUTION AND IMPACT OF AQUACULTURE DEVELOPMENT ON THE LIVELIHOODS OF PEOPLE IN LIMPOPO PROVINCE

2.5.1. The importance of aquaculture for food security

Food security is considered to exist when all people, at all times, have physical and economic access to sufficient, safe and nutritious food; allowing them to meet their dietary needs and food preferences for an active and healthy lifestyle (De Silva, 2001). Fish have been a staple food source for over a billion people, and its demand is ever increasing due to the growing population and awareness about the health benefits of aquatic animal foods (Bhujel, 2012). Aquaculture contributes to human food security either directly, by acting as a protein source for people, or by increasing household income which in turn increases the capacity to purchase other food at the market (Banze, 2005). In order for the people to ensure food security, they resort to harvesting wild fish from the dams and rivers that then leads to overharvesting of fish stocks. This continual overharvesting eventually results in wild fish harvesters catching fingerlings for consumption, as fish are removed before they are allowed to reach a proper harvest size. Aquaculture in Sub-Saharan Africa is conducted mainly in earthen ponds and is relatively less intensive compared to the same methods of food production in Asia, Europe, and North and South America (Frimpong *et al.,* 2014). Disappointingly, in

Limpopo Province, fishing for wild stock has reached a maximum point to where certain fish populations are now declining in size (Bhujel, 2012).

Fish is not only important for food security as a protein source, but is also important for creating local employment, which in turn has a significant economic role at a local level (Français, 2007). Aquaculture has an important role in the development of many national economies and plays a key role in rural development (Haylor & Bland, 2001). The development and wider adoption of aquaculture can be considered an important contribution to household food security and general welfare. By supplying food and being a commodity, aquaculture can contribute to enhanced food and nutritional status of people in at least three ways, namely, by increasing incomes, providing employment, and by providing food. The development and wider adoption of aquaculture can be seen as a significant basis for improving household food security and other needed welfare (Ahmed & Lorica, 2002).

Income and purchasing power are determinants in households with regards to the demand for food. Income therefore has a great influence on fish consumption (often a non-staple) and other non-staples with high nutritional content. Fish consumption is not continuous over the year, and can have its peaks relating to religious traditions. The largest quantity is often consumed between August and April months, when the water becomes warm and as the growth rates of warm water fish stop in May. The vital role of small-scale, yet widespread systems, in family nutrition, food security and income generation, is now beginning to gain recognition. Inland fishermen in rural populations who depend on fishing for their livelihoods, are among the poorest and most vulnerable. However, these fishing opportunities do contribute to poverty reduction and resilience building by providing food, income and employment (FAO, 2010; 2018).

2.5.2. Adoption of aquaculture and its effects on employment

In recent times, fish farming (aquaculture) has become a major source of income to many, and a substitute for beef in many homes all over Nigeria. This is because a kilogram of fish is cheaper, especially the so called ice-fish, compared to a kilogram of beef (Arabi *et al.*, 2011; Okwadu, 2016). Aquaculture is an income-generating activity, but aquaculture does not provide employment to the people of the province, since fish farming is done on a small scale and labour is provided by family households, whereas aquaculture in other countries provides job opportunities. In the Philippines, freshwater tilapia farming provides employment opportunities for fish pond operators and fish cage caretakers and their families, while other work opportunities also include full time and part time employment in pond excavation, cage and net making, boat operation services, harvesting, fish sorting and grading, marketing, transport and miscellaneous activities (ADB, 2005). The relationship between aquaculture, employment and food security is based on the hypothesis that the nutritional condition of household members is related to the household's capacity to earn an income, which in turn depends on the nutritional health of the household labour force (Ahmed & Lorica, 2002).

In developing countries, such as South Africa; where the majority of the population lives in rural areas and many families in those areas depend on agriculture, which in turn depends mostly on the family's labour force; it is important to maintain and increase productivity by increasing household income. Aquaculture can contribute towards increasing agricultural productivity labour opportunities and hence produce higher earnings for both own-family and hired labour. Fish farmers do not hire a labour force for digging and construction of their artificial ponds or for fish production, but instead they take sole responsibility for their own labour on their farms, often on a full-time basis.

The Limpopo Department of Agriculture and Rural Development has appointed an aquaculturist based at Tompi Seleka College of Agriculture, and who is offering semester course on aquaculture to students who have registered for a diploma in agriculture in animal production. The Head Office in Polokwane is also assisting in developing extension officers based at five districts, who then service 49 famers, who have undergone fish training at both Limpopo Colleges of Agriculture.

Table 1 The distribution of existing fish farmers in five districts in Limpopo Province

District	**Sex**		**Warm water fish**	**Grow-out systems**
	Female	Male		
Vhembe	6	24	Tilapia and African catfish	Earthen and Stagnant concrete ponds
Mopani	2	5	Tilapia and African catfish	Earthen and Stagnant concrete ponds
Sekhukhune	2	4	Tilapia, carp and African catfish	Earthen and Stagnant concrete ponds
Capricorn	0	3	Tilapia	Earthen and Stagnant concrete ponds
Waterberg	1	2	Tilapia	Earthen and Stagnant concrete ponds
Total in Districts	11	38		
Total no. of fish farmers in Limpopo Province	49			

2.5.3. Adoption of aquaculture and its effect on food consumption

Aquaculture provides food of high nutritional value for households, and when small-scale farmers combine agriculture and aquaculture they also improve their food supply, increase their income and become better able to withstand shocks. Aquaculture can potentially contribute to the livelihoods of the rural poor, because it generates food of high value, especially for the vulnerable groups such as pregnant and lactating women, infants and pre-school children (Aganyira, 2005). Supplying a household with a large amount of fish, which is rich in nutrients, improves the household's nutritional status. Wide adoption of aquaculture can also increase market supply and reduce fish prices, hence increasing the intake of micronutrient-rich food (Ahmed & Lorica, 2002).

2.6. WATER QUALITY PARAMETERS

Water quality is one of the most important aspects to consider during aquaculture and management of ponds, as it can largely affect fish production (Keremah *et al.*, 2014). Water is the physical place in which fish carry out their life functions such as feeding, swimming, breeding, digestion and excretion. Chowdhury *et al.* (2012), also emphasised that fish are totally dependent upon water for respiration, feeding and growth, excretion of waste material, maintenance of osmotic balance and reproduction. The production of fish thus requires a sustainable water source, such as natural water (surface, rainfall, etc.), and/or underground water from shallow and deep tube wells (Hossain *et al.*, 2011). Growth and survival, which together determine the ultimate yield, are influenced by a number of physical and chemical parameters, and are also largely dependent on managerial practices (Hossain *at al*., 2011). The water used for the cultivation of fish will not promote maximal production unless the physicochemical parameters are optimal for fish and other aquatic organisms

(Keremah *et al.*, 2014). Ehlagbonare and Ogunride (2010; Vasile *et al*., 2017), indicated that good water quality is required for optimum growth of aquatic living organisms. Every living organism has a tolerance range for all abiotic factors (water quality) in their surrounding habitats (Yap *et al.*, 2011). When this tolerance range is exceeded for any given parameter, conditions may be considered detrimental to certain living organisms in that environment.

Water quality determines, to an extent, the success or failure of a fish farm. Water testing should be done on a regular basis in order to maintain good water quality. Water quality tests are a very useful tool for pond owners who wish to manage their ponds and support the best possible population. The role of water quality parameters cannot be overlooked for maintaining a healthy aquatic environment and for the production of sufficient food organisms in ponds for increasing fish production (Bhatnagar & Devi, 2013). This study has given attention to the following physicochemical water quality parameters: dissolved oxygen, temperature, pH, ammonia, nitrite, nitrate, phosphorus, turbidity, total dissolved solids (TDS) and salinity.

All living organisms have specific ranges for water quality parameters, in which they perform optimally. When these tolerance levels are exceeded or a rapid change (increase or decrease) in water quality occurs, adverse effects on bodily functions may be experienced (Danba *et al.*, 2015). Water quality can strongly influence fish health and its ability to resist disease-causing agents. Oxygen (O_2) depletion, excess ammonia, excess carbon dioxide (CO_2) and temperature change render the water unusable for fish production (Hossain *et al.*, 2007).

There are two main categories of water supply for aquaculture purposes, namely; ground and surface water (Arabi *et al.*, 2011); and not all available water is good enough for fish farming. Both waters are considered Waters of the State, which are regulated. For example in the United States, surface waters are regulated and therefore subject to potential regulatory constraints that may limit withdrawals for pond aquaculture (Tucker & Hargreaves, 2008). Water quality standards vary significantly due to different environmental conditions, ecosystem and intended human uses.

A generalised table was compiled for the specific water quality parameters that are required by warm water fish species, especially focussing on the suitability ranges for Mozambique tilapia, African catfish and carp (DWAFF, 1996; Boyd, 1998; Boyd & Rafferty, 1998; Timmons & Ebeling, 2010; Sahni & Yadav, 2012;).

Table 2 Suitable water quality standards required by tilapia, catfish and carp

Item	Water quality parameters	Suitability	References
1	Dissolved oxygen mg/L	5 – 15 mg/L	(DWAFF, 1996)
2	Temperature (°C)	25 – 32°C	(Boyd, 1998)
3	pH	6.5 – 9.0	(DWAFF, 1996)
4	Ammonia (NH_3) mg/L	0.– 0.3 mg/L	(DWAFF, 1996)
5	Nitrite (NO_2) mg/L	0.02 – 0.25 mg/L	(DWAFF, 1996)
6	Nitrate (NO_3)	0.2 – 10 mg/L	(Boyd, 1998)
7	Phosphorus mg/L	0.005 – 3.0 mg/L	(Timmons & Ebeling, 2010)
8	Turbidity (NTU)	30 – 40 NTU	(Sahni & Yadav, 2012)
9	Total dissolved solids mg/L	50 – 500 mg/L	(Boyd, 1998)
10	Salinity (ppm)	0.5 – 1.0 ppm	(Boyd & Rafferty, 1998)

Water quality is reduced due to anthropogenic pollutions. Some groundwater and surface water sources are totally unsuitable for fish farming (Beem, 1998; Woke & Bolaji, 2015). Surface fresh water and groundwater resources are limited, and the costs of use restrict the possibilities of aquaculture development (El Gamal, 2010). Surface water and groundwater are generally of good quality for warm water fish farming. This means that surface or ground water can be used in hatcheries, if it satisfies the necessary water quality criteria (Pillay & Kutty, 2005).

Any characteristic of water that affects the survival, reproduction, growth and production of aquaculture species, influences management decisions, causes environmental impacts or reduces product quality and safety, can be considered a water quality variable (Summerfelt, 1998). Groundwater (also called well water or spring water) often differs substantially from surface water in many ways (Summerfelt, 1998). In general groundwater and surface water are considered to be the best sources of water for aquaculture (Hossain, Khan & Akter, 2011). In Limpopo Province people depend on these two sources that are most commonly used, and this has its advantages and disadvantages. Fish growth depends on good water quality in order to boost production, and physicochemical parameters are known to affect the biotic components of an aquatic environment in various ways (Adeogun *et al.,* 2005). Olopade (2013) observed that temperature, turbidity, suspended solids and dissolved oxygen concentration are among the primary factors that determine the quality of a water body.

