Cape Peninsula University of Technology

WASTEWATER TREATMENT EFFECTIVENESS OF THE DECOMMISSIONED AND CURRENT DISSOLVED AIR FLOTATION (DAF) PLANT IN A FISH FACTORY, WALVIS BAY, NAMIBIA

by

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in the Faculty of Applied Sciences
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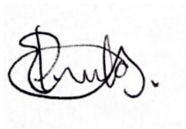
Cape Town
October 2021

DECLARATION

I, Elizabeth Lukas, declare that the contents of this dissertation/thesis represent my own unaided work, and that the dissertation/thesis has not previously been submitted for academic examination towards any qualification. Furthermore, it represents my own opinions and not necessarily those of the Cape Peninsula University of Technology.



04 October 2021

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ABSTRACT

The fish processing industries are of great concern worldwide as they produce significant volumes of wastewater which is produced during various stages of the fish canning process such as transportation, brine procedure, removal of unwanted fish parts (head and guts), cooking, canning, sterilization and cleaning of the equipment. This wastewater may contain physicochemical and microbiological pollutants as a result of the various fish canning stages that release contaminants which may not be easily removed before this wastewater is discharged into aquatic ecosystems. Pollution has been reported from fish factories that release wastewater in the Walvis Bay marine area in Namibia. This wastewater has often not met the mandatory water quality requirements, therefore, the fish factory had to determine the effectiveness of the decommissioned (old) and current (new) DAF plant in treating wastewater from their fishing operations. Wastewater from fish processing industries is highly contentious and thus poses treatment challenges due to the presence of organic matter, FOG and salt. Even though, there is a potential to reduce waste and solids in the wastewater, there is a lack of decision-making and monitoring methods to address problems of water quality caused by fish processing. There is also a big gap between the literature and wastewater management implementation methods due to the different fish processing procedures at various fish factories. Therefore, this study aimed at comparing the concentrations of parameters in the wastewater discharged from the old and new DAF plant at the fish factory. The study determined the relationship between the measured parameters at the different discharge sites and at the DAF plant as well as the differences in the wastewater discharged during different seasons. Wastewater samples were collected from three sites (old and new) namely, the DAF plant, Backwash (BW) and the Cooling Tower (CT) during both autumn and winter seasons and these were analysed using physicochemical and microbiological parameters. The results revealed that the mean concentration of most parameters was higher in the wastewater at the old sites when compared to the new sites. The new plant was found to be efficient in the removal of pollutants from the wastewater before it is discharged into the surrounding environment. Despite the better performance of the new plant, parameters such as FOG (0.3 ± 0.1 mg/l), (0.1 ± 0.03 mg/l), (0.2 ± 0.1 mg/l);DO (1 ± 0.3 mg/l),(13 ± 10 mg/l), (2 ± 0.3 mg/l), N (41 ± 15 mg/l), (11 ± 4 mg/l),(0.9 ± 0.1 mg/l), P (8 ± 2 mg/l), (4 ± 0.8 mg/l),(0.5 ± 0.1 mg/l) and NO_3 (0.9 ± 0.5 mg/l),(0.5 ± 0.0 mg/l), (3 ± 3 mg/l) at the new DAF, new BW and new CT, respectively, were not significantly different ($P > 0.05$) from those of the old DAF plant at all discharging sites. Therefore, even though the new plant seems to be working better than the old plant, the wastewater concentration being discharged into the ocean was still not acceptable. The comparison of parameters analysed between autumn and winter indicated that there were no significant differences ($P > 0.05$) of parameters in the wastewater between these seasons. The PCA multivariate tool identified a strong relationship between TSS, BOD, COD, FOG, N, P, NH_3 and FC at the old site. The relationship of parameters may signify the presence of solids, organic matter, blood, proteins and oil as well as nutrients and bacteria within the discharged wastewater. The DO levels in the discharged wastewater from the fish factory was low (> 2.0 mg/l) (below the WHO acceptable limits), implying that the final wastewater from the factory may contribute towards the increased seasonal events of local algal blooms production as a result of increased nutrients which favour low oxygen conditions for the bloom biomass decays in autumn. It is therefore recommended that the fish factory segregates waste by removing solids from wastewater to improve the quality of the wastewater before the treatment. Additionally, the application of a jar test to determine the best dosage as well as the type of chemicals to be used has proven to be successful in fish canning. The use of alternative coagulants to assist the pollutant load removal efficiency of each parameter from the wastewater will also be effective and it is important to ensure that the DAF plant operates at the correct capacity pressure to carry out its function properly. The aerobic biological treatment method is an alternative method of treating fish canning wastewater that should be considered while more research should be conducted to determine its success in removing pollutants from wastewater.

Keywords: wastewater treatment, Dissolved Air Flotation, fish factory, physicochemical parameters, microbiological parameters, seasons.

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DEDICATION

"I dedicate my thesis to my extended family, especially to the Ndombo and Nathaniel families, as well as my husband who supported and motivated me throughout my studies and allowing me the opportunity to make my dream a reality."

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GLOSSARY

Term	Definition
˚C	Degree Celsius
Ag_2S	Silver Sulphate
Al	Aluminium
Al_2S_3	Aluminium Sulphide
ANOSIM	Analysis of Similarity
ANOVA	Analysis of Variance
BOD	Biological Oxygen Demand
BOD_5	Five Day BOD Test
CFU	Colony Forming Units
COD	Chemical Oxygen Demand
DAF	Dissolved Air Flotation
DAFF	Dissolved Air Flotation Filtration
DO	Dissolved Solids
FAS	Ferrous Ammonium Sulphate
FC	Faecal Coliform
FOG	Fat, Oil and Grease
H_2SO_4	Sulphuric Acid
HCl	Hydrochloric Acid
$HgSO_4$	Mercuric Sulphate
$K_2Cr_2O_7$	Potassium Dichromate
Mg/l	Milligram/litre
M_nS	Manganese Sulphide
N	Nitrogen
$Na_2S_2O_3$	Sodium Thiosulfate
$Na_2S_2O_3$	Sodium Thiosulphate
Na_2SO_4	Sodium sulfate
NamWater	Namibia Water Corporation
NH_3	Ammonia
NO_3	Nitrate
NSI	Namibian Standards Institute
P	Phosphorus
PCA	Principal Component Analysis
pH	Potential Hydrogen

PRIMER	Plymouth Routines in Multivariate Ecological Research
RPM	Revolutions per Minute
SEM	Standard Error of the Mean
SIMPER	Similarity Percentage
SPSS	Statistical Package for the Social Science
TAC	Total Allowable Catch
TDS	Total Dissolved Solids
TSS	Total Dissolved Solids
UNWWDR	United Nations World Water Development Report
USEPA	United Nations Environmental Protection

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CHAPTER 1 : INTRODUCTION

1.1 Statement of the research problem

Globally, wastewater can be defined as water or liquid-carried waste that is generated from residential facilities, commercial and industrial establishments and is usually affected in quality by anthropogenic activities (Tchobanoglous et al. 1991; Raschid-Sally and Jayakody 2008; Tempelton and Butler 2011; UNWWDR 2017). Wastewater originates from domestic, commercial and industrial sources hence it being classified as either domestic or industrial (Raschid-Sally and Jayakody 2008; Tempelton and Butler 2011). Wastewater may consist of a high load of oxygen demand waste, bacteria related microorganisms, nutrients that promote plant growth, organic and inorganic substances as well as other contaminants (Culp and Culp 1971; Sonune and Ghate 2004; Raschid-Sally and Jayakody 2008). As Khambete and Christian (2014) highlighted, industrial and residential generated wastewater has intensified around the world as a result of increased urban activities (Mohammed 2006; Wang et al. 2014) and is often dumped into receiving environments without any form of treatment (Tarr 1984).

One such industry that generates significant amount of wastewater worldwide is the fishing industry, especially fish canning, due to their different production processes (Raquel et al. 2012; Raquel et al. 2014) (Figure 1-1). The various production operations result in wastewater with organic matter, salts and oil and grease which makes it challenging during wastewater treatment procedures and to meet allowable limits as set out for the industrial wastewater by numerous standards (Raquel et al. 2012). This leads to untreated or partially treated wastewater being discharged from fish factories into the receiving environment (Islam et al. 2004).

The untreated water discharged into receiving environments such as aquatic ecosystems eventually results in water pollution (Sonune and Ghate 2004). Polluted water affects economies, aesthetic value, health and the survival of living organisms, and leads to the reduced water quality, broad ecological degradation and unsustainability of aquatic ecosystems (O'Toole 1997; Poff et al. 1997; Raschid-Sally and Jayakody 2008; Wang et al. 2014). Polluted aquatic ecosystems can modify the distribution and structure of aquatic biota as a result of the declined water quality (Khambete and Christian 2014). Khambete and Christian (2014) further stated that, characteristics of water quality determines the ability of an aquatic ecosystem to carry out its functions. Water quality plays a crucial role in a relationship that is established when living organisms and the aquatic environment interact with one another to achieve a stable environment (Ntengwe 2006; Iscen et al. 2008). Aquatic ecosystems naturally adapt and compensate for changes in quality by diluting and changing organic compounds (Iscen et al. 2008). Once an aquatic ecosystem has reached its maximum capacity of several contaminants from unknown sources, water pollution may occur (Dallas et al. 1998).

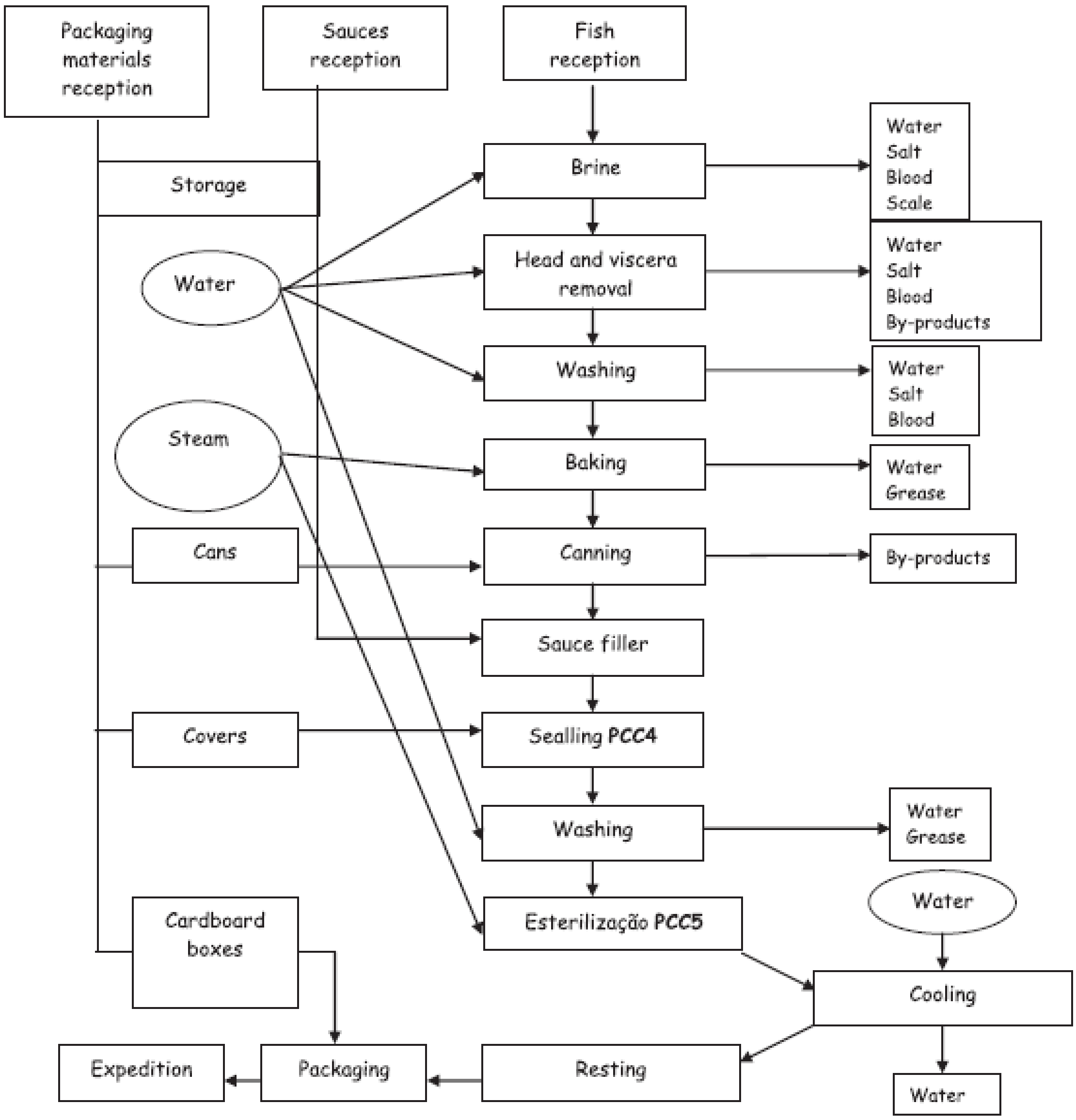

Figure 1-1: Fish canning industry flowchart (Raquel et al. 2014)

1.2 Background of the research problem in Namibia

The Walvis Bay marine environment in Namibia includes the Walvis Bay Lagoon Wetland, declared as a Ramsar site in 1995 (Wearne and Underhill 2005; Dahms et al. 2014). The Ramsar site is considered of international importance for its conservation of bird species in southern Africa (Noli-Peard and Williams 1991; Sakko 1998; Wearne and Underhill 2005; Makuti et al. 2008; Dahms et al. 2014). The Ramsar Convention is responsible for an extensive outline of wetland habitats around the world including coastal wetlands as they are highly productive natural systems supporting a variety of life (Noli-Peard and Williams 1991; Sakko 1998; Wearne and Underhill 2005). Ramsar sites are important because of their economic value, ecological importance, aesthetic appeal, rich animal life and recreational possibilities (Noli-Peard and Williams 1991). The Walvis Bay Lagoon is no exception in supporting rich bird life (such as Chestnut-banded Plover and Waders) as a result of the nutrient rich marine upwelling system of the northern Benguela (Sakko 1998; Wearne and Underhill 2005). The Benguela current supports the high phytoplankton production, fish and mammals (Dahms et al. 2014) while the lagoon is of ecological importance because of the high coastal biodiversity and its ability to provide food for bird and fish populations (Sakko 1998; Dahms et al. 2014).

The shellfish mariculture industry in Walvis Bay has been extensively affected by accumulative occurrences of phytoplankton blooms where the growth and survival of shellfish species are threatened (O'Toole 1997). In addition to the threatened survival of shellfish, the consumption of shellfish including oysters and mussels are increasing in Walvis Bay due to the expansion of the tourism industry. However, as O'Toole (1997) points out, this increase in consumption might result in health issues if polluted shellfish are consumed. Note that the mariculture industry in Namibia provides opportunities for improving food security by decreasing poverty, increasing revenue and providing employment as well as economic opportunities without affecting the natural marine resources (Makuti et al. 2008).

Natural and human induced activities such as local phytoplankton blooms and pollution from industrialization in the Walvis Bay harbour have resulted in marine pollution having large impacts on the functioning of the Walvis Bay lagoon (Sakko 1998; Makuti et al. 2008). Major pollution has been reported especially from fish processing wastewater and other toxic waste affecting water quality of the lagoon and not meeting the various mandatory water quality (O'Toole 1997; Makuti et al. 2008). There are numerous industrial wastewater discharges from fish factories in the Walvis Bay harbour, (Figure 1-2) leading to excessive nutrient settlement within the surrounding area, which may contribute to related incidences of phytoplankton blooms and sulphur eruptions (O'Toole 1997; Makuti et al. 2008). Sulphur eruption incidents have been recorded more often recently in the Walvis Bay vicinity including those taking place during 2004, 2005 and 2010 (Ohde and Dadou 2018) and those of February and March 2018 (Namib Times 2018). The latest occurrence in Walvis Bay (Figure 1-3) was described as a sulphur eruption that was responsible for multiple mortalities of fish including juveniles, and has resulted in crustaceans leaving the water due to a lack of oxygen (*APPENDIX A - SULPHUR ERUPTION EVENTS REPORTED IN WALVIS BAY*) (Namib Times 2018). Anderson et al. (2001) reported that sulphur eruptions are responsible for 80 % of mortalities in the mariculture operations in Walvis Bay, hence the need for the industry to seek alternatives for suitable habitats by for instance, relocating aquaculture farms.

Wastewater produced from fish processing can contain high pollution loads of organic matter due to the presence of oils, proteins, suspended solids as well as phosphates and nitrogen (Islam et al. 2004; Miroslav et al. 2010; Sunny and Mathai 2013; Mitchell et al. 2014). The amount of pollution is determined by the processing procedures involved (Islam et al. 2004). Wastewater from fish factories result from the processes of treatment and storage of raw fish, fluming of fish, defrosting and scaling and washing of fish products (Michaelle and David 2011; Raquel et al 2012; Sunny & Mathai 2013; Mitchell et al. 2014). In addition, the canning operations, including the fish factory in Walvis Bay, discharges wastewater from draining and precooking, spillages of sauce, brines and oils in the can filling process and from the condensate process generated during pre-cooking (Cowi 2003d; Miroslav et al. 2010). Most fish processing industries in coastal regions discharge wastewater with contents of pollution loads resulting in various environmental impacts in the receiving marine environment (Islam et al. 2004; Michaelle and David 2011; Mitchell et al. 2014) as it was evident in the Walvis Bay vicinity (O'Toole 1997; Sakko 1998).

In Namibia, wastewater from fishing industries in Walvis Bay has been listed as a threat to the Walvis Bay Lagoon Wetland (Noli-Peard and Williams 1991; Makuti et al. 2008; Dahms et al. 2014). To date, the Namibian Government promulgated two acts to enforce water resource management, namely the Water Resources Management Act, 2004 (Act No. 24 of 2004) and the Water Resources Management Act, 2013 (Act No. 11 of 2013). However, the former act was repealed while the latter act is currently under review with its regulations. According to Namibia's Constitution, (Article 140 of Act No. 1 of 1990), after independence, Namibia's government indicated that existing laws remain valid until repealed and replaced with updated laws. Therefore, Namibia currently enforces the pre-independence law, the Water Act (Act 54 of 1956) Gazette Regulation R553 of 5 April 1962, (South African adopted law) to regulate wastewater treatment and discharges through standard quality guidelines to prevent pollution (Environmental Assessment Scoping Report - update 2020). However, applicants that are unable to adhere to the standard quality guidelines restrictions can apply for an exemption permit from the standards in terms of Section 21 (5) and 22 (2) of the Water Act (Act 54 of 1956). The fish factory has an exemption wastewater discharge permit issued in terms of the Water Act and uses the World Health Organisation guidelines for wastewater discharge (WHO 2006) to ensure best practices. In addition, the Namibian Ports Authority (NAMPORT), which manages ports along Namibia's coastline, is mandated by the Government of the Republic of Namibia under the Ports Authority Act 2 of 1994 to carry out this legislation (O'Toole 1997). The marine environment has been impacted negatively by the discharging of waste by the fishing industry, affecting and contributing to water deterioration for marine species (Jähnig 2010). The deterioration of water quality can lead to an increase in costs for chemicals due to the treatment of water to assist in the prevention of pollution (Gray 1994). Since water is one of the most valuable and essential resources that form the basis of all life, accurate monitoring and assessment of our water resources is necessary for sustained water resource management (Hodgson and Manus 2006).

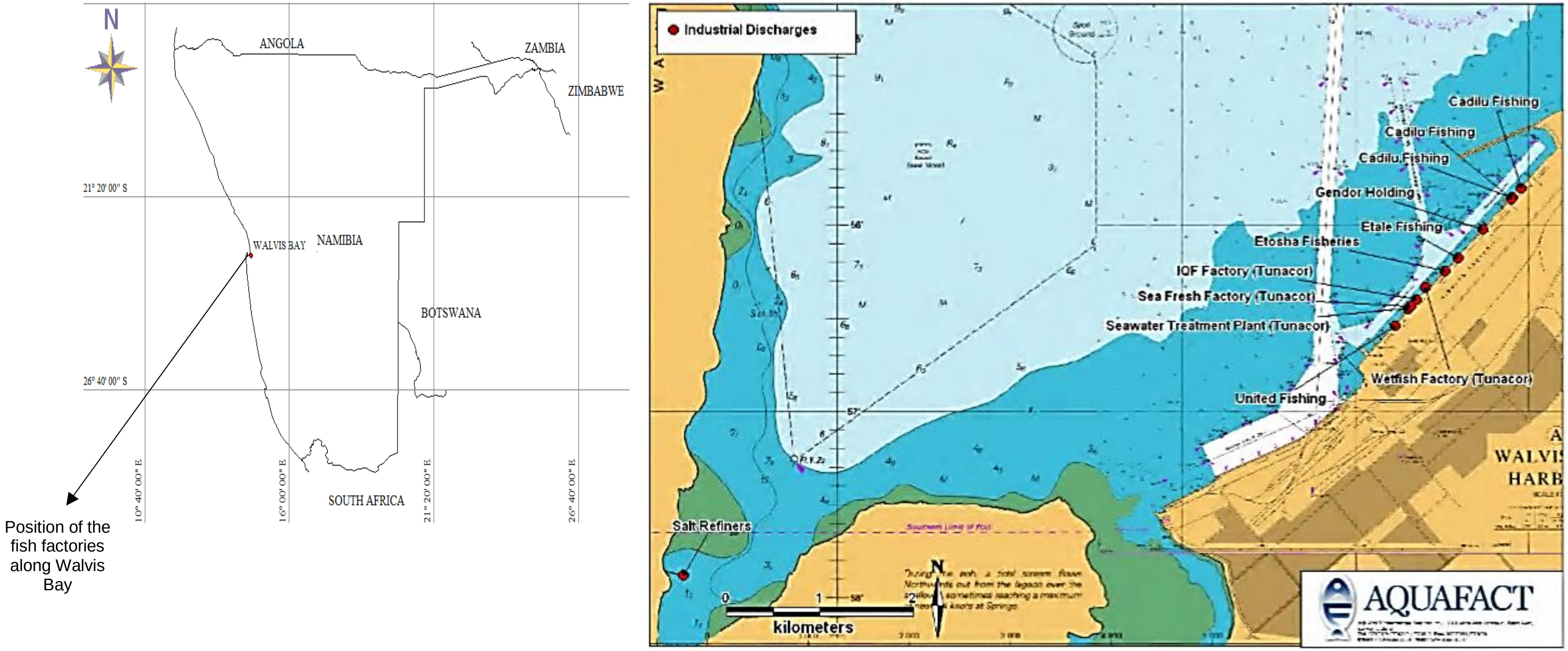

Figure 1-2: Industrial discharges from fish factories along the ocean in Walvis Bay (Aquafact International 2012)

Sulphur eruption kills off scores of marine creatures

A sulphur eruption killed off scores of fish, including large sharks and even juvenile snoek along the central Namibian coast late last week and over the weekend. Sulphur eruptions deprive the water from oxygen killing fish and resulting in crustaceans leaving the water where it also succumbs to the elements or becomes prey to seabirds.

*Also view a video clip of the sulphur eruption on our Facebook page.

Figure 1-3 : Individuals harvesting fish onshore after a sulphur eruption along Walvis Bay coast (Namib Times 2018)

1.3 Significance of the research

Despite the differences of local and regional influences of wastewater on the marine environment, O'Donoghue and Marshall (2003) suggested that current research focusses on future potential effects of wastewater on the marine environment to assist management in making better decisions in the future. Therefore, the management of the fish factory decommissioned and replaced the old DAF plant in April 2016 with a new (current) plant to improve the quality of the wastewater discharged into the ocean. The new DAF plant was constructed with a large buffer tank as opposed to the old DAF to ensure that controlled volumes of wastewater enter the plant. This reduces the risk of overflow and accidental wastewater pillages. Recent studies (Lewis et al. 1998; Alcamo et al. 2005; Trainer et al. 2010; Davies et al. 2015) have indicated that wastewater discharged from industries are poorly managed in coastal regions and have resulted in an increase of nutrients which promote phytoplankton blooms and fish mortalities reduce the aesthetic value of an area, and cause the degradation of coastal habitats. Minimal consideration has been given to the quality of wastewater discharged in the Benguela region and its possible effects in the ocean (Griffiths et al. 2004). Sakko (1998) also reported that research on anthropogenic threats such as wastewater from fish factories have not been well documented in the northern Benguela where Namibia is located. Not all the wastewater from fish operations in Walvis Bay have been found to comply with the regulations of the Namibian Water Act (Act 54 of 1956) (O'Toole 1997). The pollutants in wastewater from fish factories can include pollutants that have the potential to increase and breakdown organic matter at the bottom of the ocean causing sulphur eruptions (Michaelle and David 2011). These eruptions may result in mortalities of marine species including fish and bird species as well as generating unpleasant sulphurous smells and discoloration of water in the Walvis Bay marine environment (Makuti et al. 2008; Davies et al. 2015). It is therefore critical to assess the physical, chemical and biological parameters present in wastewater from fishing factories (Michaelle and David 2011) for the protection of water resources (Gray 1999).

The study will, therefore, add value towards informed management decisions of water treatment from fishing factories that may cause marine water pollution in Namibia. The study will also contribute to the existing literature by identifying significant management approaches that should be considered when handling wastewater from the fish factory before discharging it into the Walvis Bay harbour in Namibia.

1.4 Objectives of study

1.4.1 Main Aim

The main aim of this study was to compare the wastewater discharged from both the decommissioned and the current DAF plant in order to determine the effectiveness of the new plant in the treatment of wastewater from a fish processing factory in Walvis Bay.

1.4.2 Specific Objectives

- To determine the concentrations of physicochemical and microbiological parameters in the wastewater discharged from the current DAF plant at the fish factory.
- To compare the physicochemical and microbiological parameters in the wastewater of the decommissioned and the current DAF plant within different seasons.
- To determine the relationship between the physicochemical and microbiological parameters at the decommissioned (old) and current (new) DAF plant.

1.4.3 Thesis outline

Chapter 1: introduces a background which summarises wastewater problems globally. It also covers the research of wastewater treatment at fish factories faced in Namibia due to the fish processing industry and the impacts on water quality as well as the importance of the study. The main and specific objectives were also outlined in Chapter 1.