2.6.1. Underground water and characteristics

Underground water is any water found beneath the earth's surface, including underground streams and water that fills the tiny spaces between soil and rocks. The quality of any groundwater source depends on the type of material along the seepage routes, the dissolved salts, and the general human activities and the disposal systems in the area (Irenosen *et al.*, 2014). Underground water often differs substantially from surface water in their characteristics.

Underground water is not easily polluted, especially in non-industrial areas, and it is a popular source of water for the development of aquaculture in most of the rural areas in South Africa. Water quality and quantity varies from place to place, and is influenced by a number of factors including aspects such as air quality, soil quality and anthropogenic activities (Alatorre-Jácome *et al*., 2011).

Underground water is a globally important and valuable renewable resource which is required for human life and economic development. It constitutes a major portion of the earth’s water circulatory system, known as the hydrological cycle, and occurs in permeable geologic formations known as aquifers i.e. formations having a structure that can store and transmit water at rates fast enough to supply reasonable amounts to wells (Afolayan *et al.*, 2012). Large volumes of high quality underground water is needed for catfish production and there are concerns that the underground water resources are depleting rapidly (Ghate *et al.*, 1993). It is also believed that underground water is much cleaner and free from pollution in comparison to surface water; however, prolonged discharge of industrial effluents, domestic sewage and solid waste can result in increased underground water pollution that in turn increases the risk of health problems (Ojutiku *et al.*, 2014). When underground water becomes polluted, the risk of surface water contamination also increases.

Human activities can alter the natural composition of underground water through the disposal or dissemination of chemicals and microbial matter at the land surface and into soils, or through injections of waste directly into underground water (Harter, 2003). It has been shown in other areas of the province that human activities are largely responsible for water pollution. The greatest contamination threat to underground water comes from the leachate generated when water from precipitation, etc., percolates through waste materials which most often contain toxic substances, especially when wastes are of industrial origins at landfills (Afolayan *et al.*, 2012). Underground water and surface water that have been contaminated with leachate materials from whatever source, become unsuitable for aquaculture development. Afolayan *et al.* (2012) reported that leachates from landfills containing non-hazardous waste could still contain complex organic compound, chlorinated hydrocarbons and metals, at concentrations which pose a threat to both surface and underground water. Wastes in landfills can be washed down to the surface rivers and also percolated into underground water and make that water unusable. The volume of leachate generated is much higher in humid regions, where there is high rainfall and runoff, and a shallow water table (Afolayan *et al.*, 2012).

Naturally, groundwater contains mineral ions (Harter, 2003) which are generally found in higher concentrations than in water flowing overland, as this water has been in contact with minerals below the earth's surface for a longer period of time (Boyd, 2000). This means that underground water needs to be de-gassed or aerated before it can be used for aquaculture. Underground water can vary greatly in concentrations of major constituents (Boyd, 2000). This is due to the fact that this water receives direct sunlight which enhances the evaporation of different gases and the process of degassing can thus occur naturally without causing harm to the cultured species (Boyd, 2012).

Table 3 Comparison of the advantages and disadvantages of underground water (Swann, 1997)

Advantages	**Disadvantages**
• It is likely to be free from pathogenic agents • It usually requires no treatment • The supply is likely to be certain even during dry season • It is less subject to contamination than surface water	• It is high in mineral content, e.g. salts of calcium and magnesium which increase the water hardness • It requires pumping or some arrangement to lift the water from wells • Low temperatures and oxygen levels

2.6.2. Surface water and characteristics

Surface water from streams, rivers, lakes and the open sea may be relatively less expensive to utilize (Pillay & Kutty, 2005) and are waters that are exposed to the air and sunlight, such as streams, rivers, ponds, reservoirs, and lakes (Stone *et al.,* 2013). In some areas, fish farmers rely on groundwater, while others use surface water for fish production. Surface water is not easily available outside the summer season, unless fish farmers have stored water during rainy seasons. It is also during this season that surface water becomes more polluted by chemicals released from surrounding farms and households. This phenomenon then eventually kills fish in rivers, streams, ponds and dams. Diseases from wild fish populations can also be an issue where transmission to the farmed fish population is possible.

Surface water is the main source of water in many areas and it is prone to contamination from human and animal sources. Surface water supplies have the undesirable characteristic of being exposed to sources of pollution and should be used with caution (Daily & Economon, 1983).

Human activities are a major factor determining the quality of surface and underground water and some examples of these activities include, atmospheric pollution, effluent discharges, the use of agricultural chemicals, eroded soils and land use (Alam, 2007; Mohseni-Bandpei & Yousef, 2013). The discharge of urban, industrial and agricultural wastes have increased the quantities of various chemicals entering water systems, which considerably alter the physicochemical characteristics. Surface water also carries the threat of random contamination by pesticides or other harmful chemicals (Beem, 1998). Great care should be taken when using surface water for intensive recirculating aquaculture systems due to the higher risk of contamination by pollutants, fish eggs, insect larvae, diseases, microorganisms, and wide seasonal temperature variations (Silva, 2005). Surface water sources should thus be screened or filtered for the primary purpose of preventing undesirable wild fish, fish eggs and predaceous invertebrates from entering the pond (McGee & Cichra, 2000).

It should never be assumed that surface water is safe for human consumption and aquaculture development unless this water has been subjected to sanitary protection and purification before use. It was shown by Kortatsi (1994) that surface water bodies host many waterborne diseases (i.e. bilharzia, typhoid, cholera, guinea worm, etc.) and are therefore often unsafe for domestic use unless treated. Farms also contribute to surface water pollution. The increase in surface water contamination through human activities and the natural absence of surface water in some areas brought about the exploitation of underground water. During precipitation, surface discharge may become contaminated by anthropogenic interference during infiltration and percolation (Afolayan *et al.*, 2012). Runoff from refuse dumping sites and farming activities can also affect nitrate concentrations greatly in the receiving waters. Due to the fact that surface water is used for multiple purposes by the public, it is prone to contamination from households, industries and agriculture.

Some rivers are littered with domestic rubbish and oil spills from boats. This affects the growth of aquatic plants, which in turn can influence the rate of photosynthesis, which may consequently decrease DO levels (Yap *et al.*, 2011). Fertilizers used on farms may enter streams through leaching and surface runoff during heavy rainfall and this could contribute to the accumulation of high nitrate levels further downstream (Amankwaah *et al.*, 2014).

All human activities that exploit natural aquatic ecosystems pose the risk of altering that system's physicochemical and biological qualities (Mohseni-Bandpei & Yousef, 2013). The quality of surface water everywhere is governed by both natural processes (i.e. precipitation rate, weathering processes and soil erosion) and anthropogenic effects (i.e. urban, industrial and agricultural activities and the human exploitation of water resources). Some of the serious environmental problems involving river water quality include: eutrophication, acidification and emission dispersion; where non-point source pollution has become increasingly severe within the last few decades (Mohseni-Bandpei & Yousef, 2013). Nutrients, such as phosphorus and nitrogen from domestic wastes and fertilizers, accelerate the process of eutrophication and lead to the formation of algae blooms (Pemetsa *et al.,* 2013).

In Limpopo Province, the over-withdrawal of surface water for irrigation schemes and other development-related projects is common, as water, although often abundant in the rainy season, can run short throughout the rest of the year. The seasonal and year to year availability of surface waters is extremely variable. For example, in extremely dry years, sufficient surface water may not be available to supplement other water sources (Tucker & Hargreaves, 2008).

Table 4 Comparison of the advantages and disadvantages of surface water (Swann, 1997)

Advantages of surface water	**Disadvantages of surface water**
• Inexpensive	• Susceptible to draughts or floods • Danger of flooding and pesticides or other pollutants in the water • Requires 5-7 acre watershed per surface acre of water

CHAPTER 3

MATERIALS AND METHODS

3.1 STUDY AREA AND SAMPLING DISTRICTS

The study was conducted in five districts, namely; the Vhembe, Mopani, Sekhukhune, Capricorn and Waterberg district in Limpopo Province of South Africa. Samples were collected during September and October 2017 from earthen ponds, stagnant concrete ponds and stored water in Jojo tanks in the five districts. A total of six underground water sample sites were evaluated in Mopani, Capricorn and Waterberg; while 9 surface water sites were assessed in the Vhembe, Mopani, Sekhukhune and Capricorn districts. Samples were selected randomly, whereby three different points from each pond were identified for random sampling, and these are identified as sampling sites 1, 2 and 3 for each district in the Limpopo Province. The sampling sites and the respective water sources, latitude, longitude and altitudes of each site for the five districts were recorded.

The following physicochemical water parameters were analysed at the sites; dissolved oxygen (mg/L), temperature (°C), pH, turbidity (NTU), total dissolved solids (TDS) (mg/l) and salinity (ppm); while phosphorus (mg/L) was analysed in the laboratory at the college. All the results of the analysed samples were recorded in the developed scorecard and were then later captured in Microsoft Excel.

Figure 2 Location map of the five districts in Limpopo Province from which samples were collected

Table 5 The sampling sites, the respective water sources, latitude, longitude and altitudes for the five districts

LIMPOPO PROVINCE DISTRICTS					
Districts	**Sampling sites**	**Water sources**	**Latitude**	**Longitude**	**Altitude**
Vhembe	S 1	Surface water in earthen pond	S22˚40.4992	E30˚33.08	735 m
	S 2	Surface water in earthen pond	S22˚46.9292	E30˚27.15	662 m
	S 3	Surface water in earthen pond	S23˚02.4974	E30˚24.04	602 m
Mopani	S 1	Underground water stored in Jojo tank	S23˚18.3724	E30˚39.01	458 m
	S 2	Surface water in earthen pond	S23˚43.5228	E03˚02.76	480 m
	S 3	Surface water stored in Jojo tank	S23˚56.3853	E03˚02.66	954 m
Sekhukhune	S 1	Surface water in stagnant concrete pond	S24˚25.0762	E29˚47.44	820 m
	S 2	Surface water in stagnant concrete pond	S24˚26.2804	E02˚948.75	829 m
	S 3	Surface water in stagnant concrete pond	S24°26.7505	E29˚44.71	797 m
Capricorn	S 1	Underground water stored in Jojo tank	S23˚53.0488	E29°46.02	1292 m
	S 2	Surface water in earthen pond	S23˚52.3688	E29˚44.54	1289 m
	S 3	Underground water stored in Jojo tank	S23˚54.2252	E02˚943.65	136 m
Waterberg	S 1	Underground water stored in Jojo tank	S25˚06.2510	E28˚17.08	1079 m
	S 2	Underground water stored in Jojo tank	S24˚42.1800	E282˚6.46	1151 m
	S 3	Underground water stored in Jojo tank	S23˚59.4860	E28˚52.71	1091 m

3.2 THE SCORECARD USED FOR THE SURVEY OF PHYSICOCHEMICAL PARAMETERS OF DIFFERENT WATER SOURCES IN THE FIVE DISTRICTS

The scorecard was developed based on suitable and non-suitable water quality standards and information on tilapia, catfish and carp, which were seen in similar assessment and evaluation studies (DWAFF, 1996; Boyd, 1998; Boyd & Rafferty, 1998; Timmons & Ebeling, 2010; Sahni & Yadav 2012;). Although the scorecard only focussed on the physicochemical parameters, notes were also taken on the biological parameters (i.e. other fish species, predation, plant growth), as well as other relevant information on site accessibility, security, etc.