Chapter 2: describes the literature review and the concepts of the research problem using relevant past studies.

Chapter 3: describes the study area, materials and methods used for this study and the statistical analysis methods adopted.

Chapter 4: describes the results and discussion by including the mean physicochemical and microbiological parameters at the old and new sites as well as between seasons. It further interprets the results obtained. By so doing, the chapter includes a discussion on parameters at the old and new sites as well as between seasons.

Chapter 5: summarizes the findings of this study and makes general recommendations and discusses the lessons learnt from the findings of each objective

CHAPTER 2 : LITERATURE REVIEW

2.1 The impacts of the Benguela ecosystem in southern Africa on fish factories

The Benguela Current system (also known as the Benguela Current Large Marine Ecosystem (BCLME)) (Figure 2-1) in Sub–Sahara African stretches across the marine waters of Angola, Namibia and South Africa (Chapman and Shannon 1985; Shannon and Pillar 1986; Sakko 1998; Dahms et al. 2014). Since the Benguela Current forms part of the four major upwelling systems in the world various studies (Nelson and Hutchings 1983; Shannon 1985; Chapman and Shannon 1985; Shannon and Pillar 1986; Shannon and Nelson 1996; O'Toole 1997; van der Lingen et al. 2006) outlining the possible environmental patterns and paradigm shifts on a local and regional scale in the area have been documented. The Benguela is subdivided into the northern and southern Benguela (Shannon 1985; Chapman and Shannon 1985; Shannon and Pillar 1986; Shannon 1989). The northern Benguela is between the Angola-Benguela frontal system (north) and Luderitz upwelling cell (south) (Shannon et al. 1987). O'Toole (1997) established that the northern Benguela, which includes Namibia's coastline, is associated with upwelling processes which support more marine species when compared to other similar systems around the world.

Shannon (1989) and O'Toole (1997) described upwelling as the process caused by strong dominant south to south-westerly winds that convey near shore surface water offshore for this surface water to be replaced by deeper cooler bottom water. The deep and bottom water is accompanied by rich nutrients and together with the high sunlight in the region, stimulates the advancement of phytoplankton which maintains the marine species in high abundance (Chapman and Shannon 1985; Estrada and Marrase 1987; Sakko 1998; Davies et al. 2015). Although, the main upwelling front is found in the Luderitz area, less significant upwelling cells are found at Cape Fria (18° S), Palgrave Point (20° S) and Conception Bay (24° S) (O'Toole 1997).

O'Toole (1997) stated that the Benguela current is regulated by seasons of the south Atlantic high-pressure system. The southerly winds within Namibia's marine ecosystem are strong in winter (June to August) and spring (September to November) while in the Luderitz area, these winds are strong in spring and summer (December to February) (Shannon 1985; Chapman and Shannon 1985; Shannon et al. 1986; Shannon and Pillar 1986; O'Toole 1997). The strength of the southerly winds decreases off Namibia's coast during summer and autumn (March to May) and the warm saline Angolan Current moves towards the south, and combines with the Benguela Current waters which are cooler, resulting in a favourable marine environment for the breeding of pelagic fish as a result of the high plankton production (O'Toole 1997). Namibia's marine environment and the breeding grounds of fisheries are controlled by the variability of wind forces and the upwelling intensity which affects temperatures, nutrients and plankton production (O'Toole 1997). The position of the south Atlantic high pressure over southern Africa determines various alterations of the marine environment (Shannon et al. 1986), similarly, periodic environmental events that happen as a result of regional influences also control the resources available along Namibia's coastline (van der Lingen et al. 2006).

Associated with the upwelling process of Namibia's coastline, are the fixed events of warm water with high salinity invasion from Angola during late summer (Shannon 1985; Shannon et al. 1986; Boyd et al. 1987; Shannon 1989; O'Toole and Bartholomae 1998). These events have been discussed and published as Benguela Niños and had significant effects on Namibia's marine environment particularly during 1934, 1963, 1984 and 1993 to 1994 (Shannon et al. 1986; O'Toole 1997; Imbol Koungue et al. 2019). The Benguela Niños are accompanied by an increase in temperatures and inhibition of upwelling processes, despite the strong southerly prevailing winds (Shannon et al. 1986; O'Toole 1997; Gammelsrod et al. 1998; O'Toole and Bartholomae 1998). Oxygen depleted warm water from Angola has negative effects on the marine biota of Namibia, contributing to a decline of phytoplankton growth and mortalities of pelagic fish species resulting in a poor fishing season and reduced spawning intensities (O'Toole 1997). These influences affect the fish movement patterns and interferes with breeding of fish species along Namibia's coastline (O'Toole 1997).

Additional events reported to take place at the Namibia's coastline near the shorelines, are sulphur eruptions (O'Toole 1997; van der Lingen et al. 2006). Sulphur eruptions result from the decomposition of phytoplankton which causes elevated organic matter (Chapman and Shannon 1985). Organic matter utilizes oxygen during the decomposition process leading to provisional low oxygen levels in the bottom of the ocean (O'Toole 1997; Sakko 1998). Chapman and Shannon (1985) established that the marine water off southern Africa is often low in oxygen and this has been reported especially in the Walvis Bay vicinity. The water in the area of low oxygen does not support the wellbeing of marine species since it is rich in decomposed organic matter (Rogers and Bremner 1991). The consequences of marine water with low oxygen levels is linked to localised negative environmental effects at the shorelines and include mortalities of fish and other marine species which are accompanied by an unpleasant smell and discoloration of sea water (Chapman and Shannon 1985; O'Toole 1997; van der Lingen et al. 2006). Sulphur eruptions tend to be regulated by seasonal changes, occurring frequently between late summer and winter while upwelling is dormant, when the southerly winds are at their minimum as well as with variations in temperatures and salinity (Chapman and Shannon 1985; Sakko 1998). As a result of this event, the availability of living resources is widely affected due to the translocation of fisheries caused by environmental variations in the Benguela (Hamukuaya et al. 1998; Sakko 1998; van der Lingen 2006).

Sporadic frequencies of phytoplankton blooms or red tides occur in the northern Benguela with substantial impacts on the marine environment (O'Toole 1997). Phytoplankton blooms are formed by an increase in nutrients under natural conditions such as a rise of chlorophyll levels offshore during warm conditions favourable sunlight and increased phytoplankton production (Chapman and Shannon 1985; Shannon and Pillar 1986; O'Toole 1997). The toxin production of some blooms leads to the creation of harmful compounds into the ocean, the presence of low oxygen conditions as the bloom biomass decays, and the decrease of light conditions which in turn affects other marine organisms and biota (Sakko 1998; Michaelle and David 2011). The shortage of oxygen causes the destruction of ecological processes through the death of marine organisms such as fish and crustaceans (O'Toole 1997; Anderson et al. 2001; Makuti et al. 2008; Davies et al. 2015). Phytoplankton bloom incidences have been frequent over the years, particularly in the offshore local area off Walvis Bay between late summer and autumn when upwelling is dormant (Chapman and Shannon 1985).

The above natural events cause fluctuations of resources contributing to paradigm shifts in the northern Benguela (Curry and Shannon 2004; Collie et al. 2004; van der Lingen 2006). Even though climatic variables have transformed the marine ecosystem in the northern Benguela, anthropogenic induced activities of overfishing have created immense pressure on this marine ecosystem (Sakko 1998; Steele 2004; van der Lingen 2006). For instance, the overfishing of small pelagic fisheries in the northern Benguela transformed the biological structure of the marine ecosystem (Cury and Shannon 2004; Roux and Shannon 2004; van der Lingen 2006). Fisheries and other living marine organisms have responded to natural and anthropogenic changes by restructuring and changing species composition on a local and regional scale over time (van der Lingen 2006; Ohde and Dadou 2018). Some changes have caused a decrease in the population size of some species, affected the genetic pool of the surviving species, and have therefore reduced the ability of surviving species to adjust or adapt to the transformed ecosystem surroundings (Sakko 1998). Even though, no extinctions of species have been recorded in the Namibian marine ecosystem, it is crucial that marine species be preserved with genetic diversity to increase the chances of survival (Sakko 1998).

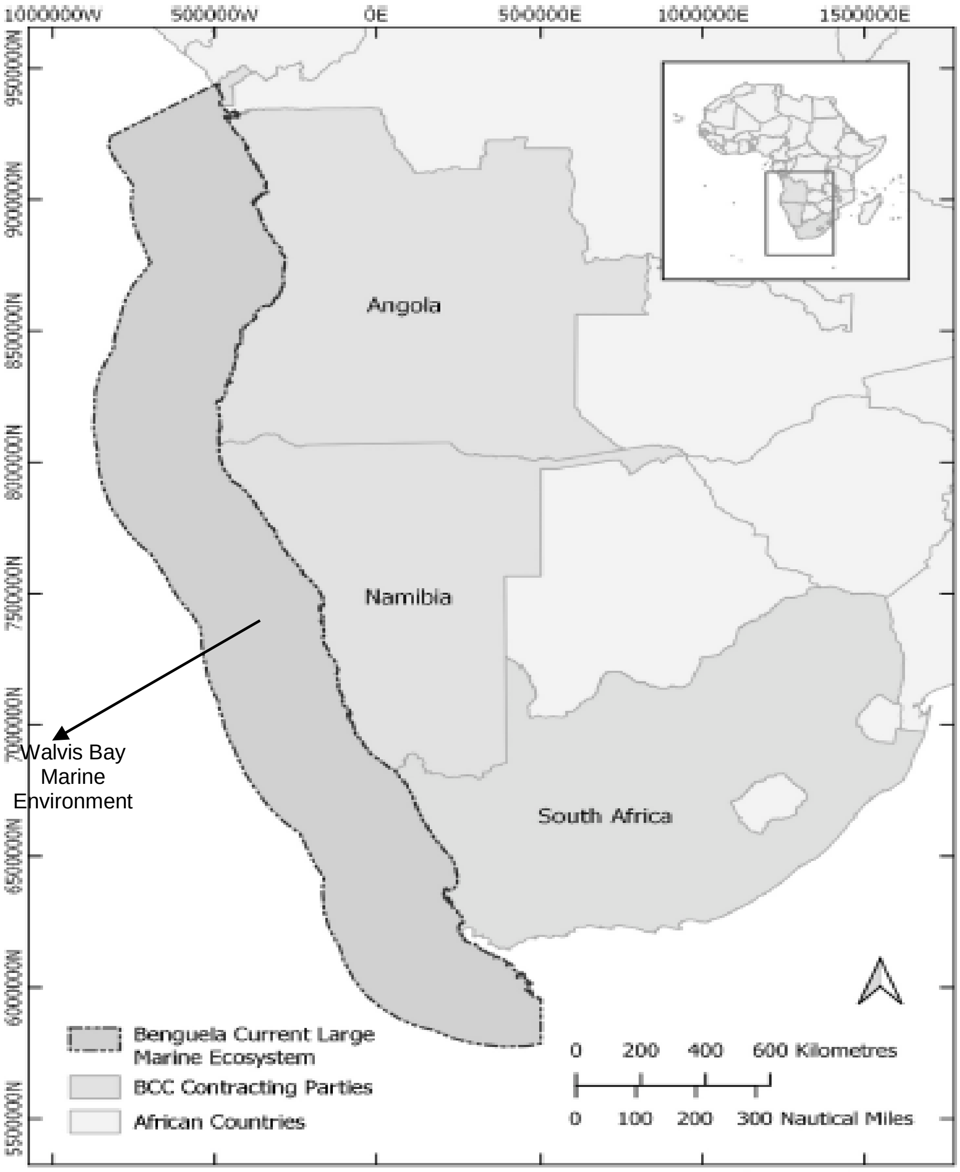

Figure 2-1: The Benguela Current system in southern Africa (Finke et al. 2020)

2.2 Wastewater from fish factories

One of the main concerns of pollution in aquatic ecosystems is from contaminants in wastewater and can cause serious environmental problems (Sonune and Ghate 2004). Even though natural processes can contribute to pollution, anthropogenic activities have accelerated these pollution events (Sakko 1998; Griffiths et al. 2004). The contaminants in wastewater can increase nutrients and affect the balance of oxygen in aquatic ecosystems, even though oxygen is essential in maintaining biological life (Morrison et al. 2001). More effort is needed to effectively treat wastewater, especially the wastewater from industrial activities in order to minimize pollutant loads before discharging it into the receiving environments (Tarr 1984; Wang et al. 2014).

Industrial wastewater varies among establishments in terms of composition and volume. The fishing industry is no exception, as significant volumes of wastewater are produced, which may contain contaminants that can cause pollution when discharged into aquatic environments (Miroslav et al. 2010). Wastewater studies (Islam et al. 2004; Miroslav et al. 2010; Raquel et al. 2012) have indicated that high volumes of industrial wastewater can be produced from fish factories around the world during several stages of operations, and this wastewater may contain contaminants that may not easily be removed during its treatment (Sonune and Ghate 2004). The contaminants in wastewater may contain different physical, chemical and biological parameters (Ujang and Henze 2006). Hodgson and Manus (2006) suggested that it is valuable to assess wastewater before it is discharged into any aquatic ecosystem, in order to minimise pollution. Before the discharge of wastewater into aquatic ecosystems, the pollutant load of wastewater from various industries can for instance be assessed by examining the following parameters: physical (turbidity, electrical conductivity, temperature, Total Dissolved Solids (TDS), colour and taste), chemical (pH, Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), non-metals, metals and Persistent Organic Pollutants (POPs) and biological (faecal coliform, total coliform and enterococci count) (Gray 1994; Edokpayi et al. 2017).

The pollution of aquatic ecosystems, especially the marine environment, in relation to wastewater discharged from industries (including fish factories), was found to have impacts on local marine species of coastal towns including Walvis Bay (O'Toole 1997; Griffiths et al. 2004; van der Lingen et al. 2006). Walvis Bay has a small human population size (Moldan, 1989) and approximately 21 fish processing and aquaculture production industries (Sakko 1998; Griffiths et al. 2004; Aquafact International 2012).

2.3 Wastewater quality parameters

2.3.1 Physicochemical parameters

Parameters can be described by their physical and chemical quality effects in water (Qasim and Mane 2013; Barbera and Gumari 2018). Helmer and Hespanhol (1997) found that numerous physicochemical parameters can guide authorities with strategies to control wastewater pollution. These parameters include Chemical Oxygen Demand (COD), Biological Oxygen Demand (BOD), Dissolved Oxygen (DO), Fat, Oil and Grease (FOG), pH, Total Dissolved Solids (TDS), Total Suspended Solids (TSS) and nutrients such as Ammonia, Nitrates, Nitrogen and Total Phosphate.

The amount of particles that are characterised by organic and inorganic dissolved material (calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates) in water is known as Total Dissolved Solids (TDS) (Brown and Caldwell 2001; Dallas and Day 2004). Increased TDS levels in wastewater can contribute to unpleasant odours and escalate the growth of phytoplankton with possible harmful effects on other aquatic species (Brown and Caldwell 2001; Tchobanoglous et al. 1991; Bilottaa and Braziera 2008). Water treatment facilities utilize flocculants to combine the solids so that they become large enough to settle at the bottom of the tank (Brown and Caldwell 2001). For example, the fish factory in Walvis Bay uses the SEDIFLOC 407C chemical as a flocculant in the Dissolved Air Flotation (DAF) Treatment Plant for the compaction of solids to allow settling at the bottom of the plant. In contrast to TDS, Total Suspended Solids (TSS) are suspended solids that are large enough and settle without difficulty (WRC 2006). As Dallas and Day (2004) reveal, settled suspended solids can suffocate and weaken the gills and feeding capabilities of fish species. They further mention that concentrations of suspended solids in wastewater are an indication of poor water quality as they reduce the suitability of water for aquatic life (Dallas and Day 2004). Miroslav et al. (2010) reported that wastewater from the fishing industry can be high in dissolved and suspended solids resulting into high BOD and COD.

Hansen (2002) and Schmidt and Hansen (2001) stated that high pH levels decrease a great number of phytoplankton species and can, over time, affect the structure of ecological communities or species especially in the marine ecosystem. According to Hansen (2002) marine species respond differently to various pH levels. Therefore, it is important that the wastewater discharged into marine ecosystems be treated thoroughly to reduce chances of phytoplankton blooms that may interfere with primary production (Brown and Caldwell 2001; Morrison et al. 2001).

The quantity of available oxygen for bacteria to break down organic matter in water can be described as Chemical Oxygen Demand (COD) (Tempelton and Butler 2011). A high COD in wastewater is an indication that there is a greater amount of oxidized organic matter which reduces Dissolved Oxygen (DO) levels, and which is toxic to biological life when discharged into aquatic environments (Burton et al. 1980; Brown and Caldwell 2001). The Biological Oxygen Demand (BOD) can be described as the measurement of DO that is crucial for bacteria to be able to decompose organic matter under aerobic conditions (Brown and Caldwell 2001; Tempelton and Butler 2011). It is essential that wastewater treatment plants focus on reducing BOD before discharging wastewater (Mitchell et al. 2014). When wastewater with high quantities of BOD is discharged into marine environments it may accelerate the growth of bacteria, resulting in oxygen depletion in the water and the mortalities of marine species (Brown and Caldwell 2001).

Fats, Oil and Grease (FOG) are the most unpleasant constituents in wastewater especially those resulting from fish canning industries (Miroslav et al. 2010). The FOG contained in wastewater discharged into the ocean are not easily broken down by bacteria, hence them causing a pollution in the receiving environment (Miroslav et al. 2010). Large amounts of FOG discharged into aquatic environments may increase BOD and float to the surface, what results in an unesthetic and unpleasant environments. A high concentration of FOG can also prevent the oxygen transfer from the atmosphere to the water, hence the reduction of DO in the aquatic environment (Helmer and Hespanhol 1997; Miroslav et al. 2010). Similar issues of unpleasant and offensive odours have been ongoing in the Walvis Bay harbour where the fish factory is situated (Davies et al. 2015). In wastewater treatment facilities, FOG was found to stick to tanks and pumps and negatively affect their long-term maintenance capacity (Miroslav et al. 2010).

Organisms living in water depend on dissolved oxygen for their survival (Ritter 2010). Dissolved Oxygen (DO) is an essential indicator for good quality of water (Brown and Caldwell 2001). The availability of DO in aquatic environments depends on the size of sediment grains, the quantity of oxygen used during the decomposition process by plants, and by the temperature of the water since less oxygen dissolves in warm water when compared to cold water, (Brown and Caldwell 2001; Ritter 2010; Tempelton and Butler 2011). A lack of DO in aquatic environments causes increased odours as a result of anaerobic decomposition, while the decaying of organic matter can, in turn, cause mortalities of fish species (Ritter 2010). Incidences of phytoplankton blooms as a result of increased eutrophication also cause a lack of DO in the water (Brown and Caldwell 2001).

Brown and Caldwell (2001) stated that nutrients are important to preserve a stable aquatic environment. However, wastewater discharged into aquatic ecosystems may most of the time contain vast amounts of nutrients such as Nitrogen (N) and Phosphorus (P) in the form of nitrate and phosphate (Murphy 2006; Tempelton and Butler 2011). Nitrogen in its gaseous form is converted through biological and physical processes into nitrate and ammonia (NH_3) which is soluble and easily transported into aquatic environments through wastewater (Dallas and Day 2004; Miller 2005; Murphy 2006). The process of converting nitrogen into nitrate and ammonia can either be through natural or human induced activities (Murphy 2006). These nutrients can accelerate the growth of algae leading to phytoplankton blooms or eutrophication, depleting oxygen in the water, and causing mortalities of biotic species resulting in alteration of diversity (Smith et al. 1999; Brown and Caldwell 2001; Foxon et al.

2004; Tempelton and Butler 2011). The high absorption of nutrients such as nitrogen and total phosphate are becoming a worldwide concern especially through the discharge of wastewater in aquatic environments (Smith et al. 1999; James et al. 2007). Aquatic ecosystems should be protected from discharged wastewater that is rich in these nutrients in order to prevent excessive growth of algae and oxygen depletion processes (Foxon et al. 2004).

The assessment of water quality for pathogenic microorganisms is crucial for the identification of the presence of bacteria (Gray 1999). Pathogenic microorganisms which cause pollution in wastewater can be bacteria, viruses, protozoa and fungi that are often discharged into aquatic environments (Weber and Legge 2008; Mitchell et al. 2014). It is not possible to constantly assess and monitor all the different microorganisms, hence the use of indicator organisms as alternatives (Ritter 2010; Tempelton and Butler 2011). For example, the *Escherichia coli* species is a subset of the faecal coliform group of bacteria and is a preferred indicator of wastewater quality (Noblea et al. 2003) as it contains other microbial pathogens including viruses and parasites (Tempelton and Butler 2011). High levels of faecal coliform in aquatic environments may result in low levels of DO and contaminate aquatic species (Brown and Caldwell 2001) while high levels of bacteria in wastewater discharged into the ocean can contaminate shellfish which is a source of protein especially to the Namibian people living along the coast, and can thus impact economies (Dahms et al. 2014; Mitchell et al. 2014).

2.4 Wastewater Treatment

The demand for water quality monitoring has increased (Antonopoulos et al. 2001) to prevent the deterioration of water resources (Nhlapi and Gijzen 2005). The implementation of pollution prevention strategies has proven to be challenging. Therefore, further effective water management mechanisms may include wastewater treatment for advancement and protection of water resources (Nhlapi and Gijzen 2005). Wastewater treatment techniques and approaches (Jamrah 1999; Lettinga et al. 2000; Leita˜o et al. 2006) may as well include mechanical, physical, chemical and biological processes (Sonune and Ghate 2004; Leita˜o et al. 2006; UNWWDR 2017). Mechanical methods consist of screening, sedimentation and flotation while physical methods are coagulation, flocculation and disinfection (Tempelton and Butler 2011; Raquel et al. 2012). Biological methods take place when oxygen is consumed by microorganisms in a controlled surrounding reducing pollutants. Note that the stabilization in wastewater, a technique well known as the activated sludge growth method is used in many wastewater treatment plants (WISA 2002; Sonune and Ghate 2004; UNWWDR 2017). An effective and efficient wastewater treatment can be accomplished by combining the above-mentioned methods (Sonune and Ghate 2004; UNWWDR 2017).

The wastewater treatment method used at the fish factory in Walvis Bay is a combination of mechanical and physical methods. The Dissolved Air Flotation (DAF) plant is a mechanical method which has been effective in treating industrial wastewater by reducing organic load in the wastewater (Jamrah 1999; Srinivasan and Viraraghavan 2009; Tempelton and Butler 2011; Khambete and Christian 2014). Coagulation and flotation processes are the physical methods used in conjunction with the DAF plant (Tempelton and Butler 2011; Raquel et al. 2012). Chemical dosage is involved in the coagulation and flocculation methods, and it has been recommended that it takes place before the flotation in the DAF plant to ensure that wastewater treatment is effective (Tchobanoglous et al. 1991; Srinivasan and Viraraghavan 2009; Raquel et al. 2012). Miroslav et al. (2010) reported that flotation, coagulation and flocculation are the best techniques in removing FOGs and suspended solids in seafood industries.

The DAF process can be defined as a wastewater treatment procedure that removes suspended components such as oil and solids from the water (Beychok 1967). The removal process is accomplished by dissolving air in the wastewater under high pressure and thereafter releasing the air at atmospheric pressure in the basin of the flotation tank (Srinivasan and Viraraghavan 2009). The released air forms tiny bubbles which adhere to the suspended components to float on top of the water where it is removed by a skimming device (Miroslav et al. 2010). Even though there are a variety of flotation treatment plants, the DAF plant is however used more often especially by the fish canning industry where components such as suspended solids and oil are believed to be major pollutant loads in the wastewater (Tay et al. 2006; Miroslav et al. 2010). Similarly, the fish factory in Walvis Bay has installed a DAF plant operating with the same techniques as described above.

Various procedures are involved during coagulation and flocculation (Miroslav et al. 2010). Aluminium Sulphide (Al_2S_3) is a commonly used coagulant (Sonune and Ghate 2004; John 2016). The Al_2S_3 is injected into wastewater as it enters the DAF plant, allowing the coagulant to mix with particles during the high-pressure mixture to distribute adsorbed coagulant molecules (Miroslav et al. 2010). The flocculent is added once the air formulates tiny bubbles or micro-bubbles that will attach to the flock allowing scum formation which is then removed by a skimming device (Miroslav et al. 2010; Templeton and Butler 2011). The flocculants are big molecules that bind together the smaller flocks produced by coagulation (Templeton and Butler 2011). The fish factory uses Al_2S_3 and SEDIFLOC 407C chemicals to achieve the process described above during the mixture of coagulant and flocculent, respectively in the DAF plant. The DAF plant has a capacity of 6 480 (m^3/d) with two chemical dosing tanks of a coagulant and flocculent each of 10 m^3 (

Figure 2-2). Wastewater from the fish processing operation enters the DAF plant at the bottom where Al_2S_3 is injected allowing the coagulant to mix with particles during the high pressure of flotation and thereafter the SEDIFLOC 407C solution is added as a flocculent once the air forms micro-bubbles which stick to the suspended components to float on top of the water where it is removed by a skimming device. The suspended components from the DAF plant are then sent to the fishmeal plant for further fishmeal production while the treated water is discharged into the ocean (Greeff 2017).

The management of the fish factory has decommissioned and replaced the old DAF plant in April 2016 with a new (current) plant to improve the quality of the wastewater discharged into the ocean. The new DAF plant was constructed with a large buffer tank as opposed to the old DAF to ensure that controlled volumes of wastewater enter the plant. This reduces the risk of overflow and accidental wastewater pillages. Recent studies (Lewis et al. 1998; Alcamo et al. 2005; Trainer et al. 2010; Davies et al. 2015) have indicated that wastewater discharged from industries are poorly managed in coastal regions and have resulted in an increase of nutrients which promote phytoplankton blooms and fish mortalities reduce the aesthetic value of an area, and cause the degradation of coastal habitats. Minimal consideration has been given to the quality of wastewater discharged in the Benguela region and its possible effects in the ocean (Griffiths et al. 2004). Sakko (1998) also reported that research on anthropogenic threats such as wastewater from fish factories have not been well documented in the northern Benguela where Namibia is located. Not all the wastewater from fish operations in Walvis Bay have been found to comply with the regulations of Namibian Water Act (Act 54 of 1956) (O'Toole 1997). The pollutants in wastewater from fish factories can include pollutants that have the potential to increase and breakdown organic matter at the bottom of the ocean causing sulphuric eruptions (Michaelle and David 2011). These eruptions may result in mortalities of marine species including fish and bird species as well as generating unpleasant sulphurous smell and discoloration of water in the Walvis Bay marine environment (Makuti et al. 2008; Davies et al. 2015). It is therefore critical to assess the physical, chemical and biological parameters present in wastewater from fishing factories (Michaelle and David 2011) for the protection of water resources (Gray 1999).