Thereafter the scorecard was used and tested for efficiency and practical application at different sampling sites in the five districts in Limpopo Province. The card was populated with the information obtained and then recorded and stored in Microsoft Excel spreadsheets for later analysis. Table 6 shows the scorecard for warm water fish species.

Table 6 The scorecard for warm water fish species (tilapia, catfish and carp)

MONTH:					DISTRICT / MUNICIPALITY:	
Parameter	Sampling sites			Water resource	Suitability of water	
	1	2	3	Surface/ Underground	Suitable values	Not suitable values
Dissolved Oxygen (DO) mg/L					5 - 15 (mg/L)	<5 and >20
Temperature (°C)					25 - 32 (°C)	<24 and >33
pH					6.5 - 9.0	<6 and >10

Ammonia (NH_3) (mg/L)					0.0 - 0.02 (mg/L)	<0.2 and >0.03
Nitrite (NO_2) (mg/L)					0.06 - 0.25 (mg/L)	<0.1and >0.26
Nitrate (NO_3) (mg/L)					0.2 - 10 (mg/L)	<0.1 and >11
Phosphorous (mg/L)					0.005 - 3.0 (mg/L)	<0.004 and >4.0
Turbidity (NTU)					30 - 40 (NTU),	<25 and >50
Total Dissolved Solids (mg/L					50 - 500 (mg/L)	<45 and >600
Salinity (ppm)					0.5 - 1.0 (ppm)	<4 and >2.0

Figure 3 The author dressed in a green work suit explaining the use of the scorecard to extension officers and a potential fish farmers in the Waterberg district

3.3 SAMPLE COLLECTION AND ANALYSIS

Six underground surface water samples were collected into 500 mL plastic bottles, which were pre-washed with ordinary water, rinsed with distilled water, left overnight for drying and then rinsed with the water to be collected prior to sampling. The underground water taps were released for three to five minutes before sample collection. The bottles were labelled with a description of the sampling location and the name of physicochemical parameter that was to be analysed in the laboratory. A cooler box with ice cubes kept samples cool at a temperature of -1°C. The collected samples were transported to the refrigerator on the same day. These samples were analysed for phosphorus using a UL – Visible Spectrophotometer (Evolution 201) at the Madzivhandila College. Other physicochemical parameters, such as dissolved oxygen (DO), temperature (°C), pH, turbidity (NTU), total dissolved solids (TDS)(mg/L) and salinity (ppm) were all analysed on site using a portable Aqua-meter (model 200) at the scheduled set times. Five samples were analysed at 10h00, 12h00 and 15h00 on different days, for the five districts. A GPS (model 200 with AP-700 probe) was used to record the geographic location of the sampling points. The nutrient parameters, including ammonia (NO_3) (mg/L), nitrite NO_2 (mg/L) and nitrate (NO_3) (mg/L), were analysed on site using a Sera Ammonia Test Kit NH_4/NH_3 on different days. All of the results of the analysis were expressed as mg/L; except temperature, pH, turbidity and salinity, which were expressed as °C, pH, NTU and ppm, respectively.

CHAPTER 4

RESULTS AND DISCUSSION

The study was conducted at five districts in the Limpopo Province. The results of the physicochemical parameters of underground and surface water in the earthen ponds, stagnant concrete ponds and water stored in Jojo tanks, were compared to the water quality standards.

Different water sources could be used for fish production depending on the availability of good quality water. Most of the fish farmers use underground water and/or surface water (from rivers) for fish farming, whereas others use underground water as the only source of water in their area of operation in Limpopo Province. According to Tucker (1991), underground water is suitable for catfish hatcheries. Farmers use underground water for growing all warm water fish species in Limpopo Province. Warm water fish species can be farmed in both underground and surface water without problems, as long as the physicochemical parameters are monitored and kept constant. Below are the results of the underground and surface water measurements that were taken from earthen ponds, stagnant concrete ponds and water stored in Jojo tanks for Mozambique tilapia (*Oreochromis mossambicus*), African catfish (*Clarias gariepinus* and Common carp (*Cyprinus carpio*). Statistical analysis was carried out using descriptive methods and the suitable ranges were used to investigate the relationship of each water quality parameter for underground and surface water in earthen, stagnant concrete ponds and Jojo tanks. Table 7 show the results of the physicochemical data for ground and surface water that were analyzed at the sites and in the laboratory as captured by use of a scoring card. Comparisons of the results of the sites and laboratory are also presented in Table 8 below.

Table 7 The results of the physicochemical data for ground and surface water that were analyzed at the sites and in laboratory as captured by use of a scoring card

Parameters	Vhembe			Mopani			Sekhukhune			Capricorn			Waterberg		
	Surface water in Earthen ponds			UW Jojo tank	SW in Earth ponds	UW Jojo tank	SW in Stagnant Concrete ponds			UW Earthen ponds		UW in Jojo tank	Underground water stored in Jojo tanks		
	Sampling sites			Sampling sites			Sampling sites			Sampling sites			Sampling sites		
	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
Dissolved oxygen (mg/L)	15.43	10.82	6.18	0.81	10.19	8.44	16.57	17.93	17.83	18.96	15.18	8.24	6.48	6.88	3.10
Temperature (°C)	30.73	35.53	33.80	26.60	31.83	22.75	33.06	33.40	33.50	28.90	21.50	18.20	25.50	28.00	27.30
pH	9.51	8.60	7.21	7.91	7.91	9.91	9.34	9.36	9.56	9.11	9.71	8.27	7.40	7.34	8.25
Ammonia (NH_3) (mg/L)	0.00	0.00	0.16	0.50	0.33	0.50	0.00	0.00	0.50	0.50	0.50	0.00	0.50	0.00	0.50
Nitrite (NO_2) (mg/L)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nitrate (NO_3) (mg/L)	0	0	0.50	0	0	0	0	0	0	0	0	0	10	50	0
Phosphorus (mg/L)	4.37	3.89	3.81	5.70	4.72	5.32	4.89	5.70	4.92	5.50	1.18	1.40	1.12	0.42	1.11
Turbidity (NTU)	24	44	17	22	84	18	35	44	48	45	59	11	0	5	27
Total Dissolved Solids (mg/L)	51.43	0	130.33	32.46	218.00	5.00	476.33	497	507.66	300	440	140	494	317	356
Salinity (ppm)	0.05	0.00	0.1	0.00	0.00	0.00	0.4	0.4	0.4	2.1	0.03	0.01	0.4	0.2	0.3

All parameters are in mg/L, except temperature (°C), turbidity (NTU), pH and salinity (ppm)

Table 8 Comparison of the results of the sites and laboratory are presented below as captured by the use of scoring card in five districts in the Limpopo Province

	Vhembe	Mopani			Sekhukhune	Capricorn			Waterberg	Suitable range	References
Parameters		Sampling sites				Sampling sites					
		1	2	3		1	2	3			
Dissolved oxygen (mg/L)	10.81 ± 4.625	0.81	10.19	8.44	17.44 ± 0.76	18.96	15.18	8.24	5.49 ± 2.08	5 - 15mg/L	DWAFF, 1996
Temperature (°C)	26.67 ± 13.85	26.60	31.83	22.75	33.32 ± 0.23	28.90	21.50	18.20	26.93 ± 1.29	25 - 32 ºC	Boyd, 1998
pH	8.44 ± 1.16	7.91	7.91	9.91	9.42 ± 0.12	9.11	9.71	8.27	7.66 ± 0.51	6.5 - 9.0	DWAFF, 1996
Ammonia (mg/L)	0	0.50	0.33	0.50	0.17 ± 0.29	0.50	0.50	0.50	0.33 ± 0.29	0 - 0.3 mg/L	DWAFF, 1996
Nitrite (mg/L)	0	0	0	0	0	0	0	0	0	0.02 - 0.25 mg/L	DWAFF, 1996
Nitrate (mg/L)	0.17 ± 0.29	0	0	0	0	0	0	0	20 ± 26.46	0.2 - 10 mg/L	Boyd, 1998
Phosphorus (mg/L)	4.02 ± 0.30	5.70	4.72	5.32	5.17 ± 0.46	5.50	1.18	1.40	0.91 ± 0.43	0.005 - 3.0 mg/L	Timmons & Ebeling, 2010
Turbidity (NTU)	28.33 ± 14.01	22	84	18	42.33 ± 6.66	45	59	11	10.67 ±14.36	30 - 40 NTU	Sahni & Yadav, 2012
Total Dissolved Solid (mg/L)	60.59 ± 65.65	32.46	218.00	5.00	493.66 ±15.93	300	440	140	389 ± 93	50 - 500 mg/L	Boyd, 1998
Salinity (ppm)	0.05 ±0.05	0.00	0.00	0.00	0.4±6.80	2.1	0.03	0.01	0.3 ± 0.1	0.5 - 1.0 ppm	Boyd and Rafferty, 1998

All parameters are in mg/L, except temperature (°C), turbidity (NTU), pH and salinity (ppm)

4.1 WATER QUALITY ANALYSIS RESULTS OF THE DISTRICTS IN THE LIMPOPO PROVINCE

4.1.1 Dissolved oxygen (DO)

Dissolved Oxygen (DO) is the measure of gaseous oxygen (O_2) dissolved in an aqueous solution. DO depends greatly on temperature; the higher the temperature, the lower the dissolved oxygen, and vice versa. The amount of DO in water is very important for aquatic organisms (Deekae *et al.*, 2010). The minimum safe level of DO in water is dependent on the temperature and to a certain extent the species (Boyd & Rafferty, undated). When taking measurements of dissolved oxygen from aquaculture ponds, it is important to note that readings will differ depending on the time of day, the amount of plant growth within the pond and the position in the pond from which the measurement is taken (Aquaculture SA, 2003).

The suitable range encourages the growth and survival of Mozambique tilapia, African catfish and Common carp as warm water fish species. According to Bhatnagar and Devi (2013), DO levels that are higher than 5 mg/L are essential to support adequate fish production, while DO levels that are less than 4 mg/L have sub-lethal effects on growth and feed utilization. Fish will survive at these levels, but they will grow slowly and will be sluggish. Bhatnagar and Devi (2013) also stated that DO levels that are greater than 14 mg/L are lethal to fish fry and gas bubble disease may occur.

African catfish and other air breathing fish can survive in low oxygen conditions (Santhosh & Singh, 2007). It has been reported that the African catfish can survive at DO levels of between 0 and 4 mg/L, because they are obligate air breathers (Danba *et al.*, 2015).

Low dissolved oxygen (DO) levels are responsible for more fish kills, either directly or indirectly, than all other problems combined (Aniebone *et al.*, 2017). In fish systems, low dissolved oxygen levels can become lethal to cultured fish species. Prolonged exposure to low concentrations of DO can be harmful to fish life, as fish will die at a level of 1 mg/L and their growth and feeding will decrease when levels are between 1-5 mg/L of DO. Growth and production is thus optimal when DO is more than 5 mg/L (Hossain *et al.*, 2007). DO concentrations that are less than 5 mg/L will result in fish experiencing stress, which can then lead to mortalities. DO concentrations above 15 mg/L can also lead to supersaturation and the outbreak of gas bubble trauma, which results from bubbles of gas forming in the blood (Boyd, 1998). Cloudy weather can influence dissolved oxygen concentrations, as it reduces the rate of photosynthesis through light penetration, however it has little or no effect on respiration (Boyd, 1998). The effect of weather (e.g. cloudy weather) is more prominent in water bodies with high levels of phytoplankton, in comparison to those with little or no phytoplankton (Boyd, 1998). Warm water fish can tolerate lower levels of dissolved oxygen better than cold water fish and the level should be maintained above 3.0 and 5.0 mg/L for warm water and cold water fish, respectively (Boyd & Rafferty, 1998).

Figure 4 shows the average dissolved oxygen (mg/L) per district. All of the measurements were within and above the recommended values of 5 – 15 mg/L. Warm water fish species in water with high DO levels may suffer from gas bubble disease (Boyd, 1998). This disease prevents the flow of blood through blood vessels, and signs include external bubbles that occur and can be seen on the fins, skin and on other tissues. Gas trauma bubble disease ultimately causes death (Boyd, 1998). Overhanging tree branches and vegetation need to be pruned or removed from the vicinity of ponds. Feed management, aeration and lime application is required in order to balance DO levels in fish growing systems, more particularly in earthen ponds, so as to maximize fish production at districts that recorded higher values of DO.

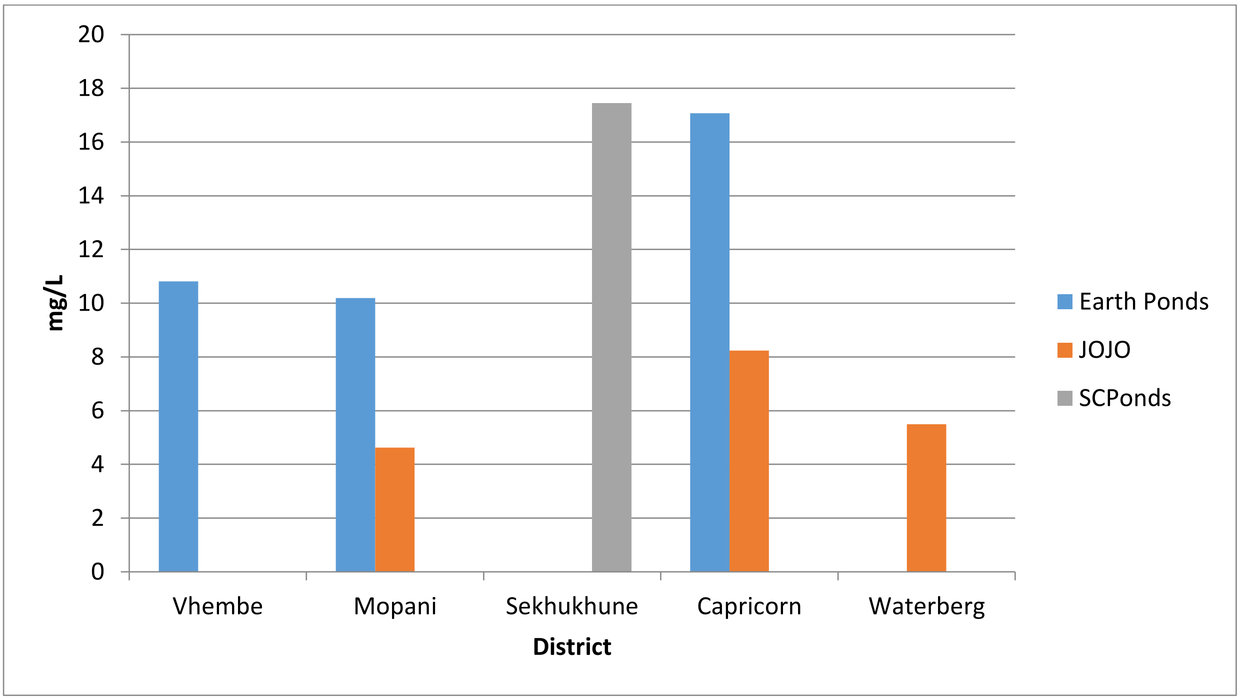

Figure 4 The average dissolved oxygen (DO) (mg/L) per district

Three water sampling sites in each district were analysed and the results observed have shown different values. The average DO concentration values of surface water in earthen and stagnant concrete ponds from all three water sampling sites ranges between 6.18 - 15.43 mg/L with a mean values of 10.81 ± 4.63 as depicted in Table 8 in the Vhembe district. These values are within the suitable range of 5 -15 mg/L as recommended by DWAFF (1996). Figure 5 shows a fish farmer feeding tilapia in a stagnant concrete pond in the Vhembe district and Figure 6 is a photo of surface water in an earthen pond in the Vhembe district.

Figure 5 Fish farmer feeding tilapia fish in a stagnant concrete pond in Vhembe district

Figure 6 Stagnant surface water in earthen pond in Vhembe district

In the Mopani district, the DO value for surface water in an earthen pond was 10.19 mg/L, while underground water stored in Jojo tanks showed values that ranged between 0.81 and 8.44 mg/L. The DO level for underground water at sampling site 1 was recorded as 0.81 mg/L, which was the lowest recorded DO value, and might have been attributed to the fact that the Jojo tank was under a tree. Figure 7 shows the farmer removing plastics from earthen pond in the Mopani district.

Figure 7 The farmer removing plastics from earthen pond in the Mopani district

The DO levels for surface water in stagnant concrete ponds in the Sekhukhune district had recorded values of between 16.57 and 17.93 mg/L with a mean value of 17.44 ± 0.76 mg/L. These values are above the suitable ranges and are thus unsuitable for fish culture. These high values might have been attributed to small pond sizes. The ponds were also used as a swimming pool with overhanging trees, which means the ponds were not exposed to sunrays for a large part of the day, as seen in Figure 8.

Figure 8 Surface water in stagnant concrete pond in Sekhukhune district

The DO results of sampling sites 2 and 3 of the Capricorn district, showed recorded values of 8.24 and 15.18 mg/L, which fall within the range as recommended by DWAFF (1996); whereas sampling site 1 had a recorded DO value of 18.96 mg/L which is above the recommended value. This value is not suitable for fish culture.

The underground water stored in Jojo tanks in the Waterberg district had recorded DO values ranging between 3.10 and 6.88 mg/L with a mean value of 5.49 ± 2.08 mg/L, which are within the suitable range as recommended by DWAFF (1996).

4.1.2 Temperature

Temperature can be defined as the degree of hotness or coldness in the body of living organisms either in water or on land (Deekae *et al.*, 2010).Temperature has an influence on all biological and chemical processes in an aquaculture operation. Fish are cold blooded animals, so their temperature is dependent on the temperature of their environment and thus changes with the temperature of their surroundings. Fish adjust their body temperature and metabolic rate by moving into cooler or warmer water layers within the pond. Each species has its own suitable temperature at which it grows best, and growth rates are reduced when the temperature is above or below the suitable level. At extreme temperatures mortalities can occur (Boyd & Rafferty, 1998). It affects cultured biomass in various ways, such as behaviour, feeding and breathing. Higher temperatures are lethal to fish and also influence the DO concentration.

Warm water fish species grow best at temperatures between 25 and 32°C (Boyd, 1993). Temperatures of the surface water in earthen ponds and stagnant concrete ponds in the two districts, Vhembe and Sekhukhune, had recorded averages of 26.67 and 33.32°C, respectively, as depicted in Table 8. These values are higher than the suitable range of 25 – 32°C as recommended by Boyd (1998). It is possible that these temperatures were higher due to fact that there were no trees overhanging these ponds.

Each fish species has a comfort zone in which it shows the most potential in terms of growth, feeding, reproduction, and market size within specific production cycles. For example, carp (*Cyprinus carpio*) are more comfortable when the water temperature is between 2 and 11°C. Water temperatures that are between 18 and 23°C are still suitable for egg incubation and the larval development of carp; whereas for *Oreochromis mossambicus and Clarias gariepinus,* suitable water temperature ranges for egg incubation and larval development are 27 - 30°C and 24 - 28°C, respectively.

Water temperatures that are above the range 32 - 45°C are regarded as the upper lethal temperature range for all warm water fish under discussion.

Tilapia is a warm water fish with optimal temperatures in the range of 24 - 32°C. Their growth rate declines rapidly at temperatures below 20°C with little or no growth at temperatures below 15°C (Stander, undated). Tilapia is more susceptible to diseases at these temperatures and death can be expected at temperatures of 11°C and below. According to DEEDI (2012), *O. mossambicus* has been found to survive temperatures as low as 11°C in brackish waters in South Africa. According to Danba *et al.* (2015), the best temperature range for the optimum production of *Clarias gariepinus* is 25 - 35°C. Figure 9 shows the average water temperatures by district.

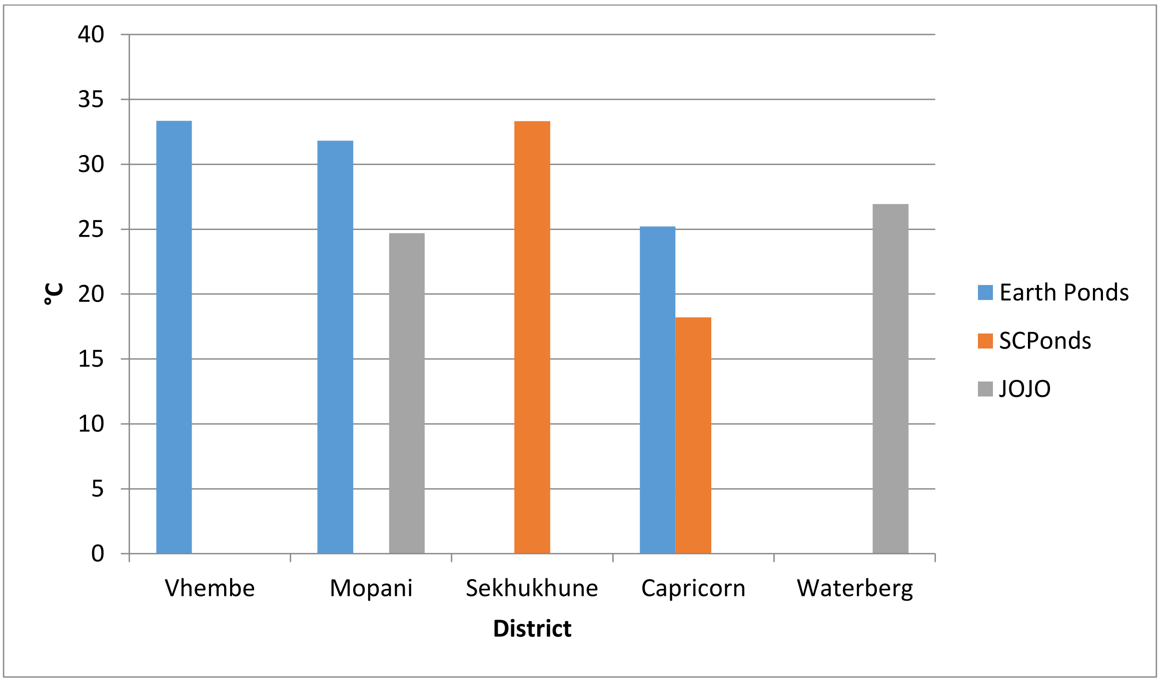

Figure 9 The average water temperatures (°C) by district

The temperature of surface and underground water was taken for earthen ponds, stagnant concrete ponds and water stored in Jojo tanks at 3 sampling sites in five districts in the Limpopo Province. The recorded values ranged between 30.73 and 33.80°C with a mean of 26.67 ± 13.85°C for the Vhembe district; temperatures ranged between 22.75 - 31.83°C for the Mopani district; a mean temperature of 33.32 ± 0.23°C was calculated for the Sekhukhune district; a range of 18.20 - 28.90°C was seen for the Capricorn district; and lastly a mean temperature of 26.93 ± 1.29°C was observed for the Waterberg district. The values recorded were very much close to the suitable temperature as recommended by DWAFF (1996). This means that the temperatures recorded are suitable for Mozambique tilapia, African catfish and common carp.