Figure 2-2: Coagulant and flocculent chemical dosing tanks at the fish factory (Source: Geo Pollution Technologies 2004)

CHAPTER 3 : MATERIALS AND METHODS

3.1 Study Area

The factory used in this study is situated in Walvis Bay (22° 54' 07.5'' S, 14° 30' 03.8'' E) (Figure 3-1a) in the Benguela ecosystem. The Benguela ecosystem covers the west coast of South Africa, Namibia's coastline and a portion of southern Angola, between 14º and 17° S (Boyer and Hampton 2001). The Benguela current is divided into the northern and southern Benguela, a split in the currents that was caused by the upwelling system in Luderitz (26º - 28° S) (Boyer and Hampton 2001). A greater portion of Namibia's coastline is situated in the Northern Benguela.

The fish factory (22° 56' 57.1'' S, 14° 30' 05.3'' E) (Figure 3-1b) was established in the 1940's and operates within the small pelagic fishing sector and processes fish species such as sardine (*Sardinops sagax*) and horse mackerel (*Trachurus trachurus capensis*). The fish processing operations consist of a cannery and fishmeal processing plant that generate wastewater that is treated in the DAF plant with a combination of coagulants and flocculants, before being discharged into the Walvis Bay harbour. The canning and fishmeal production only started after the Water Act (Act 54 of 1956) was enacted and prior to this, fishing operations consisted of a freezing plant and produced minimal wastewater.

The Walvis Bay harbour is the main deep water harbour port in Namibia (Evans 1990; Wearne and Underhill 2005). The Walvis Bay Lagoon is located in the immediate vicinity of the harbour, the lagoon is listed as a Ramsar site wetland and considered as one of the most important international wetlands for the conservation of bird species in southern Africa (Noli-Peard and Williams 1991; Makuti et al. 2008; Dahms et al. 2014). The wetland supports Palearctic migrants and African bird species with seasonal migration patterns such as Flamingos (Greater and Lesser), Pelicans (Great White) and Plovers (Chestnut-Banded) (Wearne and Underhill 2005).

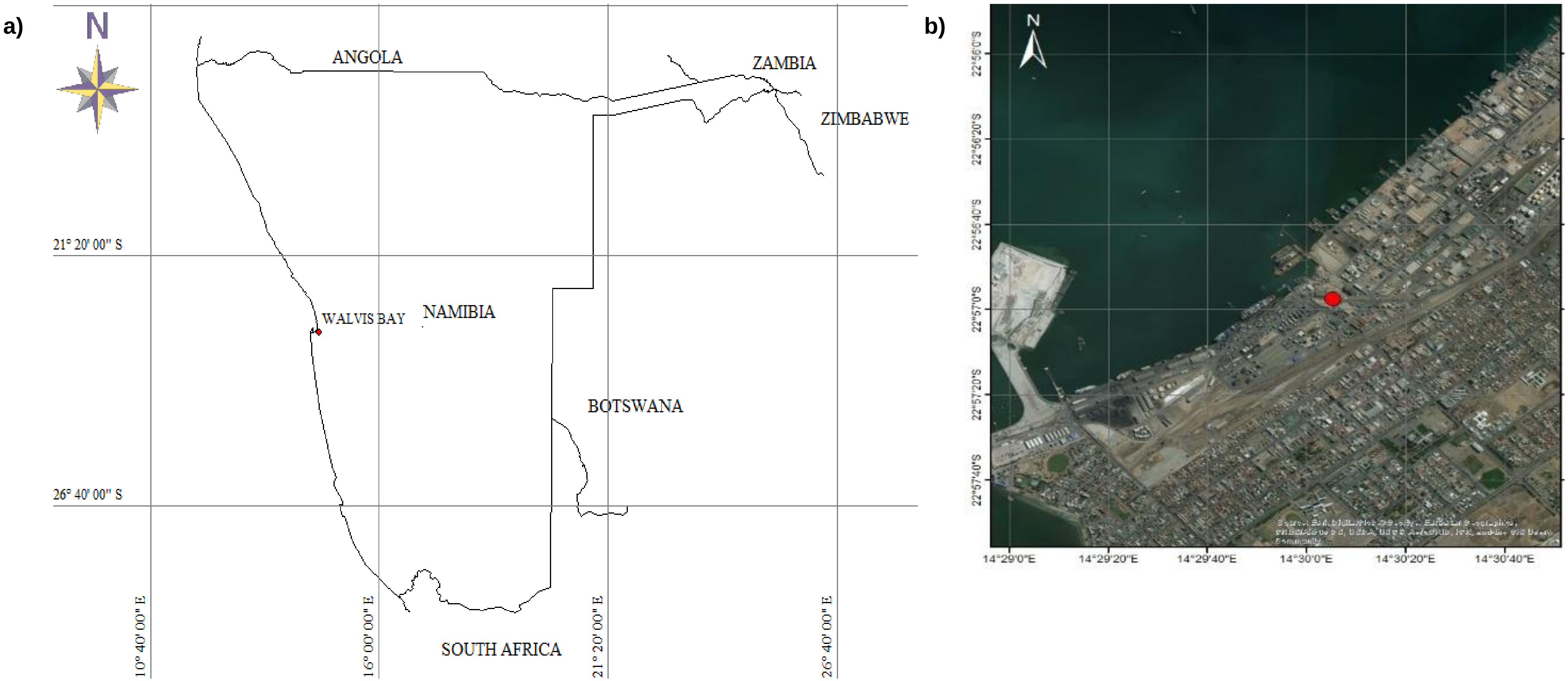

Figure 3-1: a) The Location of Walvis Bay in Namibia ( ) b) the fish factory in Walvis Bay ( ) (adapted from google earth, 2019)

3.2 Factory Sampling

The fish factory had historical water quality data which was collected between 2011 and 2016. The historical data was collected by submerging the polyethylene terephthalate (PET) bottles using a scoop method at the Old Dissolved Air Flotation (DAF) plant, Old Backwash (BW) and the Old Cooling Tower (CT). To make this study comparable to the historical data, the submersion of the PET bottles using a scoop method was adopted. Previous studies (Veijola et al. 1996; Raunio et al. 2007) indicated that multiple samples are required to sufficiently represent a single site. A total of 170 samples were therefore used to analyse data from the old (79) and new sites (91). This study compared the effectiveness of the decommissioned (old) and current (new) DAF plant in the treatment of wastewater discharged into the Walvis Bay harbour. This study could assist in providing some guidance and ideas in terms of the management of wastewater and improvements of the operations of the system. As described in Chapter 1, the new plant has an increased capacity to control wastewater volumes in the system and treat wastewater when compared to the old DAF plant.

Wastewater sampling was conducted when the fish factory was operational and discharging wastewater into the ocean. Operation of the fish factory is determined by the availability of sardine and horse mackerel during Namibia's fishing season which is between March and August annually (Boyer et al. 1997; Wilhelm et al. 2015). The fish factory imports sardines from Morocco to subsidize its annual Total Allowable Catch (TAC) in order to increase production throughout the year. Immanuel (2017) and Hartman (2017) published articles in the local newspapers about the collapse of pelagic fisheries in Namibia *(see APPENDIX B* – REPORTS ABOUT THE COLLAPSE OF THE NAMIBIAN SARDINE). The possible collapse of the pelagic fisheries has prompted the management to increase the amount of fish that the company imports (Greeff 2017). The Annual Ministerial Address to the Fishing Industry stated that the number of sardines has decreased drastically, and in 2018 the Government of the Republic of Namibia placed a three years moratorium on the Sardine stock (MFMR 2019). In addition, in-depth studies are currently being conducted by Namibia's Ministry of Fisheries and Marine Resources to determine whether sardine stocks have decreased, or whether they have moved into deeper water. Although the report was expected to be completed in 2020 (MFMR 2019), the 2020 report has however not been released yet.

Between June 2017 and June 2018, wastewater samples were collected at sampling stations for data analysis. Samples were sent to the Namibia Water Corporation Ltd (NamWater) and Namibian Standards Institute (NSI) laboratories for chemical and microbiological parameters analysis, respectively. For NamWater, two sterilised sampling containers were used for wastewater collection at each site, 2000 ml polyethylene container and another in 1000 ml glass container while for NSI, a 50 ml polyethylene container of wastewater was collected at each site. To prevent sample contamination, containers were sterilised while gloves were also used during sampling (Foxon et al. 2004). The sample bottles were clearly marked with sampling site and date, for identification (Figure 3-2), kept refrigerated after collection and sent to the laboratory within 24 hours.

Figure 3-2: Samples being collected from discharging points (Source: Lukas 2018)

3.3 Sampling Stations

Sampling stations were selected based on the fish factory's outlets that discharge wastewater into the harbour. Three sampling stations were selected within the boundaries of the fish factory, the selected sites discharge wastewater as a result of various production activities (Figure 3-3). The wastewater from the DAF plant arises from the production processing of raw fish, namely storage, defrosting and scaling of fish products as well as the canning process of condensate during pre-cooking, spillages of sauce, brines and oils (Michaelle and David 2011; Raquel et al. 2012; Sunny and Mathai 2013; Mitchell et al. 2014). The wastewater from the production process contains suspended solids, FOG, and other contaminants (Raquel et al. 2012) which are treated in the DAF plant with coagulants (Al_2S_3) and flocculants (SEDIFLOC 407C**)** before being discharged into the ocean. The wastewater from the backwash stream is abstracted from the harbour and treated in the seawater purification plant using a Dissolved Air Flotation Filtration (DAFF) process. The DAFF ensures the filtration of seawater from material and of the particles that might obstruct operations during production (Eades and Brignall 1995). The filtered seawater is pumped into 16 storage tanks, each with a capacity of 10 m^3 (10 000 litres), for use during production while the cooling towers are designed to remove odours of emissions from the fishmeal plant. The unfiltered seawater is pumped back into the ocean without being used as backwash. The seawater used in the production is pumped to the DAF plant as wastewater while the seawater used for cooling is discharged into the ocean through the stickwater plant / cooling tower. The wastewater discharged from the cooling towers / stickwater plant is from the backwash used for cooling in the fishmeal plant and from the boilers. Note that one amount of the boiler water is used for production while the rest is pumped to the cooling towers without being used and then discharged into the ocean. The three sites that discharge wastewater into the ocean are illustrated in a flow chart (Figure 3-4). Although the backwash and cooling towers are different parts of the system, the management assumes that these parts have an effect on wastewater discharged from the processes of the fish factory (Greeff 2017). Therefore, historic data of wastewater samples collected from the factory included the three sites, DAF plant, backwash and cooling tower that were also sampled for this study.

Between 2011 and early 2016 (March), wastewater sampling was only conducted when the fish factory was operational during the pelagic fishing season in Namibia, which is between March and August (autumn and winter). Since the fishing factory could only process fish during the fishing season, no sampling was conducted for spring and summer between 2011 and 2016. A total of 79 samples were collected between 2011 and 2016.

In 2017, when the management changed their strategy to increase fish processing by importing fish from Morocco, the number of times that sampling took place also increased per site. Between June 2017 and June 2018, samples were collected four times per month at each site, except during the month of December when samples were only collected three times as the factory closed for production. For the period between June 2017 and June 2018, the sampling took place during all the seasons (autumn, winter, spring and summer). For the data analysis, only the autumn and winter data of 2017 and 2018 were used for the analyses in order to be comparable to the 2011 to 2016 data.

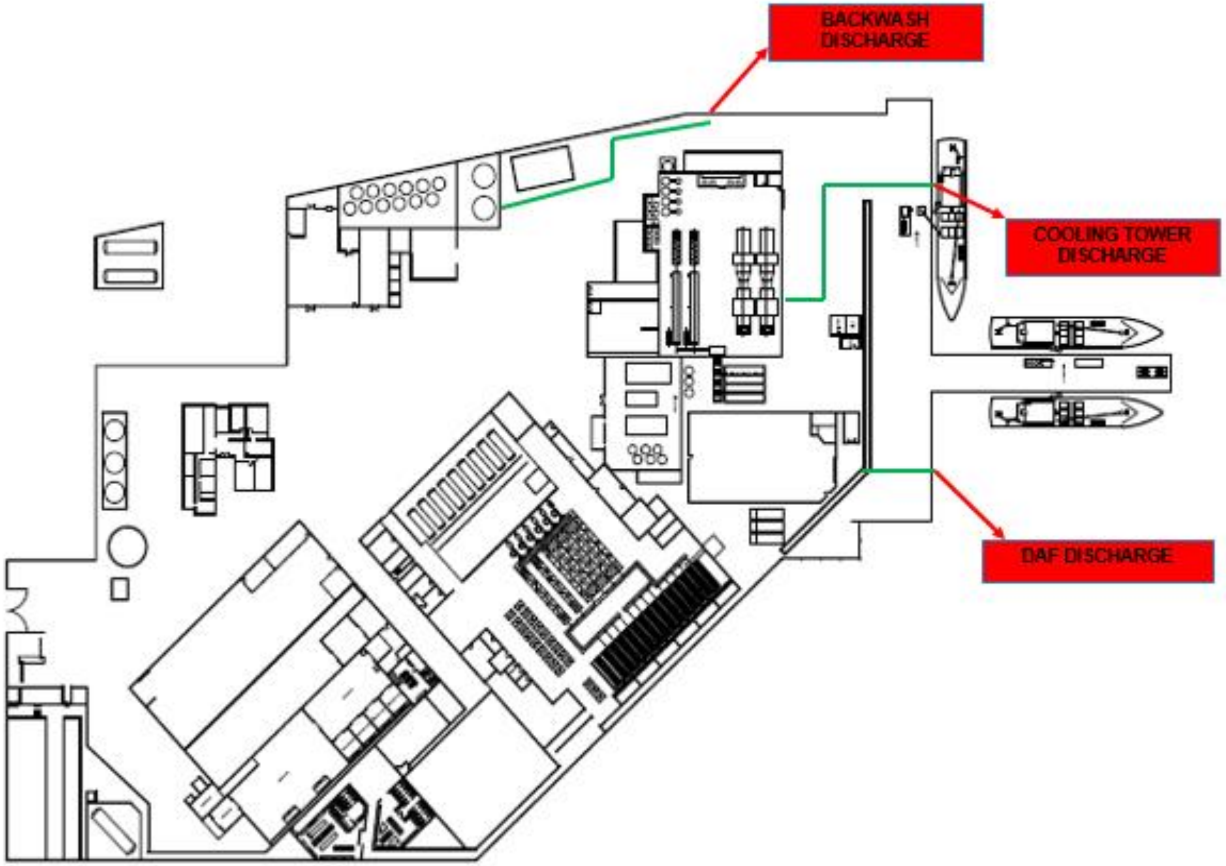

Figure 3-3: Layout of the fish factory indicating three wastewater discharging sites (Source: Van der Westhuizen 2016)

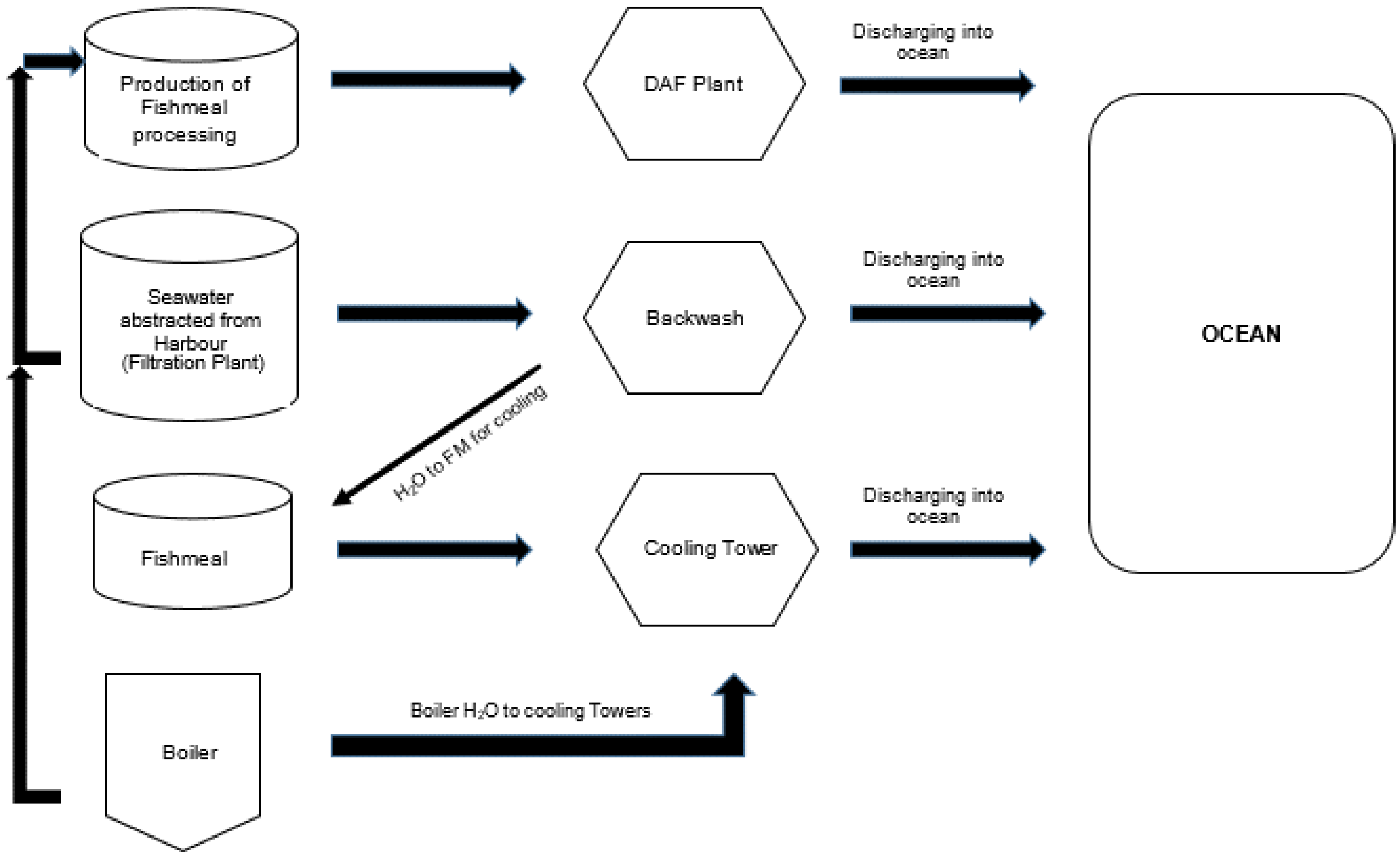

Figure 3-4: Wastewater Process Flow Chart (Source: Lukas 2018)

3.4 Sample Analysis

The wastewater samples collected from the sites in the factory were sent to two different laboratories for analysis. The physicochemical samples were sent to NamWater while the microbiological samples were sent to Namibian Standards Institute (NSI). This was done because NamWater only has the capacity to analyse physicochemical analysis while the NSI focuses on microbiological analyses. The samples were clearly labelled with the site name and date for identification purposes (Figure 3-5) and were kept refrigerated at a temperature of approximately 4 °C after collection and sent to the laboratory within 24 hours as described by Iscen et al. (2007). In the laboratory, the analyses of samples were done according to the methods in Table 3-1. Analyses were conducted as outlined in the Standards Methods for the Examination of Water and Wastewater (Clesceri et al. 1998), for the parameters of TDS, TSS, pH, BOD, COD, DO and FOG. Nutrients (nitrogen, nitrate and phosphorus) were analysed using the Spectroquant pharo 300 photometer from Merck and by following the guidelines provided by the United States Environmental Protection Agency (USEPA) (2016) guidelines. Ammonia was analysed using the guidelines of USEPA (2013). The BOD analysis was done using guidelines as described by Delzer and McKenzie (2003). The microbiological analysis of faecal coliform was conducted using the methods provided by the World Health Organisation (WHO) (1997).

The gravimetric method by Clesceri et al. (1998) was employed to analyse TSS in the collected wastewater sample. A membrane filter paper with a weight of 0.45 µm pore size was used to filter a 100 ml sample with a filtration unit. The suspended solids in the filter paper were placed in the oven and dried at 105 °C for 1 hour while wrapped in an Aluminium (Al) foil. The final load of the filter paper was documented and the difference in load of the filter paper represented the concentration in mg/l of TSS. TSS (mg/l) = (A – B) / V, where: A stands for the mass of filter + dried residue (mg); B for mass of filter (tare weight) (mg); and V for the volume of sample filtered (L).

The gravimetric method was used to analyse the TDS, as described by Clesceri et al. (1998). For dryness, the oven was set at a temperature of 105 °C for 1 hour and 30 minutes to dry a 100 ml filtrate which was in advance poured into a porcelain container weight. The secondary residue was moved to a desiccator for storage purposes and in order to dry it and maintain a constant weight. The obtained weight was calculated as the final TDS. TDS (mg/l) = (A – D x 1000) / S, where, A = final 105 °C weight of the dried residue + the tared dish, mg; D = tared dish weight, mg; and S = mL of sample volume.

The pH was measured using a pH meter proposed by Clesceri et al. (1998). The pH meter was first calibrated by rinsing the electrodes with distilled water and then blotted dried with absorbent paper. The tips of the electrodes were dipped into a beaker with sufficient buffer solution and allowed the electrode tips to immerse at least 2 cm to the bottom and margins with approximately 1 cm from the beaker. A thermometer was used to measure the temperature of the buffer solution. The pH meter was then switched on and the needle of the pH dial was adjusted to record the buffer pH. To complete the standardizing procedure, the electrodes were removed from the solution and rinsed with purified water and the meter instrument was placed on standby for sample reading. The electrodes and a beaker were cleaned with a ration of the sample. The tips of the electrodes were dipped into a beaker with sufficient buffer solution which allowed the electrode tips to immerse at least 2 cm to the bottom and margins with approximately 1 cm from the beaker. A thermometer was used to measure the temperature of the buffer solution. Note that the pH of the sample was carefully recorded on the dial meter by making sure that the needle had stopped moving before the pH was recorded.

The BOD analysis was conducted using the 5 Day BOD or BOD_5 method proposed by Clesceri et al. (1998). The wastewater samples were diluted using distilled water. Since the BOD load in wastewater might surpass the load of DO in an air-saturated sample, it is suitable for nutrients (nitrogen, phosphorus and trace metals) to stimulate bacterial growth (Chapman et al.1996). To enable the capacity of a pH of the incubated sample to foster bacterial growth, nutrients were added to the diluted wastewater sample. High BOD reduces DO because the demand for oxygen by bacteria is high as the bacteria consume dissolved oxygen in the water (Chapman, 1996). A preferred amount of the sample was made up to approximately 1 litre (l) with the diluted wastewater sample and mixed thoroughly to avoid bubble formation. The formation of bubbles may give inaccurate DO measurements (Delzer & McKenzie, 2003). Two flasks of BOD (300 ml) were siphoned with the mixed solution eliminating air bubbles. One flask was incubated for five days with a temperature of 20 °C, while in the other flasks, a 2 ml manganese sulphide (M_nS) and alkali iodide azide solution were added to the content and carefully mixed. After the mixture, the precipitate was resolved, and a 2 ml concentration of sulphuric acid (H_2SO_4) was added and thoroughly mixed to dissolve the precipitate until a brown-orange colour was obtained. A 100 ml of the solution was standardized with 0.0125 M of sodium thiosulfate ($Na_2S_2O_3$) and an additional 2 ml starch until the solution became blue. The standardized process continued until the solution turned clear. To determine the absence of the colour in the bottle, a white sheet paper was used. Once the liquid was clear, the amount of titrant used was noted as this gives an indication of the concentration of dissolved oxygen in the sample. To calculate the BOD of the sample the variance in DO was determined at the completion of the five days. DO was calculated as follows: BOD_5 mg/l = (D1 – D2) / P. Where, D1 = DO of the sample diluted immediately after preparation; mg/l; D2 = DO of a sample diluted after Five days of incubation at 20 °C, mg/l; and P = Decimal volumetric fraction of the sample used (l/dilution factor).

The COD parameter was analysed by using the closed reflux method proposed by Clesceri et al. (1998). A digestion and a catalyst solution were prepared for the analysis by adding a 10 g of potassium dichromate ($K_2Cr_2O_7$) and 33 g of mercuric sulphate ($HgSO_4$) to the 500 ml purified water. The solution was dried in the oven at a temperature of 105 °C for 2 hours. A 167 ml of sulphuric acid (H_2SO_4) was further used to supplement the solution as well. The solution was allowed to cool and diluted with 1000 ml of distilled water and titrated with Ferrous Ammonium Sulphate (FAS) of 0.025M to complement the digestion solution. The catalyst solution was prepared by dissolving 10 g of silver sulphate (Ag_2S) in a 1000 ml of H_2SO_4. A 3 ml of the wastewater sample was mixed with a 2 ml and 4 ml of the digestion and catalyst solution, respectively, in screw capped test tubes before being heated at 150 °C for 120 minutes in a pre-heated thermo reactor. The tubes were allowed to cool down in a test-tube rack before the readings on the photometer took place. The COD (mg/l) was calculated as follows = (A – B) x M x 8000 / ml sample. Where, A = Volume of used blank (ml); B = Volume of used sample (ml); M = Molarity of sample; and 1000 = Milli equivalent weight of oxygen x 1000 ml/l.

The partition, – a gravimetric method proposed by Clesceri et al. (1998), was used to analyse Oil, Fat and Grease. For the samples that were not acidified previously, a 1:1 hydrochloric acid (HCl) or 1:1 sulphuric acid (H_2SO_4) was added to the wastewater sample. In general, 5 ml is regarded as sufficient for a 1 l sample (Clesceri et al., 1998). A funnel was used to transfer the sample to a separator funnel and the sample was shaken for at least 2 minutes until it was well mixed. The mixture was allowed to settle until the layers separated. The liquid layer was then drained and a minimal quantity organic level was placed in the flask with the sample. The solvent level was drained with a funnel comprising of a filter sheet with 10 g anhydrous sodium sulphide (used as a drying agent to remove traces of water), both of which had been solvent-rinsed, in a spotless tarred distillation container. Where a clear solvent level could not be attained and a mixture of greater than approximately 5 ml existed, the mixture was drained while a solvent level was placed into a flask tube and centrifuged for 5 minutes at 2400 Revolutions per Minute (RPM). The centrifuged solid was moved to a suitable sieve funnel and the solvent was drained using a funnel with a filter sheet and 10 g sodium sulphide (Na_2S), both of which were cleaned thoroughly, into a clean, tarred purified flask. The aqueous and any residual solids were re-combined in a separator funnel. Samples with less than 5 ml of mixture, namely the clear solvent, were drained through a funnel using a filter sheet and slowly drained through the crystals of Sodium sulfate (Na_2SO_4). The aqueous layer was returned to the separating funnel. A 30 ml solvent was extracted from the solvent. A 20 ml of extraction solvent was added to the bottle and to the distilled flask. At a temperature of 85 °C in a water bath, the solvent was extracted from the flask. When visible condensation of the solvent stopped, the flask was removed from the water bath. The water bath and dry containers were covered on top, with the water bath still at 85 °C, for 15 minutes. Air was then immediately drawn through the flask with an applied vacuum for one minute and cooled in the desiccator for approximately 30 minutes before being weighed. To define the final sample quantity, either the sample bottle was first filled with water which was then poured into a 1 l tube, or the empty flask and lid were deliberated and the sample quantity was calculated. Oil and grease (mg/l - 1) were calculated as = 1000 x (Wa – Wb), where, Wa = weight conical flask + residue after evaporation; Wb = weight of pre weighted conical flask; and V = volume of sample.

The Dissolved Oxygen (DO) was analysed using the Winkler‘s method (Clesceri et al. 1998). A 300 ml sample was placed in a bottle by preventing bubble formation. The formation of bubbles may contribute to inaccurate DO measurements (Delzer & McKenzie 2003) by placing a stopper on the container. A 50 ml sample was placed in a flask, 2 ml of manganese sulphate ($MnSO_4$) together with a 2 ml of sodium azide solution was further added, which formed a precipitate. A stopper was tightly placed on the bottle and the bottle was shaken to ensure proper mixing of the contents. The precipitate was allowed to settle. A 2 ml of sulphuric acid (H_2SO_4) was added to the sample and shaken to diffuse the precipitate. A 50 ml of the sample was poured into a flask and tiltrated with sodium thiosulphate ($Na_2S_2O_3$) of 0.025 N using starch as an indicator. Starch forms a blue colour which changes to colourless. The DO load in the sample is comparable to the amount of ml of titrant used, each ml of sodium thiosulfate added equals 1 mg/l of DO.

Nitrogen (N) was analysed using the Merck N (114537) Spectroquant® Nova 60 instrument. A pre-treated sample of 10 ml was pipetted into an empty cell. Six droplets of the mixture N-2K were included and, the cell was sealed and mixed. The cell was warmed with a temperature of 120 °C in the thermo reactor for an hour. The closed cell cooled in tubes at room temperature and was briefly shaken for 10 minutes. The reagent N-3K 1 was placed into a reaction cell at 15 to 25 °C, with a tightly closed-off cell, and shaken for at least 1 minute. The sample was moved from the pipette into the tilted reaction while the cell was immediately closed off and held only by the screw cap. The hot cell was allowed to stand at least for 10 minutes to cool down and was then measured using a photometer.

Phosphorus (P) was analysed using the Merck P (100474) Spectroquant® Nova 60 instrument. A sample of 1 ml was pre-treated at 10 to 35 °C from a pipette into a reaction cell.

The pre-heated sample was mixed after digestion of total phosphate and shaken tightly while the cell was closed after cooling. Five drops of the reagent P-2K were added to the mixture, until the component was completely disintegrated. Within 5 minutes, the solution was shaken, and the sample reading was taken using the photometer to determine the orthophosphate.

The ammonia (NH_3) analysis was conducted by ensuring that the test tubes were set up to unfold the colour card which was then inserted into the test tubes with the coloured end in the sample. A sample of 20 ml was pre-treated and placed in the test tube at 20 to 30 °C. A 2 ml of reagent (NH_4-1) was added with a syringe, the tube was closed and mixed. After adding another mixture of NH_4-2 the reagent was shaken to be completely diffused and was then left aside for approximately 5 minutes. The final reagent (NH_4-3) was added to the tube, mixed thoroughly and allowed to settle for 7 minutes. The final reading of the colour card was then recorded using Merck ammonia (114558) to quantify the concentration of ammonia with a Merck Spectroquant® Nova 60 instrument.

The nitrate (NO_3) analysis was conducted by pre-treating the wastewater sample from the pipette which was placed into the reaction cell and 1 ml of the mixture (NO_3-1K) was added into the pipette before the cell get sealed and mixed. The hot cell was left to cool down for 10 minutes and measured in the photometer, using Merck nitrate (114764) to quantify the concentration of nitrates with a Merck Spectroquant® Nova 60 instrument.

Faecal coliform laboratory analysis was conducted by using the membrane filtration method proposed by WHO (1997). A quantity of 10 ml of the dissolved sample was presented into a sterilized filtration comprising a membrane filter with pore size of 0.45 µm. A sample was drained from the membrane filter. Bacteria that are indicator organisms were reserved in the filter and moved to an appropriate petri dish. After recuperation, the petri dish was moved to an incubator at a suitable temperature for an appropriate time until the indicator organisms replicated. Colonies, that were visible, were recognized and counted and the final outcome was conveyed in numbers of “colony forming units” (CFU) per 100 ml of original sample.

Figure 3-5: Wastewater samples prepared for the NSI with the site name and date (Source: Lukas 2018)

Table 3-1: Water quality parameters, units and analytical methods used for wastewater analyses of the fish factory (adapted from Shrestha and Kazama 2007)

Parameters	Abbreviations	Units	Analytic methods
Total Suspended Solids	TSS	mg/l	Gravimetric
Total Dissolved Solids	TDS	mg/l	Gravimetric
pH	pH	pH unit	pH-meter
Biological Oxygen Demand	BOD	mg/l	5-Day BOD Test (BOD_5)
Chemical Oxygen Demand	COD	mg/l	Closed Reflux
Fat, Oil & Grease	FOG	mg/l	Partition - Gravimetric
Dissolved Oxygen	DO	mg/l	Winkler’s Method
Nitrogen	N	mg/l	Photometric
Phosphorus	P	mg/l	Photometric
Ammonia	NH_3	mg/l	Photometric
Nitrate	NO_3	mg/l	Photometric
Faecal coliform	FC	cfu/100	Membrane filtration

3.5 Statistical Analysis

3.5.1 Statistical packages and programmes

The data was recorded using Microsoft Excel (Copyright © Microsoft 2013). Multivariate analyses were conducted using Plymouth Routines in Multivariate Ecological Research (PRIMER V6 Copyright © PRIMER-E Ltd. 2009). Tests for equal variances, Analysis of variance (ANOVA) and distribution of data was conducted using IBM SPSS Statistics 25 (@ Copyright IBM Corp. 1989 – 2018).

3.5.2 Data Analysis

A p-value of 95 % was regarded as significant in all statistical analyses. When comparing the mean concentration of physicochemical and microbiological parameters, the Standard Error of the Mean (SEM) was used to illustrate the error margin in the estimation of the mean (Townend 2002). The mean concentration of physicochemical and microbiological parameters was compared with the permissible limits set down by the WHO Standards (Ansari, 2017).

For this study, historical data collected from 2011 to 2016 was considered even though there was missing data for seasons of spring and summer. Although data was collected for all seasons during 2017 and 2018, the data from March to August in 2017 and 2018 was used in the analyses in order to allow the comparison with the historical data for both periods (2011 to 2016 and 2017 to 2018). In total, 170 data samples were analysed for the seasons of autumn and winter. Furthermore, to ensure that all seasons are included in the analysis, the data of spring and summer (2011 to 2016 and 2017 to 2018) were added to the comparable data of autumn and winter (2011 to 2016 and 2017 to 2018) to further analyse the impacts of the discharged wastewater on seasonal events in detail. Data readings which were found to be below detection limits were changed to zero (Grd et al. 2012). Normality and homogeneity of variances tests were conducted on the physicochemical and microbiological parameters for the different sites and seasons. The Levene's test for equality of variance was conducted to test the homogeneity status of variances (Grd et al. 2012). The groups of variances were found to be heterogeneous ($P < 0.05$) (Grd et al. 2012). Regarding normal distribution, the Shapiro Wilk's test indicated that the data deviated from normal distribution ($P < 0.05$) for all the variables in each sampling site. A logarithmic transformation was also applied although the data continued to deviate from normal and equal variances assumptions. Therefore, a non-parametric, Mann Whitney *U* Test was performed on the physicochemical and microbiological parameters to determine whether there were significant differences ($P < 0.05$) between the mean concentrations at the old and new sampled sites and between the seasons of autumn and spring. Furthermore, the Kruskall-Wallis analysis was done for each parameter at both the old and new sites. The Bonferroni post hoc analysis revealed further differences between sites per season. The non-parametric Spearman's rank-order correlation was conducted to determine the relationship between various physicochemical and microbiological parameters.

3.5.3 Multivariate analysis

Evaluating complex data that involves water parameters requires appropriate statistical tools hence the use of multivariate statistics over the years to categorize the trends of water quality (Ouyang et al. 2006; Shrestha and Kazama 2007; Iscen et al. 2008; Hamzah et al. 2016). As Hamzah et al. (2016) revealed, multivariate analysis can be used to identify spatial variations of water parameters as a result of anthropogenic and natural factors. Note that the data were log x+1 transformed for multivariate analysis in PRIMER V6 (Clarke and Gorley 2006). The data was log (x+1) transformed to limit skewness since the data was not normally distributed (Clarke and Gorley 2006). The Euclidean distance was performed to create matrices on log (x+1) transformed data across variables. The Euclidean distance was used as an appropriate similarity measure for environmental variables as opposed to the Bray-Curtis similarity index which is used for biological data (Clarke and Gorley 2006).

Resemblance matrices of log (x+1) transformed data of the sampling sites (old and new) and seasons (autumn, spring, summer and winter) were used to determine similarities between sampling stations and seasons (Clarke and Gorley 2006; Iscen et al. 2008). The samples collected while the decommissioned DAF plant was operational are reported as 'old' while the samples collected during the current DAF operations are reported as 'new'. Seasonal factors were used to illustrate differences between seasons.

For this study, the Analysis of Similarity (ANOSIM) was used to test the significant differences of the physicochemical and microbiological analysis at the old and new sampling sites and between the seasons (autumn, spring, summer and winter). To determine which parameters were most responsible for the similarities within the sites and between the seasons, a Similarity Percentage (SIMPER) procedure was performed. In order to determine the structure and relationships between the parameters, the Principal Components (PCAs) was used.

The one-way ANOSIM was conducted on the matrices of the old and new sites as well as seasons, to calculate a Global R-value. The ANOSIM permits the null-hypothesis testing, that there are no significant differences in the matrices between sites or seasons (Clarke and Gorley 2006). If the R-value is close to 0, then the similarities between sites are recognized and the null hypothesis is accepted (Clarke and Warwick 2001). Note that significant differences in similarities between sites are represented by R-values close to 1 (Clarke and Warwick 2001).

The Similarity Percentage (SIMPER) is used to define the percentage similarity within each site and the percentage dissimilarities between groups (Clarke and Warwick 2001). The SIMPER analysis can be used on both environmental and biological data and can be used to identify factors which most influence the groupings (Clarke and Warwick 2001; Clarke and Gorley 2006).

The Principal Component Analysis (PCA) is also a crucial tool of multivariate analysis that identifies patterns and relationships between variables (Simeonov et al. 2003; Iscen et al. 2008; Grd et al. 2012). The data from the covariance in the PCA method leads to eigenvalues and eigenvectors representing groupings of similar data with parameters that express the complete data set while maintaining minimal loss of original data (Vega et al. 1998; Helena et al. 2000; Iscen et al. 2008). The PCA identifies matrices that define variances of related bulk data sets changing them into a minor set of independent variables (Iscen et al. 2008). PCA's are typically used on environmental data instead of biological data (Clarke and Gorley 2006). For this study, the PCA was used to reduce large raw data by forecasting it into a lesser dimension while creating distinctions of similar parameters into groupings for both sites and seasons.

CHAPTER 4 : RESULTS AND DISCUSSION

The mean concentration of most parameters recorded higher values in the wastewater at the old sites when compared to the new sites. Therefore, it appears as if the new plant is very efficient in the removal of pollutants from the wastewater before being discharged into the surrounding environment. However, despite the better performance of the new plant, parameters such as FOG, DO, N, P, and NO_3, were not significantly different in the mean concentration between the old and new DAF, old and new BW and old and new CT. In addition, even though the mean concentrations were generally higher in the old plant, these differences were not statistically significant. The majority of the parameters had values that were above the allowable limits of the World Health Organisation (WHO) (Ansari, 2017), except for pH, FOG, P and NO_3 that displayed values below the allowable limits. Therefore, even though the new plant seems to be working better than the old plant, the wastewater concentration being discharged into the ocean is still not acceptable.

A total of 170 samples were used in the analyses of this study. The physicochemical parameters analysed included Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pH, Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Fat, Oil and Grease (FOG), Dissolved Oxygen (DO), nutrients nitrogen (N), phosphorus (P), ammonia (NH_3) and nitrate (NO_3) while microbiological parameters included Faecal Coliform (FC). The Standard Error of the Mean (SEM) obtained from the physicochemical and microbiological parameters from all the sites are presented. All data are presented in *APPENDIX C – RAW DATA OF PHYSICOCHEMICAL AND MICROBIOLOGICAL PARAMETERS.* The mean concentration of physicochemical and microbiological parameters was determined between the decommissioned (old) and current (new) Dissolved Air Flotation (DAF), old and new Backwash (BW) and old and new Cooling Tower (CT). The differences between autumn and winter were also recorded for the physicochemical and microbiological parameters. The physicochemical and microbiological parameters permissible limits of the World Health Organisation (WHO) used by the fish factory for comparability as best practices are presented in *APPENDIX D - WORLD HEALTH ORGANISATION (WHO) ACCEPTABLE LIMITS OF PHYSICOCHEMICAL AND MICROBIOLOGICAL PARAMETERS*.

4.1 Physicochemical parameters

4.1.1 Total Suspended Solids (TSS)

The mean TSS within the wastewater was significantly different between the old (1111 ± 259 mg/l) and new (277 ± 85 mg/l) DAF (Mann-Whitney $U = 134$, $P < 0.05$). TSS decreased 17 fold to 67 ± 22 mg/l at the old BW and two fold to 173 ± 79 mg/l at the new BW sites (Figure

4-1). The mean TSS at the old and new CT were 18 ± 5 mg/l and 8 ± 1 mg/l, respectively (Figure 4-1). The TSS value was above the permissible limits (15 mg/l) at all the sites (old and new) although the values in the old were higher than those in the new, except for the new CT which was 8 ± 1 mg/l (see *Appendix D*).

The mean Total Suspended Solids (TSS) concentration of the wastewater at the Dissolved Air Flotation (DAF) plant was higher than the permissible limits of the World Health Organisation (WHO) at the old and the new DAF plant. In general, the mean TSS in the wastewater was higher at the old DAF when compared to the new DAF, BW and CT (old and new). Similar to the observations at the old DAF, previous study on fish canning wastewater in Portugal (Raquel et al. 2016) reported high values of TSS with a mean > 2000 mg/l in wastewater from the fishing industry that contained solid contents. A comparable study on the performance assessment of a wastewater treatment plant in South Africa (Negwamba and Dinka 2019) also revealed that TSS concentration in the wastewater was above the permissible limits. Raquel et al. (2012) found that the presence of fish residues and guts from fish cannery operations increases TSS concentration in the wastewater. In this study, the fish factory is involved in the fish canning production process which produces multiple wastewater streams in the cannery processes from transporting, gutting, cooking, sterilization and cleaning of equipment, by producing raw material waste. As a result of the fish canning processes by the fish factory, a high TSS load may, therefore, be expected in the wastewater. The wastewater streams are transported to the DAF plant from the cannery and therefore, this may explain the high TSS in the wastewater at the old and new DAF plant. In addition, the low mean TSS in the wastewater at the new DAF in comparison to the old DAF may be a result of dosing with the coagulant, Aluminium Sulphide (Al_2S_3). Raquel et al (2015) added Al_2S_3, Ferric chloride ($FeCl_3$) and other coagulants into fish canning wastewater using a jar test apparatus to determine the dosage amount and found that, $FeCl_3$ was more effective in removing TSS from the wastewater when compared to Al_2S_3. However, they also stipulated that, coagulants should be selected based on the intended purpose of the wastewater. A jar test can be conducted to determine the correct coagulant dosage to be used in the wastewater of the fish factory. In addition, other coagulants including $FeCl_3$, Ferric sulfate ($Fe_2\,(SO_4)_3$ as found in literature (Amuda and Alade 2006; Miroslav et al. 2010; Raquel et al. 2015; Lat et al. 2017) can also be evaluated through a jar test, to determine the best possible method for the removal of TSS from the wastewater. Reducing solids in wastewater before discharging it into the ocean is crucial to reduce sedimentation (Templeton and Butler 2011). Note that an increased sedimentation in the marine environment is associated with turbidity (Naidoo and Olaniram 2014) and could adversely harm the breeding grounds of aquatic species (O'Toole 1997). The presence of high sedimentation in the Walvis Bay harbour was confirmed by a recent study

(Orani et al. 2019), and was thought to be caused by human induced industrial activities including wastewater from fish factories. For instance, in Walvis Bay, Philibert et al. (2017) found that the high suspended solids can lead to increased sedimentation and may result in higher mortality of marine species, while the decreased water quality and light limitation into the ocean and may affect the aesthetic value of activities such as recreational fishing.

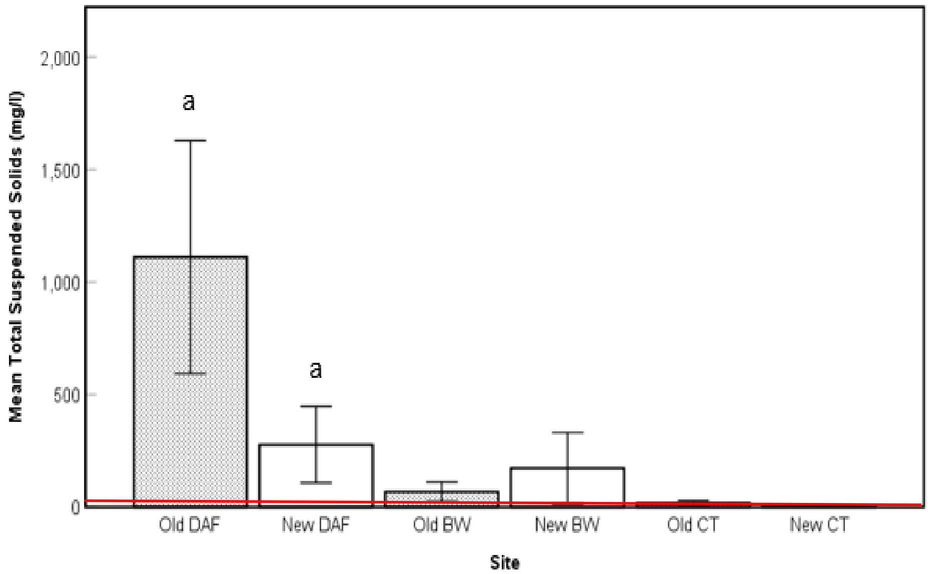

Figure 4-1: Mean (±SE) TSS concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—).

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney U test).

4.1.2 Total Dissolved Solids (TDS)

The mean TDS level in the wastewater between the old (32706 ± 1546 mg/l) and (33236 ± 474 mg/l) new DAF was not significantly different. The TDS reported at the old site (36444 ± 486 mg/l) and those reported at the new one (33149 ± 510 mg/l) BW indicate significant differences between the means (Mann-Whitney U = 161, $P < 0.05$) of the sites. At the old (36082 ± 679 mg/l) and new (34012 ± 747 mg/l) CT, the mean TDS indicated no significant differences between the old and new sites (Figure 4-2). All the values of TDS were above the permissible limits (1500 mg/l) (*Appendix D*) as set down by the WHO Standards (Ansari 2017).

The TDS concentrations in this study were higher than the acceptable limits (1500 mg/l), at all the sampled sites, for discharged wastewater as determined by the WHO standards (Ansari 2017). Previous studies on fish wastewater (Brown and Caldwell 2001; Dallas and Day 2004) reported that a high concentration of TDS in the wastewater evokes the presence of organic and inorganic dissolved material such as calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulphates. Fahim et al. (2001) found that fishing operations associated with canning activities increased organic and inorganic material in wastewater, and subsequently the level of TDS. Raquel et al (2012) described the wastewater produced during the various stages of the fish canning process as leading to a high TDS concentration. This includes the transportation of fish in the cannery which produces wastewater containing blood, fish and sand, and results in wastewater that is high in organic content, hence the presence of high TDS levels. Furthermore, during the process, a fish is placed in brine and fish parts such as guts, fins, scales and blood are removed, further resulting in wastewater with high TDS concentration as a result of the high protein content. The cooking process of the fish also results in wastewater that is high in organic content leading to a further increase of TDS concentration in the wastewater. In addition, the fish factory is also involved in the production of fishmeal, which includes the collection of fish solids such as heads, guts and tails for animal feed. Miroslav et al. (2010) reported that fishmeal production resulted in the release of wastewater with a high concentration in organic and inorganic matter and whose treatment is a challenge. The various processes involved in the canning of fish and in the fishmeal that takes place in this fish factory may thus be contributing towards the high TDS concentration found in the wastewater at all the old and new sites. Methods that can be explored to improve this, as suggested by previous authors (Ana et al. 2018; Ferraro et al. 2013) consists of reducing sardine off-cuts in the wastewater and of increasing the collection of fish products such as fish skin, scales and bones which can potentially be used in pharmaceutical and biomaterials industries. The removal of solids from wastewater reduces pollution strength and improves the quality of the wastewater (Miroslav et al. 2010). The procedure of fish waste segregation is not fully implemented in the cannery that can be applied by the fish factory to reduce the final volume of TDS in the wastewater. Similar to TSS, Fahim et al. (2001) found that $FeCl_3$ was successful in removing organic content in wastewater especially by reducing the TDS concentration. Management of the fish factory can evaluate the use of $FeCl_3$ in reducing TDS concentration in their wastewater by determining the correct dosage using the jar test apparatus. Previous studies on marine water quality (Botha 1995; O'Toole 1997; Weerasekara et al. 2015) found that pollution in the Walvis Bay harbour is caused by frequent wastewater discharges from fish processing industries, local phytoplankton blooms and high organic contaminants from commercial operations that cause excessive nutrient settlement in the harbour. For instance, in Walvis Bay, increased TDS in the ocean can affect the distribution and abundance of marine biota in the harbour and surrounding areas (MFMR 2018). High TDS in discharged wastewater into the ocean affects community structure (Morrison et al., 2001) by contributing to the growth of phytoplankton, resulting in potential effects on other aquatic species (Brown and Caldwell 2001; Tchobanoglous et al. 1991;

Bilottaa and Braziera 2008). TDS concentration from fish factory outlets in Walvis Bay was monitored and was reported to influence the capacity of marine water to hold Dissolved Oxygen (DO) and this has resulted in changes in the distribution and species richness of marine biota (MFMR 2018).

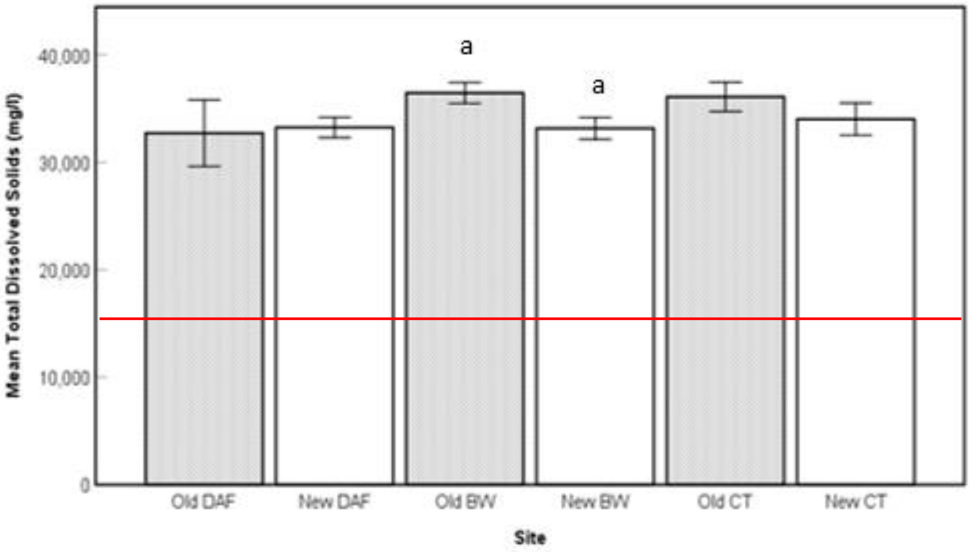

Figure 4-2: Mean (±SE) TDS concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney U test).

4.1.3 pH

The mean pH in the wastewater was not significantly different between the old (7 ± 0.10) and new (6 ± 0.1) DAF. The mean pH values at the old (7 ± 0.1) and new (6 ± 0.1) BW indicated significant differences between the sites (Mann-Whitney $U = 168$, $P < 0.05$) (Figure 4-3). The mean pH showed no significant difference at the old (7 ± 0.1) and new (7 ± 0.1) CT (Figure 4-3)The pH values fall within the permissible limits (6 – 9 mg/l) (see *Appendix D*) at all the sites as set down by the WHO Standards (Ansari 2017).