Fish farmers need to test water temperatures in the production systems on a daily basis. Bhatnagar and Devi (2013) recommend water exchange, and/or the planting of shady trees or making artificial shades during summer, while also avoiding over-shading, so as to generate suitable DO levels and temperatures in ponds. Mechanical aeration can also help to prevent excessive thermal stratification. These remedial actions are necessary in order to normalize temperatures for maximal fish production.

4.1.3 Water pH

The pH of soil is one of the most important factors for maintaining pond productivity, since it controls most of the chemical reactions in the pond environment (Adhikari, 2003). The concentration of bases and acids in the water determines the pH; where a low pH is acidic, a pH of 7 is neutral, and a high pH is basic (Buttner *et al.*, 1993). Fish grow best when the pH of water is between 6.5 and 9 and mortalities can occur at levels below 4.5 and higher than 9.0 (Boyd & Rafferty, 1998). The lowest pH of the water source is typically associated with the lowest level of dissolved oxygen; while the highest pH is typically associated with the highest level of dissolved oxygen

(Buttner *et al.*, 1993). If the pH readings are outside this range, fish growth is reduced, and at values below 4.5 or above 10, mortalities occur. The water pH affects metabolism and physiological processes of fish and also exerts considerable influence on the toxicity of ammonia (Keremah *et al.*, 2014). Optimum temperature conditions will depend on the species of fish that is cultured and these conditions will need to be met so as to ensure optimal growth and reproductive success (Aquaculture SA, 2003). Figure 10 shows the average pH values by district.

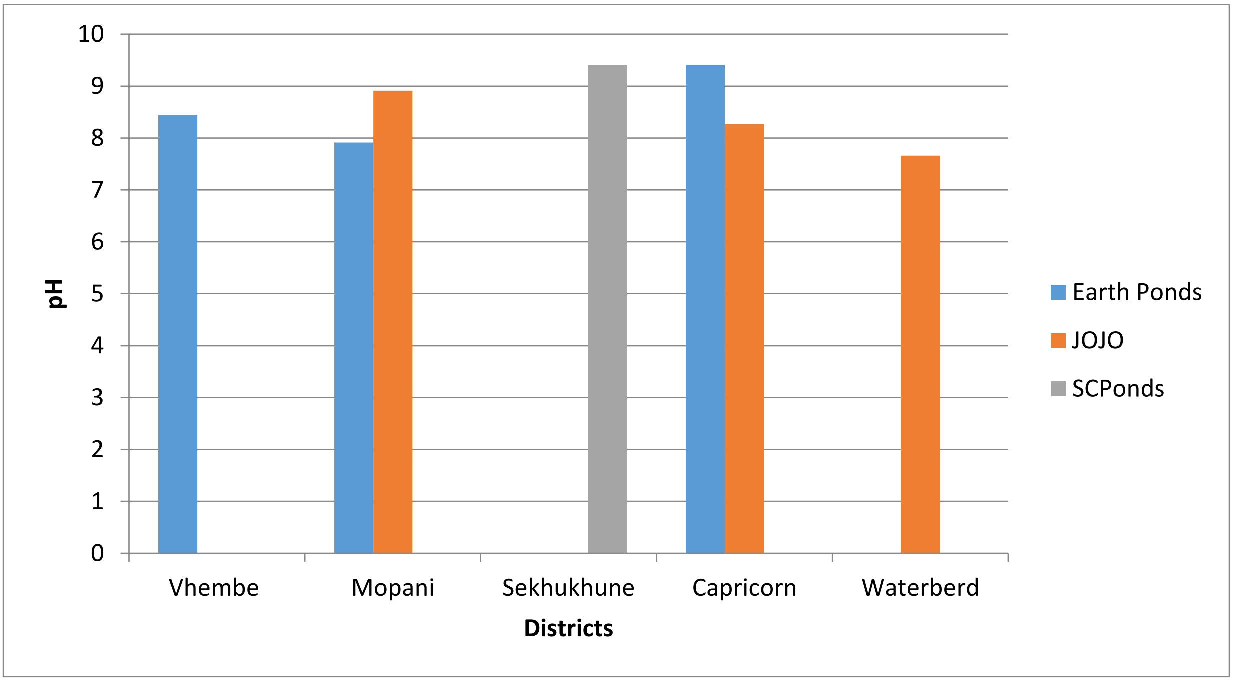

Figure 10 The average pH values by district

The pH of the surface water in earthen ponds, stagnant concrete ponds, and groundwater stored in Jojo tanks was analysed and the recorded mean value for the Vhembe district was 8.44 ± 1.16; for the Mopani district pH values were between 9.91 and 7.91; the mean value for the Sekhukhune district was 9.42 ± 0.12; the Capricorn district had pH values between 8.27 and 9.71; and the Waterberg district had a mean pH value of 7.66 ± 0.51. These values were all close to the suitable pH range as recommended by DWAFF (1996). According to Swingle (1969), a pH range of 6.5 to

9.0 is suitable for warm water pond fish, but values below this range result in slow growth and then death. When the pH rises over 10, the gills and eyes (lens and cornea) of the fish are destroyed and as a result the fish become weak and infected with parasites (Hossain *et al.*, 2007).

Santhosh and Singh (2007) also indicated that pH levels that are above and below suitable or optimal levels create stressful environments for fish. The toxic effects of having a pH above and below this range, generally arises from the disturbance in internal ion homeostasis, i.e. from the persistent decline in plasma concentrations of sodium and chlorine ions (DWAFF, 1996). When the water pH is very high, the application of rock salt at a concentration of 5 g, will reduce osmotic stress as well as mitigate the effects of excretory toxins such as ammonia. In cases of acid damage to the gills, chemotherapeutic treatment may need to be considered, because acid stress reduces immune responses (DWAFF, 1996).

A low water pH increases the toxicity of hydrogen sulphide (H_2S), copper and other heavy metals, which then makes fish prone to the attack of parasites and diseases in these acidic waters (Hossain *et al.*, 2007). Ground and surface water bodies with pH values above or below the suitable range, require intervention in terms of application of gypsum ($CaSO_4$) or organic manure, and the use of quicklime (CaO), to rectify low pH values in aquatic systems (Bhatnagar & Devi, 2013). Good water management is important in promoting optimal fish heath and production.

4.1.4 Ammonia (NH_3)

Fish excrete ammonia and a lesser amount of urea into the water as waste, and nitrates are produced when the ammonia is broken down by bacteria in the presence of oxygen (Swann, 1992). If this ammonia is not broken down, it becomes very toxic to the fish. Ammonia is a nutrient parameter in water and is a dissolved gas occurring naturally in surface waters, wastewaters, and in some well waters. It is the major nitrogenous waste product of fish and also results from the decomposition of organic matter. Ammonia is soluble in water, especially at a low pH and ordinarily is removed by plants or bacteria. Temperature and pH cause the proportion of total ammonia nitrogen (TAN) (ionized and un-ionized) to vary (Boyd & Rafferty, 1998).

There are two forms of ammonia that occur in aquaculture systems, an ionized and an un-ionized form. The un-ionized form is extremely toxic to fish; while ionized ammonia is not. Both forms are grouped together as total ammonia nitrogen (Swann, 1992). Ammonia occurs in the un-ionized form and becomes toxic when the pH is high. Un-ionized ammonia levels rise as temperature and pH increase. The toxicity levels for un-ionised ammonia depend on individual species (Swann, 1992; 1993). Un-ionized ammonia is introduced into the water through dead phytoplankton, uneaten feed, and dead and decaying organic matter (Keremah *et al.*, 2014). Aquaculture SA (2003) indicated that high levels of ammonia can occur in fish growing media due to high stocking densities, overfeeding (which is especially common during winter), high productivity, and dead plant and animal matter.

It is obvious that uneaten feed seriously impacts the water environment and higher stocking densities also result in the accumulation of faeces; more often in re-circulated fish growing systems. Ammonia is the main residual compound, as a result of the metabolic activity of fish in the water (Coadã *et al.*, 2011). High ammonia concentrations in the water affect the health of the fish and it can also result in poor breeding, mucous hypersecretion, and gill inflammation and bleeding (Coadã *et al.*, 2011).

Ammonia (NH_3) → Nitrites (NO_2) → Nitrate (NO_3)

Nitrosomonas sp. *Nitrobactor* sp. (Swann, 1992)

Water analysis conducted for underground water in earthen ponds, surface water in stagnant concrete ponds, and water stored in Jojo tanks, showed different values of ammonia. These values were, however, suitable for the identified fish species as shown in Figure 11 which shows the average ammonia levels (mg/L by district). Water samples that were collected and analysed in most of the districts had ammonia levels that were suitable for warm water fish species, as they fell within the suitable range of 0.0 - 0.3 mg/L as recommended by DWAFF (1996). The highest ammonia value for the Vhembe district was 0.16 mg/L for surface water in a stagnant concrete pond, while the average value recorded for the two sites with water stored in Jojo tanks in the Mopani district was 0.50 mg/L. Figure 11 shows the average ammonia (mg/L) values by district for different water sources.