The pH values for this study at the old and new DAF (6 -7) as well as the BW and CT sites all fell within the acceptable limits and were similar to data reported on wastewater in other studies (Ansari 2017). Similar pH ranges have been reported for wastewater from fish factories discharged into the environment in Egypt and Portugal (Fahim et al. 2001; Raquel et al. 2012; Raquel et al. 2016). Those studies also found that, in comparison to other physicochemical parameters, pH appears to have a minimal effect in the wastewater. Therefore, the wastewater from the fish factory may not negatively impact the surrounding oceanic environment, as a pH of 6 – 9 is regarded as optimal to maintain growth of fisheries and aquatic species (Chapman et al.1996). An increase or decrease in pH can change the toxicity of other pollutants in aquatic systems. For instance, NH_3 is more harmful at high (pH > 8.5) and more toxic to aquatic biota (DWAF 1996c; Odjadjare and Okoh 2010; Morrison et al. 2001). More recently, a report on the observation of ocean acidification in marine water at St Helena Bay, South Africa, which has similar upwelling conditions as Namibia's coastline, revealed a correlation between lower pH levels and low oxygen levels (Tsanwani et al. 2020). Ocean acidification studies in Walvis Bay reported that low oxygen levels and consequently low pH levels affect the consumption efficiency and development and deteriorates shells of the shellfish and oyster used in the mariculture industry (Hupenyu et. al. 2021; Omoregie et al. 2019).

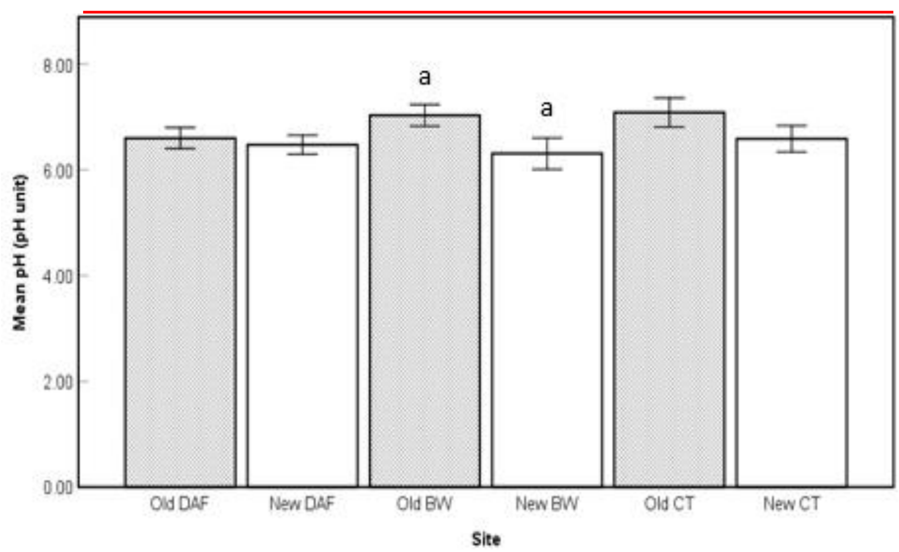

Figure 4-3: Mean (±SE) pH concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney U test).

4.1.4 Biological Oxygen Demand (BOD)

The mean BOD within the wastewater was significantly different at the old (1096 ± 282 mg/l) and new (154 ± 34 mg/l) DAF (Mann-Whitney U = 108, $P < 0.05$). The mean BOD at the old (57 ± 45 mg/l) and new (95 ± 32 mg/l) BW showed no significant differences between the sites. The mean BOD at the old (28 ± 16 mg/l) and new (6 ± 0.5 mg/l) CT showed no significant difference between the sites (Figure 4-4). The BOD value at the new CT was less than the acceptable limits (15 mg/l) and it was 6 ± 0.5 mg/l (see *Appendix D*).

Wastewater at the old DAF had a higher BOD concentration when compared to the wastewater at the new DAF. The higher BOD levels recorded at the old DAF could be a result of the fact that coagulants and flocculants were not used in the old DAF. It is significant to note that, the fish factory has been dosing coagulants and flocculants in the new DAF plant to reduce the pollutant load in the wastewater. This could explain the difference in BOD levels between the old and new DAF plant. Studies found that the treatment of wastewater in DAF plants mixed with the use of coagulants and flocculants stimulates the effective removal of solids and oils in the wastewater, therefore reducing the pollutant load including BOD levels before discharging it into the receiving environments (Dallas and Day 2004; Miroslav et al. 2010). Furthermore, all the sampled sites, except for the new CT, recorded BOD levels above the permissible limits. It is more likely that the low BOD levels at the new CT resulted from the process that takes place at the Cooling Towers where the seawater mixed with fresh water from the boilers is only used for cooling the towers and discharged into the ocean without any production usage. Moreover, despite the low BOD at the new CT, high BOD levels at the old DAF are a result of high organic contents in the wastewater (Raquel et al. 2015; Raquel et al. 2016). High organic content in canning wastewater is caused by an increase in blood, solids, soluble proteins and fish oil as postulated by similar studies (Miroslav et al. 2010; Raquel et al 2012; Raquel et al. 2016). Similarly, the operations in the fish factory such as the slaughtering of fish in the production process may therefore contribute to blood, solids and oil in the wastewater and consequently to high BOD concentrations. This process leads to high BOD in the wastewater and is comparable to the practices of the fish factory described above that cause an increase in organic content in the wastewater and in TSS and TDS concentrations as well. In this study, operations in the cannery do not focus on mechanisms to collect fish solids and blood to reduce organic content in the wastewater. Some means to recover waste in canning wastewater and to reduce pollutant waste may include the use of vacuum cleaners to clean the fish, the collection of blood and fish solids before the wastewater reaches the treatment plant and the equipment of the cannery with trays for solid waste accumulation (Raquel et al. 2012). The fish factory can further reduce BOD levels in the new DAF by exploring several coagulant dosages in the wastewater by means of a jar test that determines the influence of wastewater treatment, as advocated and suggested by other studies , on dosage amounts of TSS and TDS (Miroslav et al. 2010; Raquel et al 2015). Wastewater discharged with high levels of BOD into marine environments may accelerate the growth of bacteria, resulting in oxygen depletion in the water and may in turn cause mortalities of marine species (Brown and Caldwell 2001). Low oxygen conditions may be a result of both natural and anthropogenic activities in the Walvis Bay coastline (O' Toole 1997; Sakko 1998; van der Lingen et al. 2006). Effluent discharged from fish factories into the ocean contributes to low oxygen levels as a result of organic pollution in Walvis Bay (MFMR 2018). Recently, Pitcher and Louw (2021) found that anoxic conditions resulted in high mortalities of fish species and a high concentration of toxins in mussels in Walvis Bay. Similar effects of low oxygen on marine ecosystems were reported in South Africa which resulted in rock lobster (*Jasus lalandii*) walking out of the ocean, high mortality of pelagic fish and possible effects on fish spawning grounds (Moloney et al. 2013).

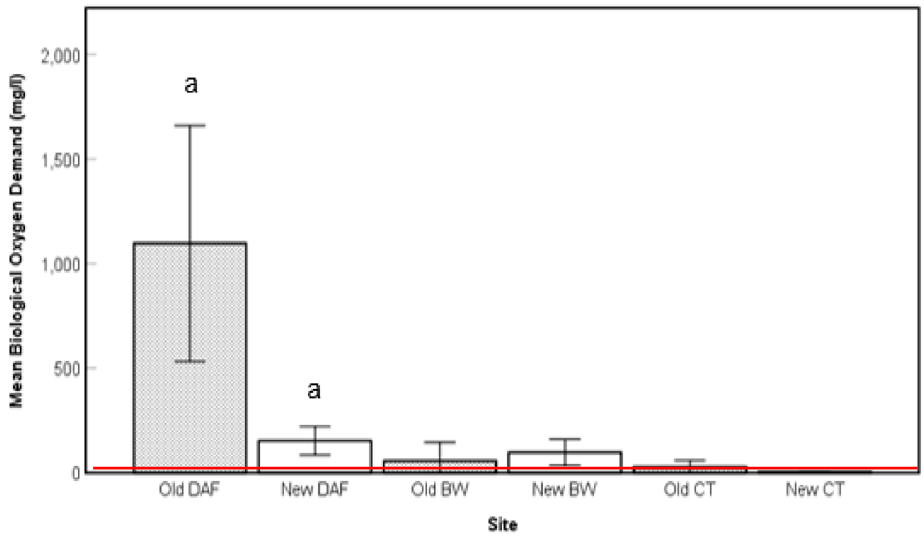

Figure 4-4: Mean (±SE) BOD concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney *U* test).

4.1.5 Chemical Oxygen Demand (COD)

The mean COD in the wastewater was not significantly different at the old (1131 ± 317 mg/l) and new (1265 ± 386 mg/l) DAF. The mean COD decreased to 3 and 4 fold less from the old and new DAF at the old (412 ± 107 mg/l) and new (334 ± 153 mg/l) BW, showing no significant differences between the two sites (Figure 4-5). The mean COD recorded at the old (428 ± 130 mg/l) and new CT (30 ± 4 mg/l) differed significantly (Mann-Whitney $U = 87$, $P < 0.05$) between the sites. The mean COD value at the new CT was below the acceptable limits (150 mg/l) which was 334 ± 153 mg/l (see *Appendix D*).

Increased COD concentrations in the discharged wastewater into aquatic systems, may amount to a decline in oxygen levels which harmfully affects aquatic life (Odjadjare and Okoh 2010). As some authors highlight, a decrease in oxygen in marine environments may cause high fish mortalities, a decrease in the spawning of fish and possible walkouts of species from the ocean (Moloney et al. 2013; Pitcher and Louw 2021). The COD concentrations at the old and new DAF, old and new BW as well as the old CT were higher than the prescribed acceptable limit (150 mg/l) as recommended by the WHO. This suggests that the COD concentrations in the discharged wastewater may adversely impact the receiving environment. The wastewater discharged from fish canning industries has increased COD content due to a high organic matter contained in that wastewater (Prasertsan et al. 1994; Raquel et al. 2016). Therefore, the high COD concentration in the discharged wastewater may have similar effects on the receiving environment as high BOD concentrations. The high COD levels specifically at the new DAF compared to the old DAF indicate the inefficiency of the DAF system combined with chemical dosing. Research on the effects of wastewater treatment plants in treating wastewater indicates that the DAF system's ability to remove pollutant waste from wastewater is determined by factors such as the wastewater quality, shortage of dosed chemicals as well as the operational capacity pressure by the DAF to carry out its function (Del Nery et al. 2007; Raquel et al. 2014). Therefore, there is a possibility that the new DAF plant is not operating at the correct capacity pressure and that an increase in the chemical dosing of coagulants and flocculants has to take place in the new DAF. Additionally, similar to TDS, TSS and BOD as explained above, studies on wastewater quality (Dallas and Day 2004; Miroslav et al. 2010) found that coagulants and flocculants dosed into DAF systems stimulate the removal of solids and oil in the wastewater and consequently reduces the COD levels. The COD concentration, however, fell in the permissible limits of no risk of effluents discharged into aquatic environments (Ansari 2017) at the new CT. The low BOD and COD recorded at the new CT could be as a result of the process that takes place at the Cooling Towers where, the seawater is mixed with fresh water from the boilers and only used for cooling the towers and discharged into the ocean without any production usage (Figure 3-3).

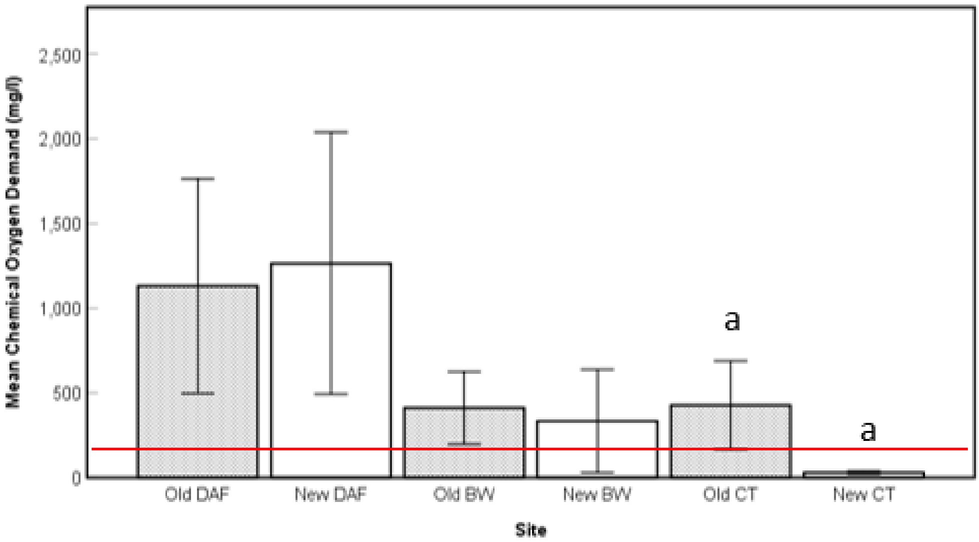

Figure 4-5: Mean (±SE) COD concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney *U* test).

4.1.6 Fat, Oil and Grease (FOG)

The mean FOG recorded in the wastewater at the old (0.8 ± 0.03 mg/l) and new (0.3 ± 0.1 mg/l) DAF showed no significant differences between the old and new sites. The mean FOG at the old (0.1 ± 0.03 mg/l) and new (0.1 ± 0.03 mg/l) BW displayed no significant differences. The mean FOG in the wastewater at the old (0.2 ± 0.1 mg/l) and new (0.2 ± 0.1 mg/l) CT indicated no significant differences between the sites (Figure 4-6). The FOG values at all the sites were within the allowable limits (0.500 mg/l) (see *Appendix D*) as set down by the WHO Standards (Ansari 2017).

The Fat, Oil and Grease (FOG) concentrations were below the permissible limits at all sites of both the old and new plant. The sardine and mackerel species are known as oily species and are used in the production process in the cannery and for fishmeal production (Fahim et al. 2001; Arumugam and Ponnusami V. 2017). Fahim et al. (2001) conducted a study on the efficient removal of pollutant waste from fish canning wastewater and found that the dosage of coagulant Aluminium Sulphide (Al_2S_3) was one of the effective methods in reducing the FOG content in the wastewater. Other studies further revealed that FOG levels are reduced efficiently in the wastewater as a result of coagulation and flocculation treatment methods (Miroslav et al. 2010; Raquel et al. 2012). Therefore, the low FOG values in this study could be explained by the dosage of the coagulant Al_2S_3 that was used by the fish factory at the DAF plant. For fish canning industries the coagulation or flocculation process is described by various authors (Miroslav et al. 2010; Raquel et al. 2015) as involving the process of colloidal particles where small mixtures of pollutants are evenly distributed in the wastewater. During the process, colloids are weakened, allowing particle collision of flocs to develop. The flocs are then detached from the water by flotation. The efficient and effective removal of pollutant waste from wastewater is dependent upon the quality and quantity of the coagulant.

Although previous studies found that fish canning operations contribute to the increase of FOG in wastewater (Miroslav et al. 2010), in this study, the FOG levels were low. Based on the WHO guidelines (Ansari 2017), the FOG concentration in the discharge wastewater would not negatively affect the receiving environment. High FOG concentrations may result in FOG which floats on water surfaces and may reduce oxygen transfer into the water (Sunny and Mathai 2013; Raquel et al. 2016). As a result, this can result in anoxic conditions and cause higher mortality of fish species and an increased concentration of toxins in shellfish among others (Pitcher and Louw 2021).

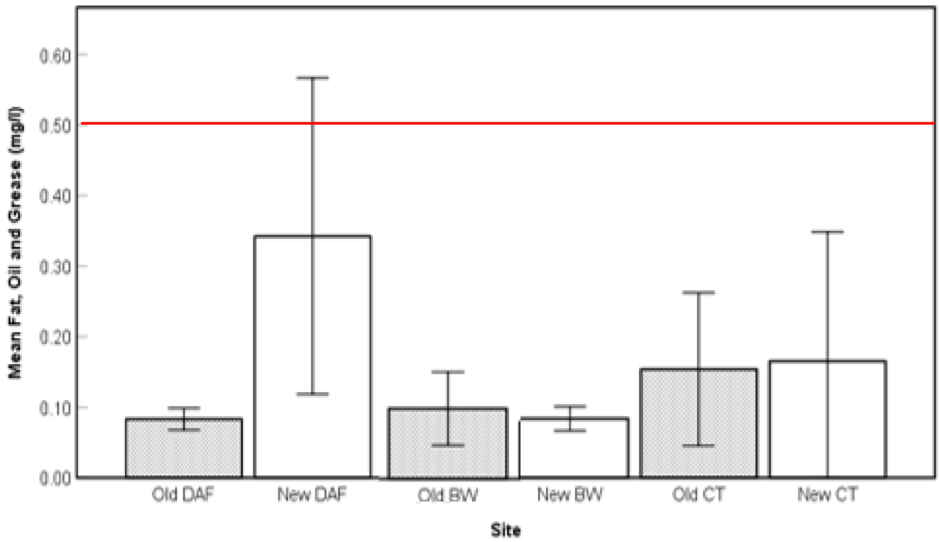

Figure 4-6: Mean (±SE) FOG concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

4.1.7 Dissolved Oxygen (DO)

The mean DO in the wastewater did not differ significantly at the old (0.7 ± 0.1 mg/l) and new (1 ± 0.3 mg /l) DAF sites. The mean DO in the wastewater was 2 ± 0.4 mg/l and 13 ± 10 mg/l at the old and new BW, respectively, and no significant differences between the old and new site were found. The mean DO at the old and new CT were 1 ± 0.3 mg/l and 2 ± 0.3 mg/l, respectively (Figure 4-7). The DO value was above the permissible limits (> 2.0 mg/l) at all the sites (old and new), except for the new BW which was 13 ± 10 mg/l (see *Appendix D*).

Dissolved Oxygen (DO) plays an important role in regulating water quality in aquatic environments (Brown and Caldwell 2001; Igbinosa and Okoh 2009; MFMR 2018). Well-aerated water is an indication of the system's health and ability to support biotic species (MFMR, 2018). For this study, the wastewater from the old and new DAF recorded DO levels < 2 while the old and new BW concentration was > 2. The WHO regulations permit DO levels > 2 in discharged wastewater. The wastewater from the BW is abstracted directly from the ocean and is either filtered or pumped back into the ocean. The filtered seawater is clarified through a filtration system that removes material and particles that may obstruct operations during production (Eades and Brignall 1995) this water is used during fishmeal production. The abstracted water that was not used for fishmeal production is pumped back into the ocean as backwash water (described in the wastewater process flow chart, Figure 3-4). Therefore, the high DO concentration in the water from the old and new BW could be explained by low organic content in the wastewater, as Chapman et al. (1996) established that waste discharge with high organic content may reduce DO concentrations. This was also supported by the Namibia's Ministry of Fisheries and Marine Resources baseline report for marine which stipulates that the wastewater discharged from fish factories in Walvis Bay contains low DO levels and high organic content, as a result of oxygen being depleted during the decomposition of organic matter (MFMR 2018). Additionally, similar to the findings of pH and BOD discussed, Suratman et al. (2016) found that the decomposition of organic matter in aquatic environments causes a reduction in pH and DO levels while BOD concentrations remain high. Chapman et al. (1996) further indicated that DO levels below 2 in aquatic systems, as found in the old and new DAF, can result in fish mortalities. Similar studies in South Africa on the effectiveness of wastewater treatment plants and on the impact of discharged wastewater on the physicochemical qualities of a receiving aquatic environments, (Morisson et al. 2001; Igbinosa and Okoh 2009) also found DO levels below the acceptable limits in the wastewater as a result of high levels of organic matter, which caused a high oxygen demand in the water. The results of this study are also in agreement with previous studies since high BOD and COD concentrations at the old and new DAF, were caused by high organic contents in the wastewater therefore reducing DO levels.

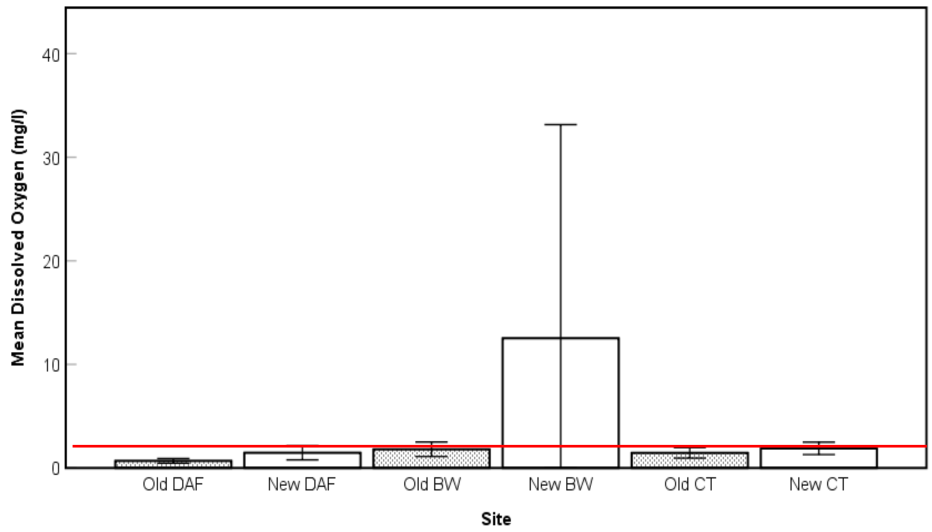

Figure 4-7: Mean (±SE) DO concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—).

4.1.8 Nutrients

Nutrients play a significant role in the growth of algae and assist in preserving stable aquatic environments (Brown and Caldwell 2001). The role of nutrients in the production of phytoplankton blooms during the upwelling process in the northern Benguela Current region, within Namibia's coastline, has been well established (Shannon 1985; Shannon et al. 1986; Boyd et al. 1987; Shannon 1989). The upwelling process occurs as a result of prevailing dominant south to south-westerly winds that convey near shore surface water offshore, which is in turn replaced by deeper cooler water from the bottom (Shannon 1989). The deep and bottom water is accompanied by rich nutrients and together with the high sunlight in the region, stimulates the advancement of phytoplankton which maintains the high abundance of marine species (Chapman and Shannon 1985; Sakko 1998). The supply of nutrients from the upwelling process combined with increased sunlight gives rise to high chlorophyll levels during warm conditions and increases phytoplankton production (Chapman and Shannon 1985; Shannon and Pillar 1986). The plankton production increases in abundance in the Walvis Bay area, which leads to local algal blooms (Shannon and Pillar 1986). Some blooms produce toxins that release harmful compounds into the ocean, and create low oxygen conditions as the bloom biomass decays, hence the decrease of the light conditions in the water that affects other marine vegetation (Sakko 1998; Michaelle and David 2011). The resultant phytoplankton blooms or eutrophication events have occurred frequently over the years (Hutchings et al. 2009), particularly in the offshore local area of Walvis Bay between late summer and autumn

(Chapman and Shannon 1985). As Shannon (1985) stated, mass mortalities of fish caused by these blooms have been reported in the inshore waters around Walvis Bay. Recently, the MFMR (2018) reported that eutrophication and phytoplankton blooms continue to impact ocean productivity especially the shellfish industry in the area. Therefore, wastewater discharged with high nutrient concentration causes great concern (Fahim et al. 2001).

4.1.8.1 Nitrogen (N)

During the study, the mean N value was 69 ± 17 mg/l at the old and 41 ± 15 mg/l at the new DAF and showed no significant differences between the sites. In comparison to the DAF sites, the mean N in the wastewater was 17 fold less at the old (4 ± 1 mg/l) and 4 fold less at the new (11 ± 4 mg/l) BW. The mean N value at the old and new CT were 10 ± 5 mg/l and 0.9 ± 0.1 mg/l, respectively, and no significant differences were found between the sites (Figure 4-8). The mean N values at all the sites fell below the allowable limits (35 mg/l) except for the old and new DAF which was 69 ± 17 mg/l and 41 ± 15 mg/l (see *Appendix D*).

The N concentration was higher at all the sites of the old plant when compared to those of the new plant. Wastewater from fish factories can be high in nutrients such as nitrogen (Miroslav et al. 2010; Tempelton and Butler 2011) as a result of blood and protein waste produced during the processing (Tay et al. 2006). Although the old and new DAF both released blood and proteins during production, the dosing and use of flocculants in the new DAF may be responsible for the decrease of the N concentration in the wastewater. It appears that the high N concentration in the wastewater at the old DAF could have been reduced if the coagulant Aluminium Sulphide (Al_2S_3) and flocculent (SEDIFLOC 407C), which are currently being utilised, were used at the old DAF plant. Miroslav et al. (2010) highlighted the effectiveness of coagulants and flocculants in reducing the load of pollutants such as N in the wastewater. In addition, the efficiency of coagulants and correct operational pressure capacity of the DAF system in removing pollutants such as TSS, TDS, BOD, COD and FOG from wastewater have been confirmed by other authors (Fahim et al. 2001; Del Nery et al. 2007; Raquel et al. 2014; Raquel et al. 2015). Fish processing industries that discharge wastewater in aquatic systems can disturb the immediate ecological system by often increasing nutrients discharged and eventually causing phytoplankton blooms (Islam et al. 2004). There are several industrial wastewater discharges from fish factories in the Walvis Bay harbour that may contribute to the and increase chances of phytoplankton blooms due to wastewater discharges with excessive nutrients (O’Toole 1997; Makuti et al. 2008; Aquafact International 2012; MFMR 2018).

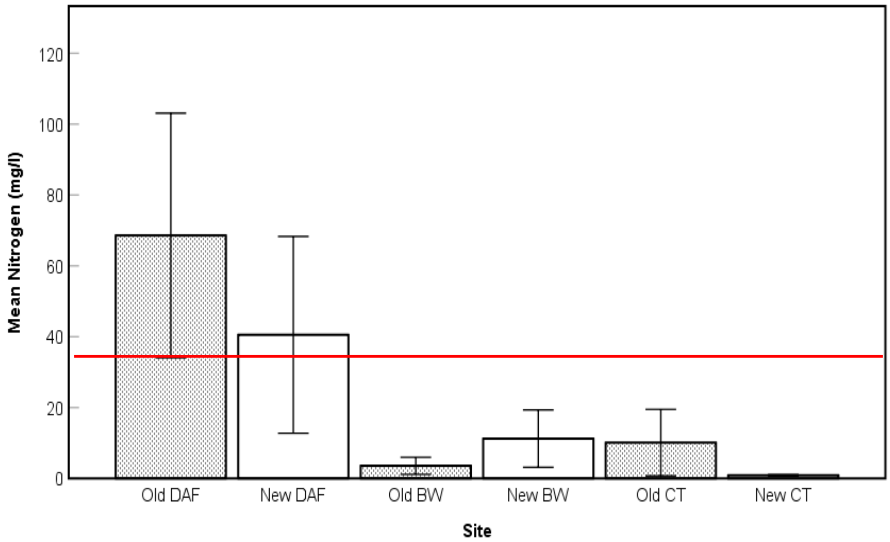

Figure 4-8: Mean (±SE) N concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—).

4.1.8.2 Phosphorus (P)

The mean P was not significantly different between the old (16 ± 3 mg/l) and new (8 ± 2 mg/l) sites. The mean P was 16 times less at the old (1 ± 0.2 mg/l) and 2 times less at the new (4 ± 0.8 mg/l) BW, and no significant differences were found between these sites. The mean P in the wastewater at the old (0.3 ± 0.3 mg/l) and new (0.5 ± 0.1 mg/l) CT, were not significantly different between the sites (Figure 4-9*)*. The P values at all the sites fell below the allowable limits (30 mg/l) (see *Appendix D*).

The presence of Phosphorus (P) in wastewater discharged into aquatic environments have similar effects as the ones of N (Islam et al. 2004; Tempelton and Butler 2011) described above. In this study, the P parameter was below the recommended permissible limits at all sampling sites of both the old and new plant. Although Chapman (1996) recognized P as one of the frequent nutrient contaminants in the wastewater, Tay et al. (2006) have however found that P concentration in the wastewater from the fishing industry is mostly minimal. This may explain the low P levels in the wastewater in the current study. There is also a possibility that the dosing of coagulants and flocculants might have reduced the P concentration in the wastewater as there is a difference in P levels between the old and new DAF.

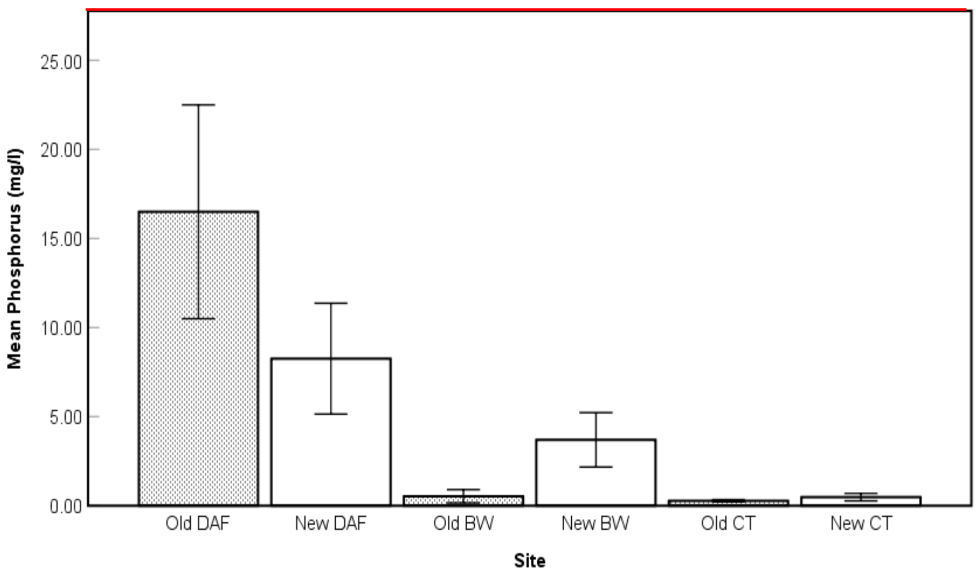

Figure 4-9: Mean (±SE) P concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

4.8.1.3 Ammonia (NH_3)

The mean NH_3 in the wastewater was 56 ± 15 mg/l at the old and 40 ± 9 mg/l at the new DAF, no significant differences were found between the sites. The mean NH_3 at the old (2 ± 1 mg/l) and new (43 ± 8 mg/l) BW, were not significantly different between the sites (Mann-Whitney $U = 52$, $P < 0.05$). The mean NH_3 in the wastewater at the old (6 ± 4 mg/l) and new (0.4 ± 0.4 mg/l) CT showed no significant differences between the sites (Figure 4-10). Recorded values at the old BW as well as the old and new CT were below the allowable limits (15 mg/l) while the NH_3 concentration at the other sites were above the allowable limits (see *Appendix D*).

The N concentration in water is in the form of Ammonia (NH_3) (Brown and Caldwell 2001). The NH_3 concentration in the wastewater was high at the old DAF when compared to the new DAF and the new BW. The NH_3 concentration for this study was above the allowable limits by WHO at the old and new DAF as well as the new BW, previous studies reported similar NH_3 (0.7 mg/l to 70 mg/l) concentration in fish processing wastewater (Chowdhury et al. 2010). Some studies (Chowdhury et al. 2010; Sunny and Mathai 2013; Selvi et al. 2014), reported that the increased concentration of NH_3 in fish processing wastewater is caused by the increase of blood and slime content, and associated with high BOD levels. High BOD concentrations were also recorded in this study as previously discussed. The increased NH_3 recorded in the wastewater in this study may be attributed to blood related substances from the fish butchering process in the cannery since the fish factory has no mechanisms in place to collect excess waste such as blood before it reaches the wastewater in the DAF plant. Previous studies have found that collecting blood during cannery operations may reduce excess waste content and minimize the pollutant load of parameters in the wastewater from fish processing factories (Raquel at el. 2012). Furthermore, wastewater discharged with surplus NH_3 load combined with increased pH can cause mortalities of biotic species (Chapman et al. 1996). In Walvis Bay, the NH_3 from fish factories wastewater was monitored and found to exceed the acceptable limits (MFMR 2018). The monitoring of NH_3 in Walvis Bay is conducted to prevent nutrients from causing coastal ecosystem issues such as eutrophication, phytoplankton blooms and low oxygen conditions which all eventually lead to fish mortalities as discussed (MFMR 2018).

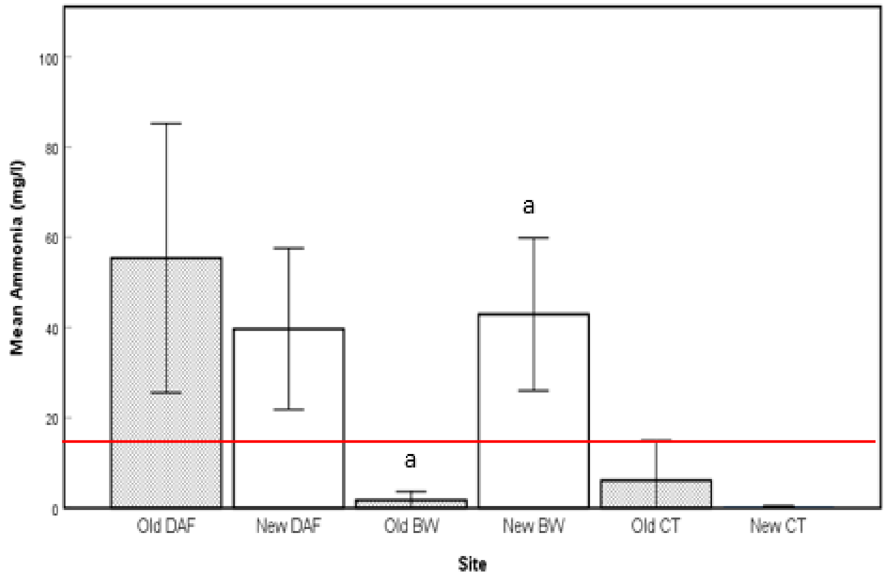

Figure 4-10: Mean (±SE) NH_3 concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney *U* test).

4.1.8.4 Nitrate (NO_3)

The mean NO_3 concentration in the wastewater recorded at the old DAF was 0.7 ± 0.2 mg/l and 0.9 ± 0.5 mg/l at the new DAF, with no significant differences occurring between the sites. The NO_3 concentration in the wastewater did not show any significant differences between the sites because the mean was the same at the old and new BW with 0.5 ± 0.0 mg/l. The NO_3 in the wastewater at the old (1 ± 0.5 mg/l) and new (3 ± 3 mg/l) CT were not significantly different between the sites (Figure 4-11). The NO_3 concentration at all the sites were below the allowable limits (50 mg/l) (see *Appendix D*).

Nitrate (NO_3) is a source of nutrients and the final product of inorganic nitrogen especially in polluted water (Naser 2006). The concentration of NO_3 in aquatic environments indicates the level of nutrients and the ability to support plant growth, as high levels of NO_3 promote phytoplankton growth (Smith et al. 1999). The NO_3 concentration in the discharged water from the fish factory's wastewater was below the WHO acceptable limit (50 mg/l). This suggests that the NO_3 concentration in the wastewater discharged from this study may have minimal effects on the marine ecosystem. This was also found in previous studies (Metcalf and Eddy 1991; Fahim et al. 2001) where NO_3 and other parameters were treated using various coagulants to reduce wastewater pollutant load before discharge.

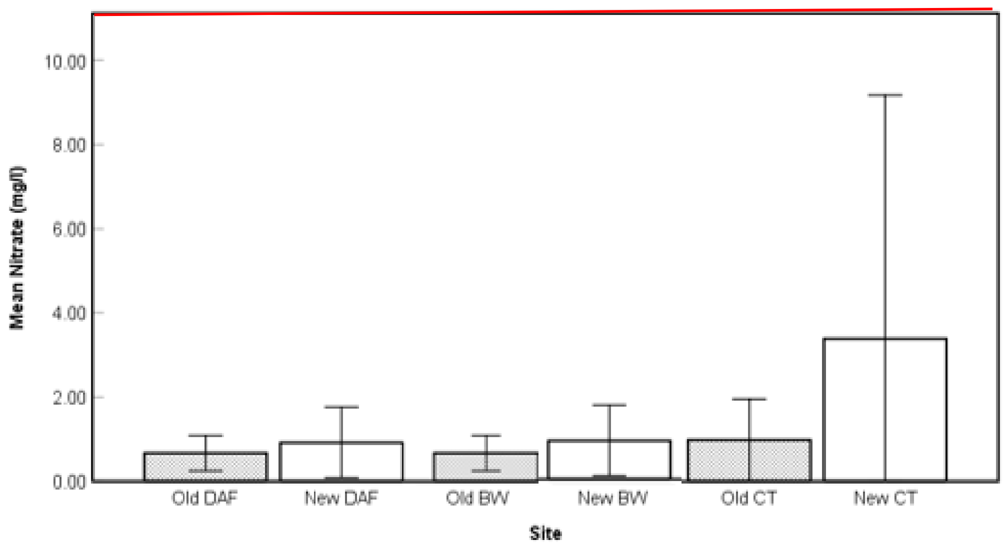

Figure 4-11: Mean (±SE) NO_3 concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

4.2 Microbiological parameter

4.2.1 Faecal Coliform (FC)

The mean FC was lower at all the new sites when compared to the old sites, the old and new DAF (982 ± 64 cfu/100, 584 ± 89 cfu/100), the old and new BW (451 ± 89 cfu/100, 187 ± 53 cfu/100) and the old and new CT (396 ± 85 cfu/100, 173 ± 43 cfu/100) (Figure 4-12). Although the mean FC concentration was higher at the old sites, there was only a significant difference (Mann-Whitney $U = 221$, $P < 0.05$) in the mean FC between the old and new DAF sites. The

FC values at all the sites were above the allowable limits (200 cfu/100) except for the new BW (187 ± 53 cfu/100) and the new CT (173 ± 43 cfu/100) (see *Appendix D*).

The Faecal Coliform (FC) bacteria is used as an indicator of wastewater quality and the possible presence of other microbial pathogens such as viruses and parasites (Brown and Caldwell 2001; Noblea et al. 2003; Tempelton and Butler 2011). A study conducted by Microslav et al. (2010) indicated that fish processing wastewater treated in DAF systems with a combination of coagulants and flocculants chemicals can reduce the pollutant load in the wastewater and subsequently decreases the FC bacteria concentration. For this study, the FC mean concentrations were higher at the old DAF in comparison to the new DAF. The discharged wastewater from the old and new DAF and old BW and old CT all fell above the permissible limits. The fish factory uses chlorination to disinfect the wastewater before discharging it into the ocean. The use of Ultraviolet (UV) light for disinfecting fish canning wastewater has been found to be successful in reducing the FC bacteria when compared to the conventional method of chlorination (Raquel et al. 2015; Mohamad et al. 2019). Excess FC in wastewater may result in anoxic water and contaminate aquatic species such as mussels (Brown and Caldwell 2001; Mossa 2006). The anoxic water occurs during the eutrophication process discussed earlier, which releases toxins from algae under adverse concentrations (Akpor and Muchie 2011). The algal toxins are concentrated into the food chain by mussels after consuming algae (Akpor and Muchie 2011). Mussels are particularly prone to absorbing the coliform bacteria present in the sea water which may lead to contamination of their tissues (Mossa 2006). In the Walvis Bay area, previous reports indicated that water with low oxygen leads to mortalities of fish species (O'Toole 1997) and high levels of bacteria in wastewater discharged into the ocean can contaminate shellfish. Since shellfish is a source of protein especially to the Namibian people living along the coast its contamination can negatively impact the economy of Namibia (Dahms et al. 2014). Different studies (Kazmi et al. 2008; Raboni et al. 2016) revealed that the FC concentration in the wastewater is dependent on high concentrations of parameters such as TSS and BOD. Therefore decreasing TSS and BOD levels consequently reduces FC as well. In addition, as previously discussed, finding the suitable coagulant and coagulant dosage through a jar test methodology can minimize the pollutant load of TSS and BOD in the wastewater (Raquel et al. 2015) and thus reduces FC concentration in the wastewater.

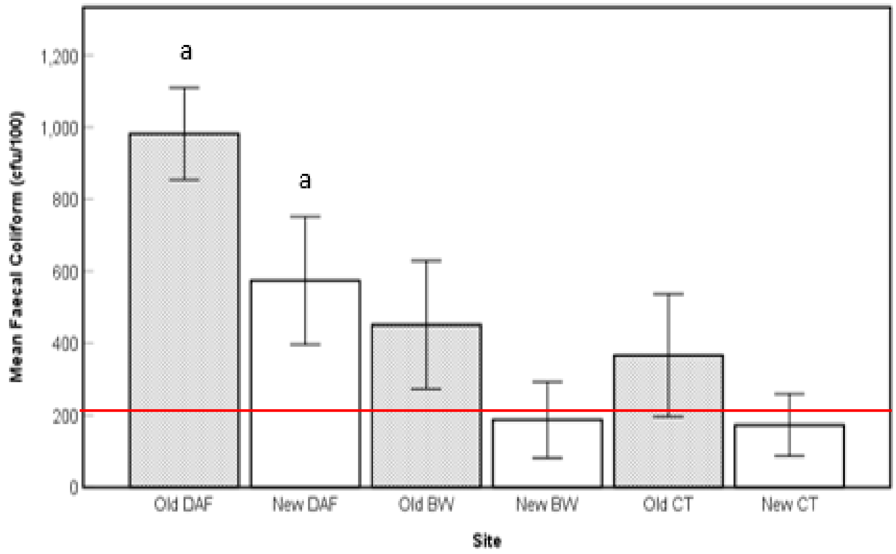

Figure 4-12: Mean (±SE) FC concentrations at the old and new Dissolved Air Flotation (DAF) sites as well as the World Health Organisation (WHO) acceptable limits as indicated by the red solid line (—)

The letter indicates a significant difference between the old (decommissioned) and new (current) DAF sites indicated by $P < 0.05$ (Mann Whitney *U* test).

4.3 Correlations between physicochemical and microbiological parameters

The non-parametric Spearman Rank Order correlations of most physicochemical and microbiological parameters revealed significant relationships (Table 4-1). The mean TSS was significantly correlated with most other parameters. It appears that P and NH_3 also had a significant relationship with most other parameters, including TDS, TSS, pH, BOD, COD, FOG and N. Therefore, TSS, P and NH_3 concentrations could be regarded as good indicators of the quality of wastewater released from these plants.

The significant correlations between the physicochemical parameters of TSS, pH, BOD, COD, nutrients (N, P, NH_3) and microbiological parameter (FC) in the wastewater from the fish factory was evident in this study. The relationship between the physicochemical and microbiological parameters in fish canning wastewater was found in previous studies (Kazmi et al. 2008; Raquel et al. 2012; Sunny and Mathai 2013; Raquel et al. 2016). The authors recognized the relationship among parameters such as BOD, COD and nutrients (Raquel et al. 2012); BOD, TSS and FC (Kazmi et al. 2008); nutrients (NH_3), BOD and COD (Sunny and Mathai 2013; Raquel et al. 2016); nutrients (N and P), BOD and COD (Raquel et al. 2016) that occur simultaneously within the wastewater. The interrelationship between these parameters indicates the presence of solids (TSS), organic matter such as blood, proteins and fish oil (BOD and COD), nutrients as well as bacteria (FC) in the fish factory's discharged wastewater.

Table 4-1: Spearman Rank Order correlation of the physicochemical and microbiological parameters (significant R values in bold)

	TSS	TDS	pH	BOD	COD	FOG	DO	N	P	NH_3	NO_3	FC
TSS												
TDS	-0.00											
pH	**0.23**	**0.34**										
BOD	**0.69**	**-0.16**	**-0.27**									
COD	**0.56**	**0.22**	0.02	**0.42**								
FOG	-0.04	0.11	0.12	0.02	0.02							
DO	-0.14	**0.19**	0.11	-0.13	-0.09	-0.09						
N	**0.39**	0.04	0.13	**0.39**	**0.41**	-0.03	-0.00					
P	**0.58**	**-0.19**	**-0.32**	**0.57**	**0.38**	**-0.16**	**-0.15**	**0.32**				
NH_3	**0.47**	**-0.16**	**-0.17**	**0.46**	**0.34**	-0.05	-0.07	**0.34**	**0.53**			
NO_3	-0.09	-0.04	0.14	-0.23	-0.09	0.02	0.10	0.04	-0.05	-0.02		
FC	**0.33**	-0.09	0.25	**0.29**	0.26	-0.13	-0.04	**0.19**	**0.25**	0.19	-0.12	

4.4 Seasonal differences in physicochemical and microbiological parameters

Due to the fact that sampling was only conducted during autumn and winter for the old plant, and for the seasonal comparison, analyses between historical data (old plant) and the new plant could only be conducted for these two seasons. The comparison of physicochemical and microbiological parameters were analysed between autumn and winter using the Mann-Whitney *U* test, the results are presented in Table 4-2 (*APPENDIX E – The analysis of Mean (±SE) physicochemical and microbiological concentrations during autumn and winter seasons using Mann-Whitney U test*). The Mann-Whitney *U* indicated that there were no significant differences ($P > 0.05$) of parameters in the wastewater between these seasons.

The TSS, TDS, COD, P, NH_3 and FC parameters in the wastewater during the autumn and winter seasons were above the allowable limits of the WHO guidelines. The DO level in winter, was within the acceptable limits.

4.4.1 Parameters describing seasonal differences between the old and new sites

As a result of the fact that no seasonal differences were found in the measured parameters of the old and new sites (Table 4-2), further in-depth statistical analyses were conducted to determine parameter differences between sites, per season *(see Appendix F presenting the parameters describing seasonal differences at the old and new sites).* The Kruskall-Wallis analysis was conducted for each parameter where mean concentrations of the old and new sites indicated significant differences. In order to determine significant differences at each site, per season, the Bonferroni post hoc analysis was conducted. The parameters presented in *Appendix F indicated* significant differences between sites, per season ($P < 0.05$).

During autumn, significant differences ($P < 0.05$) were recorded for the following parameters: TDS between the new and old BW as well as between the old and new CT; pH between the old and new BW; BOD between the old and new BW; COD between the old and new CT; NO_3 between the old and new DAF; NH_3 between the old and new BW; and FC between the old and new DAF (see *Appendix F*).

In comparison to autumn, the winter season recorded fewer significant differences ($P < 0.05$) between sites per season (*Appendix F*). These differences were for the COD, between the old and new CT as well as for NH_3 between the old and new BW.

Table 4-2: The analysis of Mean (±SE) physicochemical and microbiological concentrations during autumn and winter seasons using Mann-Whitney U test

Physicochemical and Microbiological Parameters	Autumn	Winter
TSS (mg/l)	273	216
TDS (mg/l)	34 700	35 000
pH (pH unit)	7	7
BOD (mg/l)	246	174
COD (mg/l)	445	688
FOG (mg/l)	0.16	0.17
DO (mg/l)	0.80	4.30
N (mg/l)	28	15
P (mg/l)	4.40	4.60
NH_3 (mg/l)	22	24
NO_3 (mg/l)	1.90	0.50
FC (cfu/100)	390	480

*****No significant differences recorded between seasons ($P > 0.05$)

4.5 Multivariate analysis

An Analysis of Similarity (ANOSIM) using all parameters between all the samples of the old and new plant produced a Global R-value of 0.084, indicating no significant differences. An ANOSIM between autumn, spring, summer and winters seasons produced a Global R-value of 0.008, also revealing no significant differences between the seasons. The Similarity Percentage (SIMPER) procedures performed on the physicochemical and microbiological parameters revealed a similarity of 11.71 within all samples of the old plant, and a similarity of 11.60 % within all samples of the new plant (Table 4-3 *a*). The parameters most responsible for similarities of the samples within the old plant were TDS (17.26 %), BOD (12.12 %), P (10.36 %) and TSS (10.28 %) whereas the parameters contributing the most to the similarity within the samples of the new plant were FOG (14.28 %), NO_3 (12.36 %), pH (11.84 %) and DO (9.36 %) (Table 4-3 *a*). The average dissimilarity between the two groups was a Euclidean distance of 24.70, with the highest contributors to this difference being pH (8.90 %), FC (8.80 %), COD (8.70 %), TDS (8.55 %) and NH_3 (8.45 %) (Table 4-3 *b*).

The SIMPER performed between the seasons, revealed a similarity of 15.88 (summer), 10.60 (spring), 8.17 (summer) and 10.58 (winter) (Table 4-4 (*a*)). The parameters most responsible for the similarities of the samples were NO_3 (21.31 %) and FOG (17.05 %) during autumn; FC (12.76 %), NH_3 (12.61 %), BOD (11.91 %), TSS (11.37 %) and COD (11.02 %) for spring; N (17.67 %), FC (14.89 %) and DO (12.85 %) for summer; and TSS (11.11 %), P (10.68 %), TDS (10.28 %), NH_3 (10.11 %) and COD (10.09 %) for winter (Table 4-4(*a*)). The average dissimilarity between the seasons was a Euclidean distance of 28.58, with the lowest contributors to this difference being N (0.001 %), FC (0.001 %), COD (0.002 %), TDS (0.002 %), NO_3 (0.002 %) and FOG (0.002%) (Table 4-5 (*b*)).

From the PCA, it appears that there is a bit of variation among the parameters at the sites (old and new) as well as during the seasons (autumn, spring summer and winter). The PC1 appears to be more associated with the old site and positively correlated with parameters such as DO and FC whereas it negatively correlated with the rest of the parameters (Table 4-6). The PC1 plot appears to be more associated with the old site (TSS, BOD, COD, FOG, N, P, NH_3 and FC) while the new site is more associated with PC2 (TDS, pH, DO and NO_3) (Figure 4-13) For the seasons, PC1 seems to be more associated with parameters such as pH and DO during autumn and winter whereas PC2 is more associated with TSS, TDS, BOD, COD, NH_3, NO_3, P, N, FOG and FC during spring and summer seasons (Figure 4-14).

The PCA is a crucial multivariate tool that identifies patterns and relationships between variables (Simeonov et al. 2003; Iscen et al. 2008; Grd et al. 2012). The PCA's support the correlation above, where the findings from the old site have shown that there was a strong relationship between the parameters such as TSS, BOD, COD, FOG, N, P, NH_3 and FC once they are grouped together. The relationship of this group of parameters may signify the presence of solids, organic matter, blood, proteins and oil as well as nutrients and bacteria in the discharged wastewater (Kazmi et al. 2008; Raquel et al. 2012; Sunny and Mathai 2013; Raquel et al. 2016). Associated parameters of TDS, pH, DO and NO_3 at the new site, further imply the high presence of organic matter at the new site in the wastewater. The PCA further indicated a seasonal association between pH and DO during autumn and winter. As mentioned previously, the DO levels in the discharged wastewater from the fish factory was low (below the WHO acceptable limits), implying that the final wastewater from the factory may contribute towards increased seasonal events of local algal blooms as Shannon (1985) stated that blooms production are a result of increased nutrients which favour low oxygen conditions for the bloom biomass decays in autumn. Similarly, the relationship between TDS, BOD, COD, NH_3, NO_3, P, N, FOG and FC during spring and summer seasons could suggest that, as a result of these parameters, organic matter, solids and nutrients may stimulate conditions for sulphur eruptions. Chapman and Shannon (1985) found that a rise in organic matter consumes oxygen during the decomposition process leading to provisional low oxygen levels at the bottom of the ocean. In addition, Griffiths et al. (2004) stated that sufficient attention has not been given to possible impacts of industrial activities in discharging nutrients such as N and P and that this is a worldwide issue. Wastewater discharged into the ocean from processing plants contains harmful substances which can result in short-term and long-term impacts on environments and biota at the point of discharge especially when there are too many processing plants that are discharging wastewater in one area (Islam et al. 2004). Walvis Bay harbour has approximately 12 processing plants that discharge wastewater into the harbour (MFMR 2018). Short-term effects of wastewater discharges may result in nutrient increase and could lead to habitat diversity and food production causing a rise in fish species, but the long-term effects may include excessive plankton blooms which may decrease fish diversity as a result of algal blooms (Islam et al. 2004). Despite the possible impacts of discharged wastewater into the environment, some authors (Griffiths et al. 2004; van der Lingen et al. 2006) suggested that the levels of pollution from industries in the northern Benguela may have little effects on the marine ecosystem in comparison to industrialized regions. However, since 2004 and 2006, there is a possibility that pollution from increased industrial activities have been having effects on the marine ecosystem and that things might have changed in the northern Benguela.