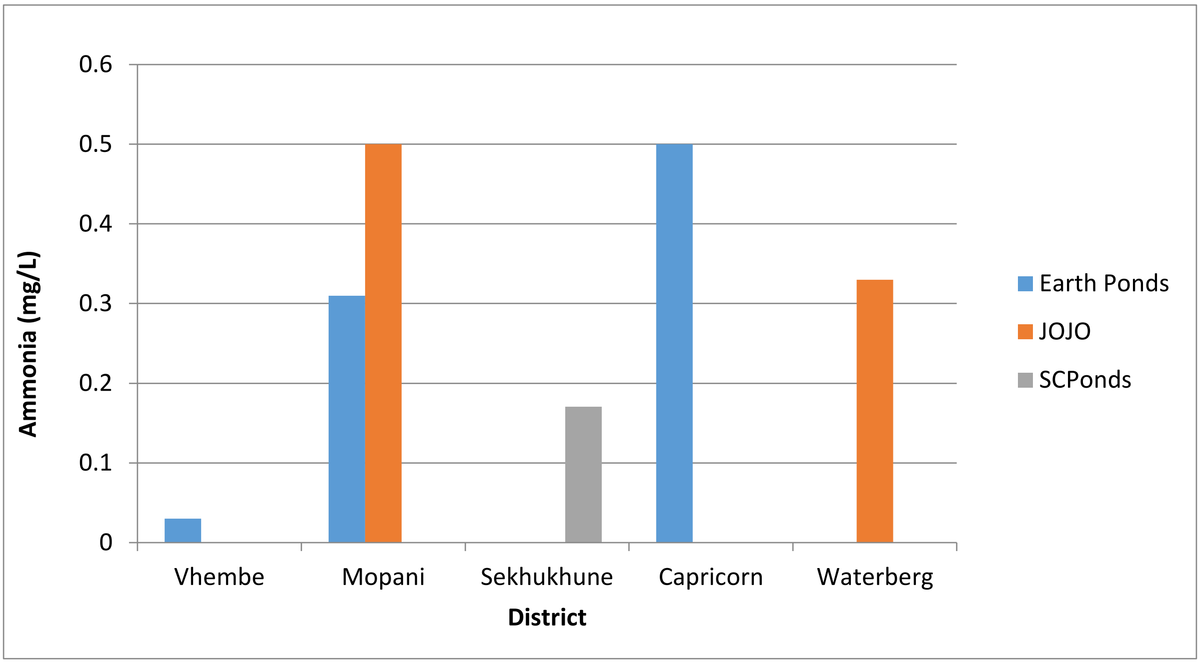

Figure 11 The average ammonia (mg/L) values by district for different water sources

Surface water and underground water in earthen ponds, stagnant concrete ponds and water stored in Jojo tanks had high recorded ammonia levels from all sampling sites analysed in four districts. These levels are not suitable for the warm water fishes under discussion with the exception of sampling site 1 in the Vhembe district, which had a recorded ammonia level of 0 mg/L. The slightly high values of ammonia could be linked to overfeeding and uneaten feed which decomposes, releasing nutrients into the water. Fish faeces in small stagnant concrete ponds and water in the tanks have never been exposed to the outside environment in all five districts. Toxic un-ionized ammonia which is above optimum levels can influence susceptibility to non-infectious diseases (Ngueku, 2013). Feed fed to aquaculture species results in pollution of pond waters by organic and inorganic metabolic wastes (Boyd, 1998; Islam *et al*., 2013).

Fish species start experiencing sub-lethal effects when ammonia concentrations are above 0.3 mg/L as it affects larvae development, reduces the growth and also damage the gills of the adult Mozambique tilapia, African catfish and common carp. Fish release CO_2 through their skin and gills and this activity is hampered if the amount of this gas is higher in the water (Hossain *et al.*, 2007).

It is recommended that fish farmers check the ammonia levels of ground and surface water in earthen and stagnant concrete ponds on a daily basis, in order to detect the level of ammonia and try to come up with mitigation methods to avoid fish mortalities due to toxicities. Fishery projects should not be next to vicinities where insecticides, herbicides or other chemicals are used and agricultural runoff should be prevented from entering the ponds, so as to reduce or avoid excessive ammonia levels. It is also important to avoid too high stocking densities, as more fish means more excrement, which results in ammonia accumulation which can be directly related to the feeding rate and protein level of the feed. The harvesting of fish reduces the number of fish in the growing media. Fish farmers should allow the development of small quantities of algae to grow in the media, as algae can help to reduce ammonia levels through a nitrification process, where ammonia undergoes an oxidization process. Farmers should, however, take note of salinity level when algae is abundant in the pond.

Other ways to reduce ammonia levels include; reduced feeding rates, aeration of water, addition of lime, the fertilization of ponds with phosphorus to increase phytoplankton in order to serve as sinks for ammonia, reduce the stocking density, reduce the pH level, flush the pond with well water and increase pond depth (Hargreaves & Tucker, 2004). When water from the Jojo tanks is used, it should be exposed to direct sunlight for de-gassing or aeration. Daily checks of ammonia levels is of paramount importance as it assists in identifying problems earlier.

Bhatnagar and Devi (2013) recommended that pond aeration, the application of hydrated lime or quick lime, formaldehyde and zeolite treatment, and regular water exchange will reduce or dilute the ammonia content in ponds.

4.1.5 Nitrite (NO_2)

Nitrite is an intermediate product of inorganic oxidation and of the bacterially mediated processes, nitrification and denitrification, which involves the transformation of nitrogen in soil and water (DWAFF, 1996). Nitrites are toxic products for aquatic organisms and the excessive accumulation of nitrites can delay growth and decrease resistance to disease (Coadă *et al.*, 2011). Nitrites are more likely to be detected in fish culture systems than nitrates and they are usually the result of inefficient nitrification in systems with high nitrogen loading rates, which can come from feed protein and high stocking densities (DWAFF, 1996).

Underground water, surface water and water stored in Jojo tanks were analysed and all showed readings of 0 mg/L nitrite content, which was lower than the suitable range of 0.06 – 0.25 mg/L as recommended by DWAFF (1996) in all five districts. This meant that all of these warm water fish species will be saved from dangerous nitrite levels. According to Bhatnagar and Devi (2013), nitrite levels that are above the suitable range are lethal for many warm water fish species. Even though the underground water, surface water in earthen and stagnant concrete ponds, and underground water stored in Jojo tanks, were free from toxic nitrite, continuous analysis will still be required to monitor ammonia levels and to prevent mortalities of fish, so as to increase production.

According to Bhatnagar and Devi (2013), nitrite levels above the suitable range require management mitigations, such as the reduction of stocking densities, improve and/or restrict feeding, biological filtration, general husbandry procedures, the increase of aeration to a maximum, the addition of small amounts of chloride salts, regular water exchanges, and the use of bio-fertilizers to accelerate nitrification.

4.1.6 Nitrate (NO_3)

Nitrate (NO_3) is the major form of nitrogen found in natural waters (Deekae *et al.*, 2010). It is formed through a nitrification process, i.e. the oxidation of NO_2 to NO_3 by the action of aerobic bacteria (Devi *et al.*, 2017). It is an essential nutrient, but also a good indicator of contamination from natural and human activities (Kiran, 2010). The sources of nitrates in water include human and animal waste, the weathering of igneous and volcanic rocks, and oxidation of vegetable and animal debris (Deekae *et al.*, 2010). It is found in an ionized form, which is non-toxic, except at extremely high levels and is predominantly found in water with a low pH (Sallenave, 2012). Fish can tolerate nitrate levels to several hundred mg/L (Boyd & Rafferty, 1998).

Results obtained showed that with the exception of values recorded in the Vhembe and Waterberg districts, nitrate levels in other municipalities were 0.0 mg/L, which was less than the recommended suitable ranges as recommended by Boyd (1998). For the Vhembe district, surface water in earthen ponds had a recorded nitrate value of 0.50 mg/L, which was still within the suitable range of 2–10 mg/L as recommended by Boyd (1998). In the Waterberg district, nitrate levels for underground water stored in Jojo tanks at sampling site 2 was 50 mg/L, which was the highest value and did not fall within the suitable range as recommended by Boyd (1998). This high value may have been attributed to the fact that this underground water (of bore-hole origins) was located in the vicinity of livestock kept in a kraal. Fertilizers that are applied to crop fields may have also seeped into wells in this area.

According to Stone and Thomforde (2004) nitrate is relatively non-toxic to fish and will not cause any health hazards, except at exceedingly high levels that are above 90 mg/L. Nitrate is relatively non-toxic to tilapia, however, prolonged exposure to elevated levels may decrease immune response and induce mortality (Khattaby, 2015). In cases where nitrate levels are above the recommended 10 mg/L limit for warm water fish species (Boyd, 1998), management mitigations, such as using ion exchange materials, increasing plant density and the use of denitrifying biological filtration, may aid in reducing nitrate concentrations (Bhatnagar & Devi, 2013). Water treatment is required to improve water quality parameters with reference to certain low and high readings, as they have potential effects on the health and productivity of animals in aquaculture systems. Good quality water is necessary to make underground and surface water suitable for aquaculture and continuous monitoring of all parameters is essential for aquaculture development. Due to the low nitrate levels in underground and surface water in earthen ponds, stagnant ponds and water stored in Jojo tanks, results were not depicted in the form of a graph.

4.1.7 Phosphorus

Phosphorus is present in natural waters either as orthophosphate or as undifferentiated organic phosphate (Deekae *et al.*, 2010). This is the main nutrient used by algae. It is an essential nutrient present in soil and water in inorganic and organic forms (Kiran, 2010). It can be introduced into the water through fertilizers, which can often stimulate phytoplankton blooms, enhance the abundance of natural food organisms, and promote aquaculture production (Boyd, 1998). Phosphorus is present in water in the form of phosphate (PO_4). Phosphates are absorbed by aquatic plants and algae and constitute an integral part of their body component (Deekae *et al.*, 2010). Phosphorus can stimulate plant and algae growth which enhances eutrophication and can result in the prevention of light. Figure 12 shows the average phosphorus levels by district.

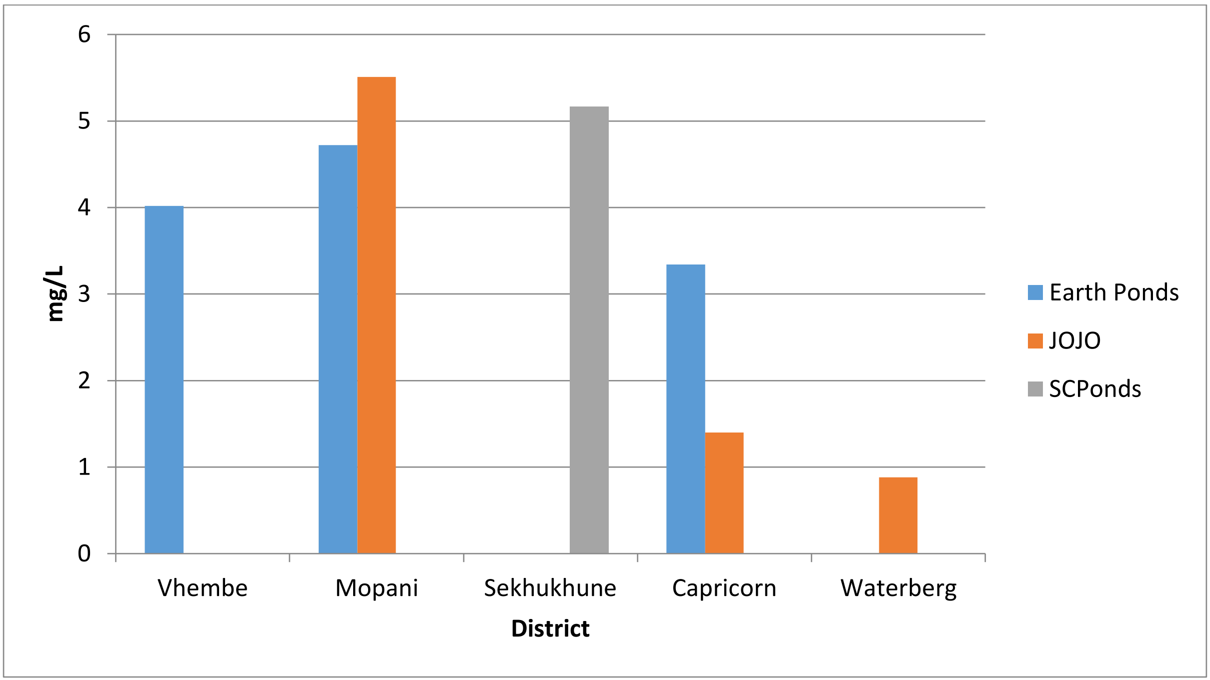

Figure 12 The average phosphorus (mg/L) by district

Underground water in earthen and stagnant concrete ponds and underground water stored in Jojo tanks samples were analysed for phosphorus content and had recorded values that were mostly higher than the suitable range of 0.005 – 3.0 mg/L, as recommended by Timmons and Ebeling (2010) in the Vhembe, Mopani and Sekhukhune districts as shown by Figure 12. Exceptions were for underground water stored in Jojo tanks from sampling sites 2 and 3 in the Capricorn district which had phosphorus readings of 1.18 and 1.40 mg/L, respectively; and underground water stored in Jojo tanks for the Waterberg district, which had a mean value of 0.91 ± 0.431 mg/L.