Despite the possible effects of discharged wastewater on the marine biota, anthropogenic and natural phenomena may also influence the marine living organisms off Walvis Bay's coast. In addition, climate change may also be a contributing force that impacts the resources of the northern Benguela due to change in wind patterns that increases upwelling and intensifies Benguela Niños (Shannon et al. 1996; van der Lingen et al. 2006). Therefore, the combination of environmental variabilities may have shaped and impacted the availability of fisheries and other living resources in the Walvis Bay shoreline over time (van der Lingen et. al. 2006).

Table 4-3: SIMPER indicating the physiochemical and microbiological parameters that are most responsible for a) average similarity and the % contribution of each factor towards the similarity within each group (old and new plants) and b) the average dissimilarity between the old and new plant and the % contribution of each of the factors towards the dissimilarity of the two DAF plants. A resemblance matrix using Euclidean distance was used in the analysis.

a) Average similarity and the % contribution of each factor towards the similarity			b) Average dissimilarities between the old and new DAF plant groups			
Site	Old	New	**Site**	Old	New	
Average Squared Distance	11.71	11.60	**Average Squared Distance**	24.70		
Parameter	% Contribution	% Contribution	**Parameters**	Average Value	Average Value	% Contribution
FOG	2.06	14.28	pH	0.36	-0.31	8.90
NO_3	4.60	12.36	FC	0.30	-0.26	8.80
pH	6.60	11.84	COD	0.32	-0.28	8.70
DO	6.69	9.36	TDS	0.03	-0.03	8.55
COD	6.11	8.97	NH_3	-0.25	0.22	8.45
NH_3	7.24	8.60	P	-0.14	0.12	8.30
FC	9.63	7.93	BOD	0.04	0.04	8.26
N	9.05	7.01	N	0.15	-0.13	8.25
TSS	10.28	6.83	TSS	0.11	-0.09	8.23
P	10.36	6.50	DO	-0.14	0.12	7.97
BOD	12.12	5.53	NO_3	-0.04	0.04	7.83
TDS	17.26	0.99	FOG	0.00	0.00	0.00

Table 4-4(*a*): SIMPER indicating the physiochemical and microbiological parameters that are most responsible for the average similarity and the % contribution of each factor towards the similarity within each group (autumn, spring, summer and winter) and b) the average dissimilarity between the autumn and winter seasons and the % contribution of each of the factors towards the dissimilarity.

Note that a resemblance matrix using Euclidean distance was used in the analysis of data contained in this table.

a) Average similarity and the % contribution of each factor towards the similarity

Season	Autumn	Spring	Summer	Winter
Average Squared Distance	15.88	10.60	8.17	10.58
Parameter	% Contribution			
TSS	5.46	11.37	9.12	11.11
TDS	7.03	4.97	6.10	10.28
pH	8.62	7.40	7.60	9.43
BOD	6.08	11.91	8.43	9.64
COD	5.91	11.02	5.86	10.09
FOG	17.05	0.59	0.77	5.30
DO	7.24	9.2	12.85	6.81
N	5.13	8.71	17.67	7.69
P	7.06	9.40	8.52	10.68
NH_3	5.46	12.61	8.18	10.11
NO_3	21.31	0.06	0.00	0.00
FC	3.44	12.76	14.89	8.86

Table 4-5(*b*): SIMPER indicating the physiochemical and microbiological parameters that are most responsible for the average dissimilarity between the seasons and the % contribution of each of the factors towards the dissimilarity of the two DAF plants

a) Average dissimilarities between the seasonal groups

Season	Autumn Winter	Spring Summer	Autumn Spring	Winter Spring	Autumn Summer	Winter Summer
Average Squared Distance	27.18	18.83	28.58	21.30	25.91	18.97
Parameter	% Contribution					
TSS	0.69	0.77	0.69	0.77	0.67	0.87
TDS	0.60	0.00	0.52	0.67	0.58	0.63
pH	0.79	0.63	0.77	0.62	0.82	0.69
BOD	0.79	0.85	0.82	0.77	0.80	0.79
COD	0.62	0.69	0.72	0.75	0.00	0.67
FOG	0.30	0.00	0.26	0.00	0.26	0.00
DO	0.91	0.88	0.91	0.81	0.84	0.89
N	0.49	0.77	0.00	0.70	0.70	0.73
P	0.76	0.81	0.74	0.87	0.66	0.86
NH_3	0.83	0.91	0.90	0.91	0.82	0.85
NO_3	0.20	0.00	0.20	0.00	0.20	0.00
FC	0.00	0.83	0.73	0.79	0.66	0.73

Table 4-6: *(a)* Coefficients in the combinations of physiochemical and microbiological parameters for the sites (old and new) and seasons (autumn, spring, summer and winter) *(b)* Eigenvalues and corresponding percentage of parameters explained by each of the PCA at the sites and seasons

(a) Eigenvectors			(b) Eigenvalues			
Variable	PC1	PC2	PC	Eigenvalues	% Variation	Cumulative % Variation
TSS	-0.44	-0.03	1	3.39	28.30	28.30
TDS	-0.09	0.15	2	1.60	13.30	41.60
pH	-0.01	-0.17	3	1.42	11.80	53.40
BOD	-0.34	0.09	4	1.03	8.60	62.0
COD	-0.44	0.07	5	0.88	7.30	69.40
FOG	-0.12	-0.65				
DO	0.02	0.15				
N	-0.34	-0.05				
P	-0.36	0.05				
NH_3	-0.40	0.16				
NO_3	-0.08	-0.67				
FC	0.24	0.13				

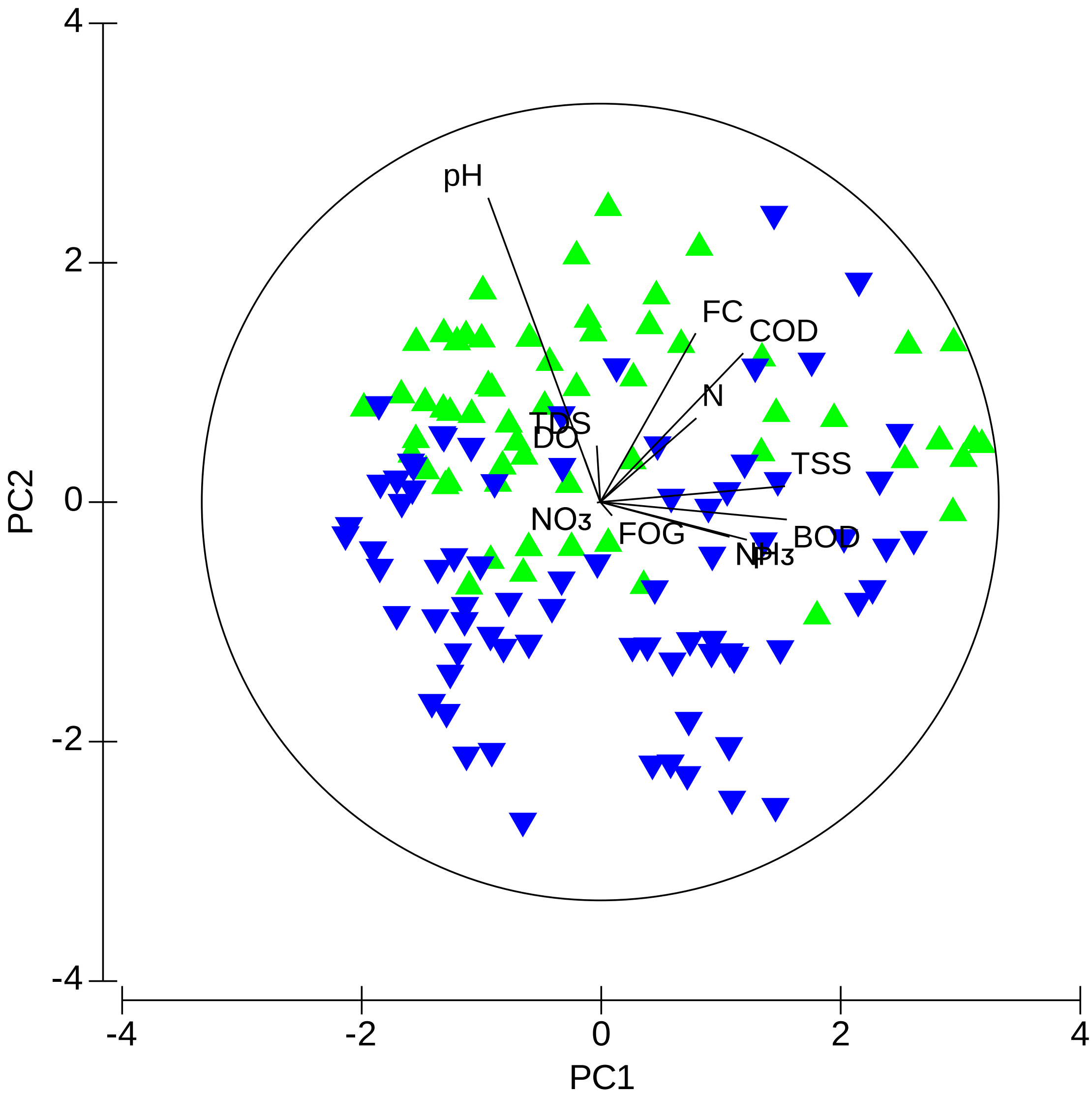

Figure 4-13: Principal Components Analysis (PCA's) on the normalized physicochemical and microbiological parameters at the old (▼) and new (▲) sampling sites

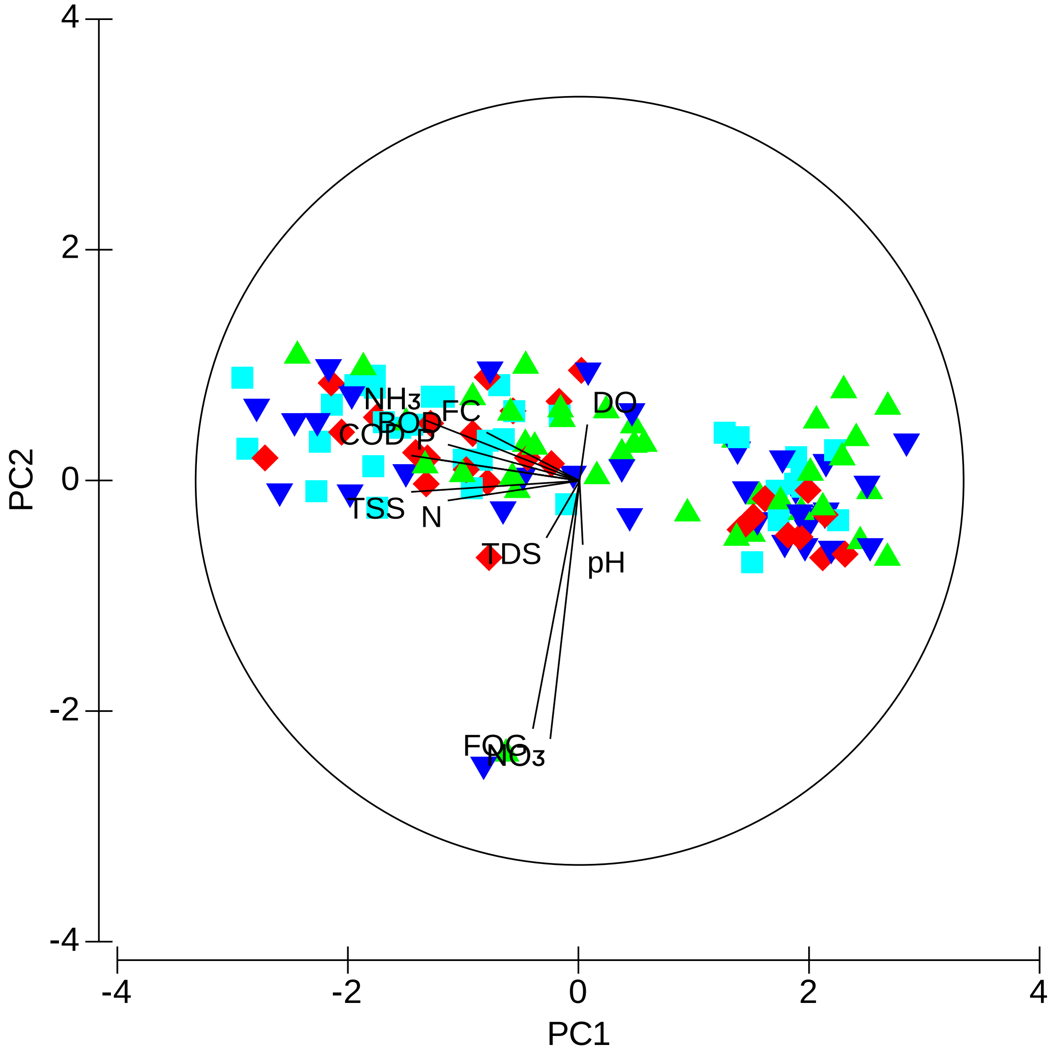

Figure 4-14: Principal Components Analysis (PCA's) on the normalized physicochemical and microbiological parameters during the seasons of autumn (▲) spring (■), summer (◆) and winter (▼)

CHAPTER 5 CONCLUSION AND RECOMMENDATIONS

5.1. Conclusions

This study revealed that the mean concentration of most parameters was higher in the wastewater at the old sites than at the new sites. It appears that the new DAF plant is better able to remove pollutants from the wastewater before discharging into the surrounding environment than the old DAF plant. Although the new plant generally performed better than the old plant, parameters such as FOG, DO, N, P, and NO_3, did not show any significant differences in the mean concentration between the old and new DAF, old and new BW and old and new CT. The majority of the parameters recorded had values that are above the allowable limits of the World Health Organisation (WHO) (Ansari 2017), except for pH, FOG, P and NO_3 that all displayed values below the allowable limits. Therefore, even though the new plant seems to be working better than the old plant, the wastewater concentration being discharged into the ocean is not yet acceptable.

This study clearly indicated that the removal of physicochemical and microbiological parameters from fish canning wastewater poses challenges as revealed by previous studies (Raquel et al. 2012; Sunny and Mathai 2013; Raquel et al. 2016). This is due to the interrelationship among parameters leading to the presence of solids (TSS and TDS), organic matter (BOD and COD), nutrients (N, P and NH_3) and bacteria (FC) in the discharged wastewater. Although parameters such as FOG could be reduced in the wastewater due to the possibility of dosing with the coagulant Aluminium Sulphide (Al_2S_3) (Fahim et al. 2001), the improvement in the reduction of pollutant load from the wastewater for other parameters could have been attained based on the type of chemicals used, quantity of the dosed chemicals and the operational capacity pressure by the DAF (Del Nery et al. 2007; Raquel et al. 2014).

Furthermore, the study revealed that the discharged wastewater may contribute to the exacerbation of seasonal events especially during autumn and winter in the Walvis Bay vicinity. The DO levels in the discharged wastewater from the fish factory was low (below the WHO acceptable limits). Therefore, this could imply that the final wastewater from the fish factory may contribute towards increased seasonal local algal blooms. Shannon (1985) stated that algal blooms favour low oxygen conditions when the bloom biomass decays in autumn. Similarly, the relationship between TDS, BOD, COD, NH_3, NO_3, P, N, FOG and FC during spring and summer seasons could suggest that, as a result of these parameters, organic matter, solids and nutrients may stimulate conditions for sulphur eruptions.

The lessons learnt from the findings of each objective of this study in conjunction with the literature review demonstrate an in depth knowledge of wastewater treatment from fish factories that management can use to improve wastewater management processes. For instance, the objective to determine the concentrations of parameters in the wastewater discharged from the new DAF plant clearly indicated that the new plant is very efficient in the removal of pollutants from the wastewater before being discharged into the surrounding environment. However, literature also revealed that, to enhance efficiency, the installation of new wastewater systems can be combined with the removal of solids from wastewater to reduce pollution strength and improve the quality of the wastewater (Miroslav et al. 2010). Currently, the procedure of fish solid segregation is not fully implemented in the fish factory's cannery.

Furthermore, lessons learnt from the objective, to compare the parameters in the wastewater of the decommissioned and the new DAF plant within different seasons, the study revealed that the discharged wastewater may contribute to the exacerbation of seasonal events especially during autumn and winter in the Walvis Bay vicinity. The DO levels in the discharged wastewater from the fish factory was low (below the WHO acceptable limits). Therefore, this could imply that the final wastewater from the fish factory may contribute towards increased seasonal local algal blooms. Shannon (1985) stated that algal blooms favour low oxygen conditions when the bloom biomass decays in autumn. Similarly, the relationship between TDS, BOD, COD, NH_3, NO_3, P, N, FOG and FC during spring and summer seasons could suggest that, as a result of these parameters, organic matter, solids and nutrients may stimulate conditions for sulphur eruptions. However, literature (Shannon et al. 1996; van der Lingen et al. 2006) also revealed that other factors such as, anthropogenic and natural phenomena may also influence the marine living organisms off Walvis Bay's coast. These phenomena could shape and impact the availability of fisheries and other living resources in the Walvis Bay shoreline over time (van der Lingen et. al. 2006).

Additionally, this study showed a relationship among parameters at the old and new DAF plant. This was also supported by previous studies (Raquel et al. 2012; Kazmi et al. 2008; Sunny and Mathai 2013; Raquel et al. 2016) that recognized the relationship among parameters such as BOD, COD and nutrients TSS and FC, that occur simultaneously within the wastewater. The correlation between these parameters indicates the presence of solids (TSS), organic matter such as blood, proteins and fish oil (BOD and COD), nutrients as well as bacteria (FC) in the fish factory's discharged wastewater.

5.2. Recommendations

This study recommends that the management of the fish factory integrates various methods of pollution control to further reduce the pollutant load of the discharged wastewater to meet the WHO acceptable limits. Effective treatment measures can reduce waste loads that are produced during the fish canning processing. One of the first steps in reducing the pollutant load of the fish factory wastewater is segregation as this will ensure the removal of solids from wastewater by reducing pollution strength and improving the quality of the wastewater before any treatment takes place. This may entail the use of vacuum cleaners to clean the fish, the collection of blood and fish solids as well as the equipment of the cannery with trays for solid waste accumulation before it reaches the treatment plant.

Furthermore, performing a jar test to determine the best possible dosage as well as the type of chemicals to be used has proven to be successful in fish canning wastewater treatment elsewhere. Apart from using the coagulant Aluminium Sulphide (Al_2S_3), the fish factory can evaluate the use of Ferric chloride ($FeCl_3$), Ferric sulfate (Fe_2 $(SO_4)_3$ and other coagulants to assist the pollutant load removal efficiency of each parameter from the wastewater. Research has proven that the correct dosage of chemicals improves the DAF system's ability to remove pollutant waste from wastewater. It is also important that the DAF plant operates at the correct pressure to carry out its function properly. Alternative methods of treating fish canning wastewater include the biological treatment. The biological treatment consists of aerobic and anaerobic, that are further divided into other methods. The aerobic method comprises of the activated sludge system recommended especially for treating fishery wastewater by reducing the BOD levels up to 95 % therefore reducing organic load. In fact, the combination of chemicals and biological treatment methods, is effective in reducing pollutant loads such as organic matter. However, it is important that the management of the fish factory further evaluate the use of chemical coagulants with alternative natural methods that are biodegradable in the environment. It is recommended to use natural coagulants as they are recognized for their cost effectiveness and for their ability to promote sustainable environments in wastewater treatment when compared to chemical coagulants.

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APPENDIX A - SULPHUR ERUPTION EVENTS REPORTED IN WALVIS BAY

8 NAMIB TIMES — COMMUNITY NEWS — 23 MARCH 2018

Sulphur eruption in the lagoon - fish die off in masses

The Walvis Bay lagoon became the centre of attention on Thursday as another sulphur eruption led to fish seeking the shallow water in desperate attempts to get oxygen.

Sulphur eruptions are caused when plankton dies off. The decaying process deprives the water of oxygen.

Crowds of people converged on the lagoon to pick dead fish off the shores. The oxygen starved fish were also easy targets for people who caught it using improvised catching devices like buckets and even plastic bags.

Tourists were seen amazed at both the masses of fish in the shallow water and also of the people catching the fish.

APPENDIX B – REPORTS ABOUT THE COLLAPSE OF THE NAMIBIAN SARDINE

Esau goes for broke on pilchards

... ignores warnings of extinction

HE WAS WARNED THAT:

- Sardine stock is virtually zero
- Five-year pilchard ban not enough
- Pilchard workers dropped from 1 900 to 950 in 2016
- No investment made in pilchard industry in 2016

Fisheries minister Bernhard Esau

• SHINOVENE IMMANUEL

FISHERIES minister Bernhard Esau has ignored advice from scientists and his officials and is pushing ahead with the allocation of pilchard quotas, a species declared as "depleted" and in danger of extinction from Namibian waters.

The Namibian understands that Esau has already gone to Cabinet to rubber-stamp his decision to exploit the sardines, going as far as hiding some of the most critical warnings from experts and from political colleagues.

Esau denied allegations that he is ignoring recommendations from his scientists, and said that he is not pushing for the interests of pilchard companies.

In his request to Cabinet, Esau has reportedly underplayed scientific research showing that pilchard has been overfished for the past several years, and that it may not recover again, even if a ban of five years was put in place.

Pilchard fishing has been the most lucrative species in the industry, generating a lot of cash for those Esau and former fishing ministers gave fishing rights to. Pilchard is a well-known fish species in Namibian households, and is famously distributed in cans under well-known brands such as Lucky Star.

Insiders in the fisheries ministry told *The Namibian* this week that Esau wants Cabinet to approve the fishing of pilchards, despite warnings from scientists in his ministry.

ESAU: continued on page 2

ESAU ➡ FROM PAGE 1

"The sardine stock size is currently estimated at virtually zero level, and the natural mortality is considered to be very high, while recruitment has been poor for five consecutive years," said an insider, stating that they have used the same wording to warn the minister, but feared the warnings were being ignored.

According to the source, the pilchard companies have struggled to fulfil their allocated total allowable catch over the past few years, even when their catching period was extended by the ministry, a sign of a depleted resource in Namibian waters.

Every year or fishing season, the minister of fisheries seeks permission from Cabinet to declare a "total allowable catch", which refers to a limit set by government on how much fish will be caught during a season.

Fisheries ministry insiders said Esau wants to propose that 14 000 metric tonnes of pilchard be harvested for the 2017 fishing season. His motives, sources said, are driven mainly by pressure from people who

will be caught during a season.

Fisheries ministry insiders said Esau wants to propose that 14 000 metric tonnes of pilchard be harvested for the 2017 fishing season. His motives, sources said, are driven mainly by pressure from people who
are lobbying him to make as much cash in the shortest time as possible.

This is despite evidence that 2016 fishing targets were not met because of the declining stock in the sea.

Last year, Cabinet, on the recommendations of Esau, approved the harvesting of 10 000 metric tonnes, but the companies only managed to catch 3 400 metric tonnes (34%) of that target.

Officials said fishing companies stopped their pursuit of pilchards because they were losing money in the hopeless search for the fish.

According to a report in *The Namibian* in 2006, concerns about the stock of pilchards started as far back as in the mid-1990s. That news report said the total allowable catch was reduced from 125 000 metric tonnes in 1994 to 40 000 metric tonnes in 1995, and reduced again by 20 000 metric tonnes in 1996. Now, statistics show that fishing companies struggle to land 3 000 metric tonnes per year.

Experts said concern over the possible extinction of pilchard is so deep because no recovery will be achieved if strict measures are not enforced.

In fact, scientists said, a five-year ban on pilchard fishing in Namibia will not be enough to recover its stock, even though it will minimise fishing pressure on the species.

Experts also warned that no sardine spawn was found between March and April last year.

A source said this is an indication of a "very low sardine adult stock".

As the third-largest employer in the fishing sector with 10%, workers in the pilchard industry have dropped from 1 900 to 950, which represents a decline of around 50% from 2015 to 2016.

The Namibian has learnt that no investment was made into the pilchard industry in 2016, and

in the fishing sector with 10%, workers in the pilchard industry have dropped from 1 900 to 950, which represents a decline of around 50% from 2015 to 2016.

The Namibian has learnt that no investment was made into the pilchard industry in 2016, and
the socio-economic contribution decreased from N$1,7 million in 2015 to N$245 000.

Some Cabinet members, known to own fishing companies or with links to fishing business associates, are said to be pushing for the maximum exploitation of fish stock.

Sources said Esau, supported by a few Cabinet colleagues such as attorney general Sacky Shanghala, wants to justify and convince Cabinet to approve the fishing of pilchards by saying that the absence of pilchard fishing will reduce economic benefits, such as a negative impact on Namibian pilchard right holders who do not own vessels and factories.

According to people familiar with how he has sidelined scientific research, Esau is using the threat of job losses to cover up the fact that his main reason is to help those who want to make a quick buck from the industry.

The fisheries ministry is accused of double standards by being strongly against phosphate mining, which it says might negatively affect fishing stock, while at the same time depleting species, including pilchards.

I WAS TOLD...

Esau told *The Namibian* yesterday that claims that he is ignoring his scientists are not true because he decided to recommend 14 000 metric tonnes for this year via recommendations by the Marine Resource Advisory Council made up of scientists, trade unions and other officials.

"I acted on the advice of the advisory council," he said.

Esau claims that he wanted to temporarily ban the fishing of pilchards, but the advisory council told him not to.

He said 4 000 metric tonnes of the 14 000 metric tonnes will go to researching the pilchard

advisory council," he said.

Esau claims that he wanted to temporarily ban the fishing of pilchards, but the advisory council told him not to.