The high values may have been due to the over feeding of fish, which resulted in more feed that remained unconsumed and thus led to the build-up of high nutrient levels, which encourages the development of plankton. Other possible reasons may include the fact that these sampling sites were located within the vicinity of heavily dense trees, and/or fertilizers and manure from the crop fields and kraals were leaching into the water supplies. The stagnant concrete pond only received sunlight in the afternoon and a large part of the day the pond received less or no sunlight, due to fruit trees in the vicinity of the pond. Fertilizers and kraal manure from the crop fields and livestock might have also been the contributing factors.

Phosphorus levels that are above the suitable range may have been attributed to organic waste effluent, and contamination of fish flesh by heavy metals and bacteria, such as *E. coli*, and should be considered (DWAFF, 1996). According to Stone and Thomforde (2004), 0.06 mg/L is a desirable phosphate level for fish culture. Higher values of phosphorus in the water could lead to eutrophication (Agbaire *et al.*, 2015). High phosphorus concentrations can result in osmotic stress in warm water fish species.

Farmers should continue monitoring the concentration of phosphorus in surface and ground water bodies in earthen and stagnant ponds by feeding fish *ad libitum*, so as to prevent the accumulation of uneaten feed in the ponds. Underground water stored in Jojo tanks, which will be used for aquaculture, have high phosphorus levels and thus require mechanisms that will reduce these concentrations.

4.1.8 Turbidity

Turbidity is a measure of the ability of water to transmit light. If turbidity is high, there is restricted light penetration and limited photosynthesis. Water turbidity in freshwater ponds is caused by phytoplankton and zooplankton (microscopic plants and animals), and also by suspended solids, such as clay and silt particles, in the water column. Turbidity is important as it determines the amount of light penetration that occurs in the water column of a pond (Aquaculture SA, 2003). High turbidity of water can decrease fish productivity, as it reduces light penetration into the water and thus oxygen production by the water plants (Ezeanya *et al.*, 2015). Turbidity is estimated based on the amount of light that is adsorbed when taking a water sample (Boyd, 1998). In aquaculture ponds, turbidity which results from planktonic organisms is a desirable trait, whereas turbidity caused by suspended clay particles is undesirable (Boyd, 1998). Turbidity restricts light penetration, limits photosynthesis and can produce undesirable macrophytes in ponds (Boyd, 1998; Keremah *et al.*, 2012). Materials that cause water to be turbid include clay, silt, finely divided organic and inorganic matter, soluble coloured organic compounds, plankton and microscopic organisms (Yap *et al.*, 2011). Ponds with high turbidity have shallow light penetration which lowers the temperature as well as photosynthetic activity and decreases the amounts of algae growing on the bottom of ponds. Figure 13 shows the average turbidity by district.

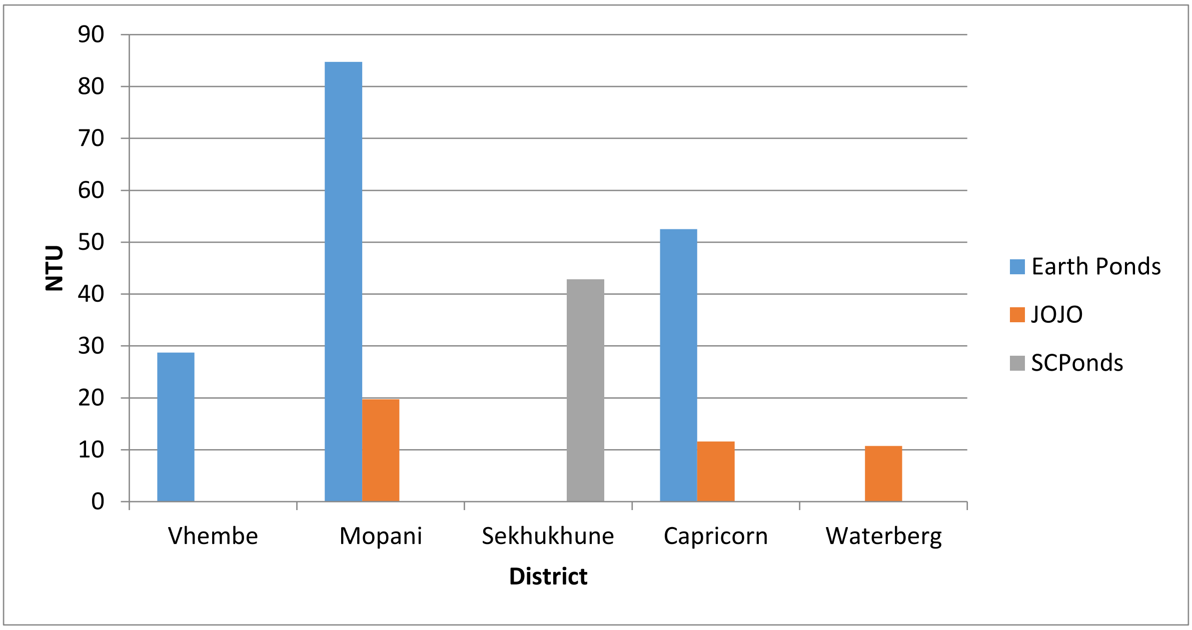

Figure 13 The average turbidity (NTU) by district

Samples of surface and underground water in earthen and stagnant concrete ponds and stored in Jojo tanks, from sampling sites 1, 2 and 3, have been analysed for turbidity. In the Vhembe district results showed values of 24.44 and 17 NTU, with a mean of 28.33 ± 14.01 NTU; in the Mopani district, turbidity values were 22, 84 and 18 NTU; in the Sekhukhune district, turbidity values were 35, 44 and 48 NTU, with a mean of 42.33 ± 6.66 NTU; in the Capricorn district, turbidity values were 45 , 59 and 11 NTU; and in in the Waterberg district, readings were 0,5 and 27 NTU with a mean of 10.67 ± 14.36 NTU. Water samples that showed high turbidity readings were from the sampling site 2 in the Mopani district; site 3 in the Sekhukhune district and site 2 in the Capricorn district; having values of 84, 48 and 59 NTU, respectively. These values were above the suitable range (30 - 40 NTU) as recommended by Sahni and Yadav (2012).

According to Bhatnagar and Devi (2013), high turbidity reduces plankton development and causes fish to be stressed. It was supported by Ezeanya *et al.* (2015), that high turbidity can decrease fish productivity, as it will reduce light penetration into the water and thus oxygen production by the water plants. It was also stated by DWAFF (1996) that high water turbidity will affect vision, feeding, breeding behaviour, cause smothering, clog filters, and damage fish gills, eggs and larvae, due to higher oxygen demands. The high suspended solids sedimentation may be as a result of excess excreta by fish and high amounts of excess uneaten feed in the pond water and that may interfere with fish finding feed and may also damage the gills of fish (Danba *et al.*, 2015).

Water in earthen and stagnant concrete ponds with high total suspended solids often means higher concentration of bacteria, nutrients, pesticides and metals in water, which are major factors affecting transparency (Danba, 2015). Removing metals and plastics from ponds could thus be a possible solution, as depicted in Figure 7.

According to Santhosh and Singh (2007), in order to continue using water with high turbidity, agricultural limestone can be added at the recommended rates, so as to reduce turbidity and improve pH and water alkalinity. A reduction in the number of common carp fish species in polyculture system may also help, as these fish stir up mud at the bottom of ponds and can thus increase turbidity. Reducing phytoplankton density in the ponds may also be a solution, as their presence in ponds reduces sunlight penetration.

Low turbidity values that were seen for some of the sampling sites, may have been due to mud particles settling down at the bottom of the Jojo tanks before being used for fish production. Turbidity may also be lower where fish farmers do not provide supplemental feeding and where ponds do not have bottom feeders, such as carp, that stir up the water. There are mining companies not far from the existing farm, which release lots of pollutants that sink down into the underground water, thereby making the water unusable unless treated. This is the main reason that water flows first into a siltation reservoir tank, until the mud has settled on the bottom, before crops are irrigated, as this farm is currently used for crop production in the Waterberg district.

The same farm has identified a plot of land that will be used for aquaculture development and in order to improve the muddy water, it has planned to treat the water before using it for pond aquaculture.

The general recommendations for reducing high turbidity levels in water bodies can include the following:

- Farmers should scoop foreign materials from their ponds during the production stage in order to remove materials that could prevent light penetration as demonstrated by a farmer in Figure 7.
- Fertilize the pond at recommended rates prior to stocking, check the visibility frequently during the culture period, and take necessary actions before problems arise.
- With regards to water with low visibility, physically remove excess plankton; while if the visibility is high, apply additional fertilizer (Ngugi *et al.,* 2007).

4.1.9 Total dissolved solids (TDS)

Total dissolved solids refer to any minerals, salts, metals, cations or anions that are dissolved in water, and includes anything present in water other than the pure water (H_2O) molecule and suspended solids (Chowdhury *et al.*, 2012). It is related to factors such as the geological watershed pattern, rainfall, and the amount of surface runoffs, and is an indication of the load of dissolved substances (Agbaire *et al*., 2015).This parameter is represented in three ways, i.e. as total dissolved solids, salinity or as conductivity. TDS and salinity are both measures of the mass of solutes in water, but differ in the components they measure (DWAFF, 1996).

TDS is the mass of dissolved inorganic and organic compounds in water, whereas salinity measures only the dissolved inorganic content (DWAFF, 1996). A constant level of minerals is necessary for aquatic life.

Surface water in stagnant concrete ponds, underground water and water stored in Jojo tanks showed different TDS values in all five districts, however they all fell within the suitable range of 50 – 500 mg/L, which is suitable for warm water fish species as recommended by Boyd (1998). If the total dissolved solids exceed the suitable standards, then water needs to be treated with chemicals to reduce the quantity of dissolved solids, before it can be used as a source of water for fish farming (Ezeanya *et al.*, 2015). Figure 14 shows the average TDS by district.

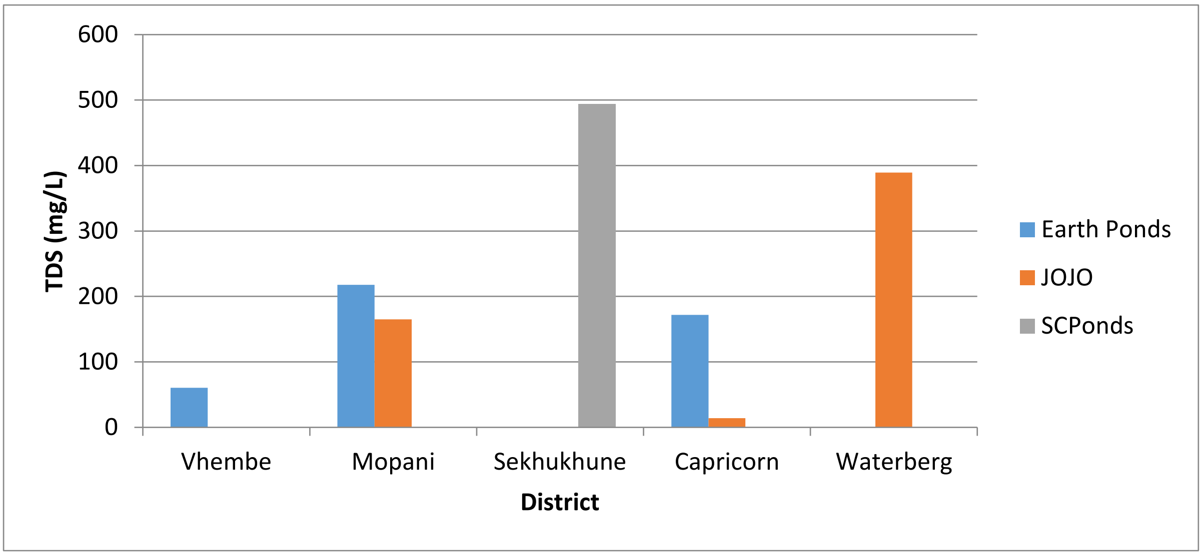

Figure 14 The average TDS (mg/L) by district

For the Vhembe district water samples had TDS readings of 51.43, 0.00 and 130.33 mg/L with a mean value of 60.59 ± 65.65 mg/L; in the Mopani district, TDS readings were 32.46, 218.00 and 5.00 mg/L; in the Sekhukhune district, readings were 476.33, 497.00 and 507.66 mg/L, with a mean value of 493.66 ± 15.93 mg/L; in the Capricorn district readings were 300, 440 and 140 mg/L; and in the Waterberg district, readings were 494, 317 and 356 mg/L, with a mean value of 389 ± 93 mg/L. Sampling site 2 in the Vhembe district and sampling site 3 in the Mopani district had the lowest recorded TDS readings of 0 and 5.00 mg/L, which are unsuitable for warm water fish species; however, the water samples in the other districts was all suitable for the candidate fish species. When water sources with higher TDS values are used, they should first be treated in order to reduce the quantity of dissolved solids to the suitable range for fish farming. The addition of rock salt to water, up to a concentration of 2 g, has been shown to have a beneficial effect on the health of fish, and promotes recovery from the toxic effects of certain water quality constituents, such as metabolites (ammonia and nitrite), low dissolved oxygen and hydrogen sulphide (DWAFF, 1996).

4.1.10 Salinity (ppm)

Salinity is the total concentration of all dissolved ions (Boyd, 1998). Deekae *et al.* (2010) defined salinity as the total concentration of dissolved ions in the water which is measured in ppm. Salinity is an ecological factor of considerable importance, as it influences the types of organisms that live in a body of water. It plays an important role in the growth of cultured organisms through the process of osmoregulation, which regulates body minerals in relation to the surrounding water. Salinity influences the concentration of un-ionized ammonia (Boyd & Rafferty, 1998).

Some warm water fish species have wide salinity tolerance limits and it has been noted that some fresh water fish grow faster in slightly saline water, while some brackish water fish grow faster in fresh water, however still they have their limits of tolerance. Even if they do survive outside these limits, their growth and reproduction may be affected (Chaudhari, 2003).

The Capricorn district had the highest level of salinity for underground water in comparison to all other districts, as it had a recorded average value of 2 ppm. This value was above the suitable level required for warm water fish species, which is 0.5 – 1.0 ppm. High salinity concentrations can be associated with the fungal and bacterial density of phytoplankton populations in the underground water used in earthen ponds. Based on the criteria for salinity, this underground water is thus not suitable as a source of water for the farming of warm water fish species, unless remedial actions of water exchange and aeration are done (Bhatnagar & Devi, 2013).

When high salinity levels occur, fresh warm water fish species lose water to the environment, as freshwater fish are not physiologically adapted for osmoregulation within a saline water source. Decreased growth and mortalities can occur under these conditions (Aquaculture SA, 2003). Salinity tolerances will vary amongst species; therefore it is important to choose an aquaculture species that is best suited to the salinity of the water source. In tropical locations the salinity of the pond decreases during the rainy season due to heavy inflow of freshwater; while during the dry season the salinity level of the pond water is high as a result of low inflow of freshwater (Kpadeh, 2011). During the rearing process, the introduction of feed and fertilizers may increase the salinity of the water (Kpadeh, 2011). Figure 15 shows the average salinity by district.

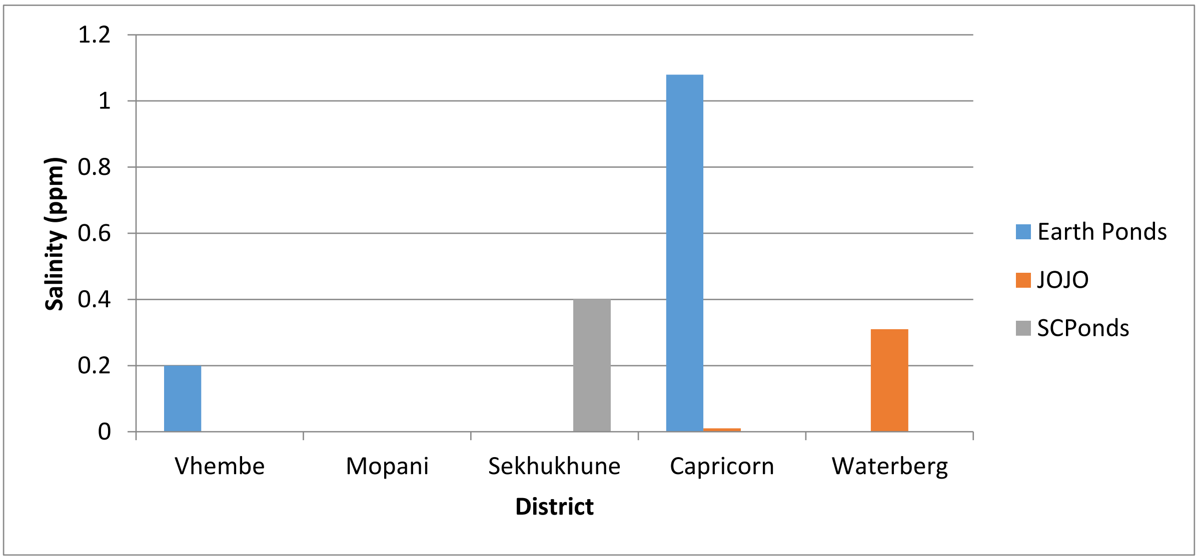

Figure 15 The average salinity (ppm) by district

Sampling sites of underground and surface water in earthen, stagnant concrete ponds and underground water stored in Jojo tanks were analysed and the results recorded.

For the Vhembe district, salinity readings were 0.05, 0.00 and 0.1 ppm, with a mean value of 0.05 ± 0.05 ppm; in the Mopani district, the salinity was 0.00 mg/L for all three sampling sites; in the Sekhukhune district, salinity readings were 0.4 mg/L for all three sampling sites, with a mean value of 0.4 ± 6.80 mg/L; in the Capricorn district, salinity readings were 2.1, 0.03 and 0,01 ppm with an average of 0.4 mg/L; and in the Waterberg district, salinity readings were 0.2 and 0.3 ppm with a mean value of 0.3 ± 0.1 mg/L. All sample sites had readings that were within the suitable range as recommended by Boyd and Raffety (1998), except for sample site 1 (2.1 ppm) in the Capricorn district which was above the suitable range as depicted in Figure 15. This high reading may have been associated with the location of the ponds i.e. at valleys and not far from the livestock kraals. According to Dinesh *et al.* (2017), high salinity concentrations can be associated with the fungi and bacteria density of phytoplankton populations. Often, salinity limits also vary from species to species.

The remedial action for underground water with high salinity levels may include water exchange and to avoid overfeeding and the application of high quantities of manure, so as to reduce the levels of salinity in earthen ponds.

CHAPTER 5

GENERAL CONCLUSION AND RECOMMENDATIONS

The aim of this study was to develop a scorecard system that could be used to establish the suitability of different water resources for the development of sustainable aquaculture production. It was conducted in five districts in the Limpopo Province and the scorecard was developed to make the collection of data in all intended districts easier, by helping to identify water sources that were suitable and unsuitable for aquaculture development, based on physicochemical properties.

The development of a scorecard went through a process of refinement and therefore different scorecards were initially developed to collect data from the fields. The first scorecard that was developed had elements such as poor, below average, average, above average and excellent; and the second scorecard had elements such as desirable and undesirable water. Both scorecard systems were a bit complicated with too many categories, thus it was not user friendly for this particular study's intended purpose. The final scoring card system was developed and its evaluation spoke directly to collecting data from underground and surface water sources in different earthen ponds, concrete ponds and water stored in Jojo tanks, so as to assess their suitability for aquaculture development. The final developed scorecard was helpful, applicable and easy to use at the sampling sites to collect and analyse water samples. It is recommended that this scorecard should be continuously used in the future to collect data from water samples at these sites, as it is user friendly and applicable. Furthermore it provided valuable information on a rapid appraisal basis of a water resource.

Water samples from each sampling site was collected and analysed for DO and phosphorus in the laboratory. The water samples that were analysed showed that the DO reading had a recorded mean value of 17.44 ± 0.76 mg/L in the Sekhukhune district; an average DO of 18.96 mg/L in the Capricorn district. It also indicated an average of 5.70 mg/L for phosphorus in the Mopani district. Although the DO values were acceptable, the results for phosphorous were not in the suitable range as recommended by DWAFF (1996), Timmons and Ebeling (2010). It is therefore suggested that water quality parameters be investigated and recorded on a weekly basis during production, for underground and surface water sources in the districts, and especially in the sites where high values were observed. Vegetation at surrounding areas of the water source should also be cleared to limit its influence on the water quality through leaf litter and debris. A quarterly investigation will assist in identifying the patterns of the physicochemical parameters. The water source/s that give high values in the quarter in the particular district/s, should be treated before and during the production period so as to increase the yield of warm water fish species from farming.

The knowledge of fish farmers need to be enhanced so as to promote good fish husbandry management. Examples of good husbandry management practices include preventing pollutants from entering the growing facilities and conducting regular water exchanges to reduce organic loading and waste accumulation. Farmers should know the importance of testing water quality timeously. Furthermore, de-gassing or aeration methods can be applied to increase the DO concentrations and stabilize other physicochemical water properties. Lime application to earthen ponds could also be useful in improving natural pond productivity. The studied water samples are generally helpful for aquaculture development, therefore continued monitoring of physicochemical water quality parameters is recommended.

The present study recommended some additional steps to be undertaken at the investigated ponds to maintain and improve the water for fish culture:

1. Pond water quality should be monitored regularly;
2. Discharge of effluents into pond water should be stopped to control pollution;
3. Pond water surface can be agitated with bamboo poles or by swimming to increase DO level;
4. Proper fertilization should help to maintain TDS and transparency levels

CHAPTER 6

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