He said 4 000 metric tonnes of the 14 000 metric tonnes will go to researching the pilchard
industry offshore, while 10 000 metric tonnes is for right holders.

The minister added that the industry had informed him that pilchards have gone into deeper waters, making it difficult for fishing companies to catch beyond the limits set by government. Unlike other fishing companies in species such as horse mackerel (maasbanker) which use trawlers, pilchard companies use nets that do not go into deep waters.

Esau also denied allegations that he is protecting the interest of associates and business people.

The attorney general has been Esau's supporter in Cabinet on many occasions.

"It is not about Shanghala supporting Esau," Shanghala said, adding that Esau is guided by the Constitution when allocating marine resources.

In this case, Esau made a decision based on advice from the advisory council, which was guided by scientific factors.

BLAME THE SEALS

One of the companies which has harvested pilchards since the 1940s is Etosha Fishing, a Namibian-registered company that also produces Lucky Star pilchards for the Namibian market.

Etosha Fishing is 45% owned by South African company Oceana Group (the owner of Lucky Star), while 30% is owned by the Government Institutions Pension Fund.

Four Namibian rights holders own a combined 20% stake (5% each), while the remaining 5% is owned by local business people.

Etosha Fishing's managing director, Pieter Greeff, said "we know pilchard has been under pressure".

He, however, said the idea of banning the fishing of pilchards is not the solution because the sector will not recover. Greeff claimed that Etosha Fishing

director, Pieter Greeff, said "we know pilchard has been under pressure".

He, however, said the idea of banning the fishing of pilchards is not the solution because the sector will not recover. Greeff claimed that Etosha Fishing
employs 650 people for the fishing season.

He said pilchard catchers failed to catch the quotas last year because the pilchards are migrating into deeper waters, which is difficult to assess, unlike in the past when they were closer to land.

Greeff said besides the migration, seals are also consuming more fish than what companies are catching per year.

"Seals are going to eat the fish anyway. Seals are eating pilchards more than what the entire fishing industry is catching," he stated.

This story was produced by The Namibian's investigative unit. Send us story tips via your secure email to: investigations@namibian.com.na

Esau says pilchard moratorium long overdue

• ADAM HARTMAN

FISHERIES and marine resources minister Bernhard Esau said the moratorium on pilchard should have been imposed long ago.

"I wanted to impose a moratorium some years back but the advisory council said we first need to find out if the pilchards are really gone or not," he told *The Namibian*.

The Marine Resources Advisory Council is a statutory body that advises the minister on issues pertaining to marine resources sustainability and exploitation.

Esau explained that the reason why a moratorium was stayed then was first to ensure what the status quo of pilchard, and reason for it, was.

"I was fine with imposing a moratorium but scientists said no, I must first give them an opportunity to do a pilchard survey," he said, adding he at least cut a three-year-roll-over total allowable catch for pilchard from 35 000 tonnes a few years back to 14 000 tonnes of which 4 000 tonnes went for pilchard stock research.

He said the yield of rightholders and scientists' findings showed the pilchards were disappearing.

"I don't know if they went into deeper waters or wherever but we will still monitor the situation and a moratorium will stay in place until such time that the pilchards recover," he said, adding he never intended to go ahead with allocating quotas because he was careful at protecting the resource.

He said besides historical over-exploitation by the South African government before Namibia's independence, scientists also suspected depletion due to Namibia's seal populations, which competes for the resource, to have impacted the pilchard biomass.

He said other factors such as pollution are also being investigated, adding that it may be an accumulation of factors that impact the resource.

"At the last evaluation, the scientists agreed that natural mortality for certain, as well as climate change, are affecting the pilchard population, so my mind was ready for a moratorium," he said, arguing that he never decided to go against his advisory council.

Esau expressed trust in the advisory council, regardless of whether they did not agree with his intention to impose a moratorium some time ago, stating that he would stick to their advice.

"I cannot say they gave the wrong advice then. They carried out the survey and my opinion is not outside their advice. I accept their findings. I have given them my trust and I am acting on their advice. It is a trust relationship, otherwise one of us must go," he said.

"They are scientists and are experts in marine biology. I am not a marine scientist – I am a commoner like you."

He said his ministry was consulting companies affected by the moratorium to find ways to maintain business and employment while the moratorium is in place.

"It is a very difficult situation. If a resource is depleted, how can one compensate? Legally, the rightholders for small pelagic were given rights to exploit the pilchard but if the resource has gone down, what compensation can one give?" Esau asked.

He said part of the consultations include encouraging the right holders to talk to horse mackerel companies, and so participate in some sort of value addition.

Last week the chairman of the Confederation of Namibian Fishing Associations, Matti Amukwa, and president of the Namibia Seamen and Allied Workers' Union, Paulus Hango told media that the only hope for saving jobs in the pilchard industry was by allocating horse mackerel quotas to United Fishing Enterprises and Etosha Fishing, who own fishing rights for pilchard.

Amukwa and Hango also suggested the fisheries ministry arranges with other horse mackerel right holders, for their catches to be processed at United and Etosha Fishing.

Chairman of the Pelagic Fishing Association and managing director of Etosha Fishing Corporation, Pieter Greeff also told media last week that the company will continue to import fish from Morocco and that there would be no job losses next year.

He, however, admitted that there will be no profit as the company will only be paying salaries and other operational costs to stay afloat while monitoring the situation.

Last Tuesday information minister, Tjekero Tweya announced that Namibia will not harvest pilchard for the next three years, due to climate change.

Tweya said the Total Allowable Catch (TAC) for pilchard was set at zero metric tonnes for the years 2018-2020, in order to allow the species to recover.

He added that the decision to suspend the pilchard catch was taken based on "scientific advice" from the scientific advisory council, that climate change caused the species to move away from Namibian waters.

Bernhard Esau

APPENDIX C – RAW DATA OF PHYSICOCHEMICAL AND MICROBIOLOGICAL

Sample	Year	Month	Season	Site	NH_3 (mg/l)	COD (mg/l)	BOD (mg/l)	DO (mg/l)	FOG (mg/l)	N (mg/l)	NO_3 (mg/l)	TDS (mg/l)	TSS (mg/l)	P (mg/l)	pH (pH)
1	2011	April	Autumn	Old_DAF	180	4280	4000	0	0	300	1	34904	1875	40	8
2	2011	April	Autumn	Old_DAF	125	764	4550	0	0	150	1	34200	3240	22	7
3	2011	April	Autumn	Old_DAF	164	247	2050	0	0	46	1	34360	3156	16	6
4	2011	May	Autumn	Old_DAF	136	480	3000	1	0	225	1	35300	3220	19	8
5	2011	June	Winter	Old_DAF	165	202	150	0	0	0	1	33200	121	19	6
6	2011	July	Winter	Old_DAF	6	2880	3600	1	0	0	1	34479	2580	19	7
7	2011	August	Winter	Old_DAF	0	250	210	0	0	48	0	32199	270	16	6
8	2011	August	Winter	Old_DAF	0	208	340	1	0	10	1	25667	110	0	7
9	2011	August	Winter	Old_DAF	1	450	350	0	0	50	0	35600	235	11	6
10	2011	August	Winter	Old_DAF	150	355	410	0	0	18	1	36400	430	20	6
11	2012	March	Autumn	Old_DAF	0	530	800	2	0	137	1	38100	355	2	6
12	2012	April	Autumn	Old_DAF	0	403	250	1	0	2	1	39370	3321	11	6
13	2012	June	Winter	Old_DAF	0	800	490	1	0	76	1	31860	252	23	7
14	2013	May	Autumn	Old_DAF	1	1100	245	0	0	43	1	32697	282	1	7
15	2013	May	Autumn	Old_DAF	0	60	2	1	0	6	5	866	7	2	7
16	2013	July	Winter	Old_DAF	0	920	450	0	0	0	1	34208	345	18	6
17	2014	April	Autumn	Old_DAF	0	110	210	1	0	18	1	35500	112	0	8
18	2014	May	Autumn	Old_DAF	0	164	210	1	0	17	1	36169	316	1	6
19	2014	July	Winter	Old_DAF	3	6260	800	1	0	1	1	33274	2756	56	6
20	2015	May	Autumn	Old_DAF	92	2560	480	0	0	110	1	35025	285	18	7
21	2015	June	Winter	Old_DAF	0	1020	1020	1	0	9	1	32532	835	2	6
22	2016	March	Autumn	Old_DAF	121	620	800	2	0	138	1	32549	767	41	6
23	2016	March	Autumn	Old_DAF	130	1340	800	2	0	174	1	33785	678	24	7
24	2011	April	Autumn	Old_CT	0	37	6	4	0	1	1	37046	32	0	8
25	2011	April	Autumn	Old_CT	0	1450	15	0	0	2	1	35640	8	0	6

26	2011	April	Autumn	Old_CT	3	20	3	1	0	5	1	32980	11	0	6
27	2011	May	Autumn	Old_CT	2	106	1	0	0	1	1	34560	5	0	7
28	2011	June	Winter	Old_CT	1	30	30	2	0	2	1	32780	7	0	6
29	2011	July	Winter	Old_CT	1	200	6	2	0	10	1	34220	2	0	8
30	2011	August	Winter	Old_CT	0	234	19	4	0	3	1	39890	7	0	7
31	2011	August	Winter	Old_CT	0	1570	26	1	2	0	1	38760	34	0	7
32	2012	March	Autumn	Old_CT	2	1380	45	1	0	56	1	38620	46	0	5
33	2012	March	Autumn	Old_CT	0	209	2	0	0	1	1	37690	9	0	6
34	2012	April	Autumn	Old_CT	1	54	24	2	0	2	1	37450	8	1	7
35	2012	June	Winter	Old_CT	2	2920	3	2	0	4	1	35448	10	0	7
36	2013	May	Winter	Old_CT	0	300	14	1	0	2	1	34469	6	0	7
37	2013	May	Winter	Old_CT	0	216	6	1	0	2	1	38650	7	0	7
38	2013	July	Winter	Old_CT	0	320	2	1	0	1	1	37875	6	0	7
39	2014	August	Winter	Old_CT	0	15	1	4	0	12	14	21653	2	1	9
40	2014	April	Autumn	Old_CT	0	204	6	2	0	1	1	38458	6	0	8
41	2014	May	Autumn	Old_CT	0	116	2	2	0	1	1	38123	7	0	8
42	2014	July	Winter	Old_CT	3	92	29	0	0	2	1	38033	8	0	7
43	2014	August	Winter	Old_CT	0	110	7	0	0	1	1	37707	21	0	7
44	2015	May	Autumn	Old_CT	33	650	43	1	0	34	1	36327	141	0	7
45	2015	June	Winter	Old_CT	1	88	3	1	0	1	1	38194	16	0	8
46	2015	August	Winter	Old_CT	116	980	440	0	0	116	1	36604	47	1	7
47	2015	August	Winter	Old_CT	0	23	2	1	0	11	1	34520	13	0	7
48	2016	March	Autumn	Old_CT	1	62	3	4	0	1	1	37857	3	0	7
49	2016	March	Autumn	Old_CT	0	56	3	2	0	1	1	38090	5	0	7
50	2016	March	Autumn	Old_CT	0	117	2	0	0	1	1	32560	8	0	7
51	2011	April	Autumn	Old_BW	0	37	6	4	0	1	1	37046	32	0	8
52	2011	April	Autumn	Old_BW	0	27	9	2	0	2	1	35580	74	1	7
53	2011	April	Autumn	Old_BW	0	265	0	0	0	0	1	32740	93	0	6
54	2011	May	Autumn	Old_BW	0	176	1	2	0	2	1	31870	5	0	6
55	2011	June	Winter	Old_BW	0	2540	27	5	0	1	1	37630	5	0	7

56	2011	July	Winter	Old_BW	0	56	2	1	0	0	1	38753	90	1	6
57	2011	August	Winter	Old_BW	0	79	8	0	0	15	1	39702	134	0	6
58	2011	August	Winter	Old_BW	1	16	31	3	0	23	1	36407	29	0	7
59	2011	August	Winter	Old_BW	3	130	103	1	0	0	1	32074	267	1	7
60	2011	August	Winter	Old_BW	0	219	29	1	0	1	1	33910	2	0	6
61	2012	March	Autumn	Old_BW	1	346	4	1	0	2	1	32910	10	0	8
62	2012	March	Autumn	Old_BW	3	850	1	7	0	4	1	39920	32	0	7
63	2012	April	Autumn	Old_BW	1	54	4	0	0	1	1	31970	8	0	7
64	2012	June	Winter	Old_BW	0	1680	3	1	0	1	1	35610	17	0	7
65	2013	May	Autumn	Old_BW	0	340	9	1	0	1	1	34057	19	0	7
66	2013	May	Autumn	Old_BW	2	275	2	0	0	2	1	32050	4	0	7
67	2013	July	Winter	Old_BW	1	340	30	0	0	1	1	37509	180	0	7
68	2014	March	Autumn	Old_BW	0	134	1	3	0	0	1	38107	3	0	7
69	2014	April	Autumn	Old_BW	1	36	8	2	0	26	1	38278	15	0	8
70	2014	May	Autumn	Old_BW	0	140	2	2	0	1	1	38242	12	0	7
71	2014	July	Winter	Old_BW	0	200	35	1	0	3	1	37932	12	1	7
72	2014	August	Winter	Old_BW	28	880	1300	0	0	1	1	35381	581	5	6
73	2015	May	Autumn	Old_BW	3	1340	5	0	0	3	1	38844	15	0	7
74	2015	June	Winter	Old_BW	0	324	18	3	0	3	1	38646	150	0	7
75	2015	August	Winter	Old_BW	4	870	7	1	0	4	1	38009	104	0	7
76	2015	Winter	Winter	Old_BW	1	228	3	1	0	1	1	37984	22	1	8
77	2016	March	Autumn	Old_BW	1	220	8	1	0	1	1	38940	18	1	7
78	2016	March	Autumn	Old_BW	0	90	1	4	0	1	1	38623	13	0	7
79	2016	March	Autumn	Old_BW	0	58	4	7	0	1	1	38154	7	0	7
80	2016	April	Autumn	New_DAF	78	122	540	1	0	85	1	33001	200	7	7
81	2016	July	Winter	New_DAF	87	2840	402	2	0	130	1	31918	967	10	7
82	2017	March	Autumn	New_DAF	131	9460	800	0	2	322	1	33720	2037	17	7
83	2017	May	Autumn	New_DAF	180	5610	2	0	0	280	14	34085	1449	52	6
84	2017	June	Winter	New_DAF	36	3567	350	1	1	93	1	35750	104	12	7
85	2017	June	Winter	New_DAF	1	2450	5	2	0	75	1	38760	15	10	7

86	2017	June	Winter	New_DAF	5	350	230	0	0	125	1	37580	340	3	6
87	2017	June	Winter	New_DAF	49	260	290	1	0	58	1	34704	268	4	7
88	2017	July	Winter	New_DAF	125	3420	25	1	0	1	1	32350	1050	9	7
89	2017	July	Winter	New_DAF	62	2460	420	0	0	4	1	35280	58	8	7
90	2017	July	Winter	New_DAF	92	870	20	2	0	37	1	35540	950	6	7
91	2017	July	Winter	New_DAF	83	5640	15	5	0	1	1	32670	35	7	6
92	2017	August	Winter	New_DAF	141	376	12	3	0	3	1	31450	205	12	6
93	2017	August	Winter	New_DAF	34	550	440	0	0	54	1	32234	134	10	6
94	2017	August	Winter	New_DAF	1	85	6	1	0	6	1	32200	6	9	7
95	2017	August	Winter	New_DAF	45	320	8	0	0	2	1	38760	84	3	7
96	2018	March	Autumn	New_DAF	58	357	45	2	0	1	1	32420	44	9	7
97	2018	March	Autumn	New_DAF	12	460	287	5	0	3	1	32240	99	9	8
98	2018	March	Autumn	New_DAF	36	354	56	1	0	3	1	33600	54	8	7
99	2018	March	Autumn	New_DAF	3	75	4	9	0	1	1	35440	54	9	6
100	2018	April	Autumn	New_DAF	2	36	55	0	0	0	1	31200	32	3	6
101	2018	April	Autumn	New_DAF	1	50	38	0	0	2	1	23520	7	1	7
102	2018	April	Autumn	New_DAF	0	63	29	0	0	1	1	33567	35	1	7
103	2018	April	Autumn	New_DAF	0	65	83	4	0	0	1	32130	27	6	6
104	2018	May	Autumn	New_DAF	0	31	94	3	0	2	1	32300	175	8	6
105	2018	May	Autumn	New_DAF	1	123	183	0	0	3	1	33320	87	2	7
106	2018	May	Autumn	New_DAF	1	95	35	0	1	2	1	31400	91	3	6
107	2018	May	Autumn	New_DAF	0	54	128	0	0	1	1	33240	55	2	6
108	2018	June	Winter	New_DAF	0	108	47	0	0	1	1	32170	113	9	6
109	2018	June	Winter	New_DAF	2	172	73	1	2	1	1	31290	4	5	7
110	2018	June	Winter	New_DAF	2	28	64	1	2	2	1	32450	9	3	7
111	2018	June	Winter	New_DAF	2	30	135	0	1	0	1	33260	86	8	7
112	2016	April	Autumn	New_CT	1	84	9	2	0	2	1	37782	4	0	7
113	2016	July	Winter	New_CT	1	42	2	3	0	1	1	37519	10	0	8
115	2017	April	Autumn	New_CT	1	84	9	2	0	2	1	37782	4	0	7
116	2017	May	Autumn	New_CT	0	39	8	2	3	2	93	38913	45	0	7

117	2017	June	Winter	New_CT	1	25	12	4	0	1	1	25380	6	0	8
118	2017	June	Winter	New_CT	0	30	2	2	0	0	1	37680	7	0	7
119	2017	June	Winter	New_CT	1	25	5	1	0	1	1	37650	5	0	6
120	2017	June	Winter	New_CT	0	20	5	3	0	1	1	38942	18	0	7
121	2017	July	Winter	New_CT	0	26	3	2	0	0	1	37550	9	0	6
122	2017	July	Winter	New_CT	0	34	9	2	0	2	1	37680	6	0	6
123	2017	July	Winter	New_CT	0	65	7	2	0	1	1	38760	5	1	6
124	2017	July	Winter	New_CT	1	48	7	3	0	0	1	35850	2	0	7
125	2017	August	Winter	New_CT	0	41	5	3	0	1	1	36770	8	0	7
126	2017	August	Winter	New_CT	1	26	4	3	0	2	1	37560	5	0	7
127	2017	August	Winter	New_CT	0	54	9	2	0	0	1	37670	4	4	6
128	2017	August	Winter	New_CT	1	63	5	3	0	1	1	33450	5	0	7
129	2018	March	Autumn	New_CT	0	88	7	0	0	0	1	32550	8	0	6
130	2018	March	Autumn	New_CT	0	4	5	0	0	1	1	32320	6	0	7
131	2018	March	Autumn	New_CT	1	3	7	0	0	0	1	31250	10	1	7
132	2018	March	Autumn	New_CT	1	13	8	0	0	2	1	30540	8	1	7
133	2018	April	Autumn	New_CT	1	13	6	4	0	0	1	30860	7	0	6
134	2018	April	Autumn	New_CT	0	13	3	1	0	1	1	31760	8	0	6
135	2018	April	Autumn	New_CT	0	13	4	2	0	2	1	33540	10	1	5
136	2018	April	Autumn	New_CT	1	13	1	0	0	0	1	28950	5	1	6
137	2018	May	Autumn	New_CT	1	13	8	8	0	0	1	37760	7	1	6
138	2018	May	Autumn	New_CT	0	13	6	0	0	2	1	32560	7	1	8
139	2018	May	Autumn	New_CT	1	13	3	0	0	0	1	22750	7	0	6
140	2018	May	Autumn	New_CT	0	13	9	3	0	2	1	28460	5	0	5
141	2018	June	Winter	New_CT	0	13	3	0	0	1	1	32530	4	0	7
142	2018	June	Winter	New_CT	1	13	8	0	0	0	1	31330	3	1	6
143	2018	June	Winter	New_CT	0	13	2	4	0	2	1	28790	1	1	7
144	2018	June	Winter	New_CT	0	13	4	1	0	0	1	35480	2	1	7
145	2017	June	Winter	New_BW	0	65	5	0	0	0	1	32780	4	1	6
146	2017	June	Winter	New_BW	37	350	50	2	0	63	1	34590	320	4	7

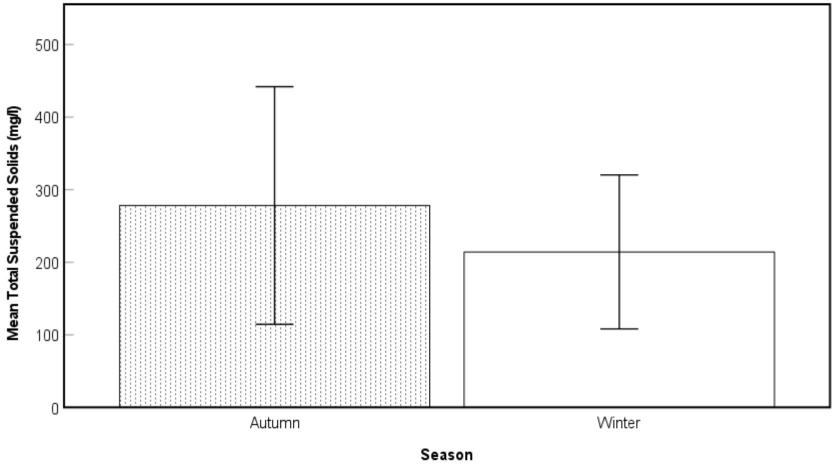
147	2017	July	Winter	New_BW	98	53	270	2	0	1	1	39820	990	5	7
148	2017	July	Winter	New_BW	75	1250	680	2	0	5	1	38990	69	6	7
149	2017	July	Winter	New_BW	160	980	20	270	0	45	1	36970	1905	9	7
150	2017	July	Winter	New_BW	90	3870	80	6	0	1	1	33370	40	7	6
151	2017	August	Winter	New_BW	132	450	16	5	0	2	1	34220	150	12	6
152	2017	August	Winter	New_BW	19	276	530	7	0	60	1	32234	176	12	6
153	2017	August	Winter	New_BW	1	96	4	1	0	6	1	33000	9	9	7
154	2017	August	Winter	New_BW	50	127	5	0	0	5	1	36540	38	4	7
155	2018	March	Autumn	New_BW	35	132	59	0	0	6	1	32330	93	1	7
156	2018	March	Autumn	New_BW	98	76	61	2	0	5	1	34580	39	0	7
157	2018	March	Autumn	New_BW	4	23	147	6	0	2	1	32680	26	1	6
158	2018	March	Autumn	New_BW	16	47	130	3	0	64	1	34270	37	4	7
159	2018	April	Autumn	New_BW	65	145	37	0	0	3	1	29870	85	2	6
160	2018	April	Autumn	New_BW	31	87	48	2	0	1	1	33210	13	9	6
161	2018	April	Autumn	New_BW	18	37	29	6	0	3	1	31120	53	3	6
162	2018	April	Autumn	New_BW	45	84	94	0	0	0	1	32120	39	0	6
163	2018	May	Autumn	New_BW	40	39	27	0	0	0	1	32540	29	0	6
164	2018	May	Autumn	New_BW	0	46	15	0	0	0	1	31870	42	0	8
165	2018	May	Autumn	New_BW	7	52	42	1	0	4	1	29870	38	0	6
166	2018	May	Autumn	New_BW	5	63	84	1	0	6	1	30108	27	3	5
167	2018	June	Winter	New_BW	7	93	19	2	0	0	1	32090	101	2	5
168	2018	June	Winter	New_BW	5	103	21	3	0	1	1	31990	72	0	5
169	2018	June	Winter	New_BW	23	58	19	4	0	9	1	30430	18	0	8
170	2018	June	Winter	New_BW	56	78	63	3	0	0	1	30290	82	0	6

APPENDIX D - WORLD HEALTH ORGANISATION (WHO) ACCEPTABLE LIMITS OF PHYSICOCHEMICAL AND MICROBIOLOGICAL PARAMETERS

Parameters	**Acceptable limits**
Total Suspended Solids (mg/l)	15
Total Dissolved Solids (mg/l)	1500
pH	6.0 – 9.0
Biological Oxygen Demand (mg/l)	15
Chemical Oxygen Demand (mg/l)	150
Fat, Oil and Grease (mg/l)	0.500
Dissolved Oxygen (mg/l)	>2.0
Nitrogen (mg/l)	35
Phosphorus (mg/l)	30
Ammonia (mg/l)	15
Nitrate (mg/l)	50
Faecal Coliform (cfu/100)	200

*As per the World Health Organisation, Regional Office for the Eastern Mediterranean, Regional Centre for Environmental Health Activities

APPENDIX E – The analysis of Mean (±SE) physicochemical and microbiological concentrations during autumn and winter seasons using Mann-Whitney U test



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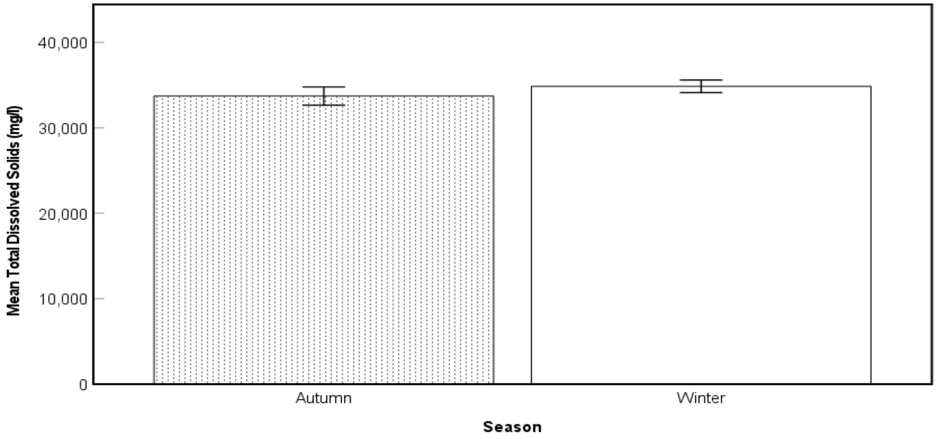

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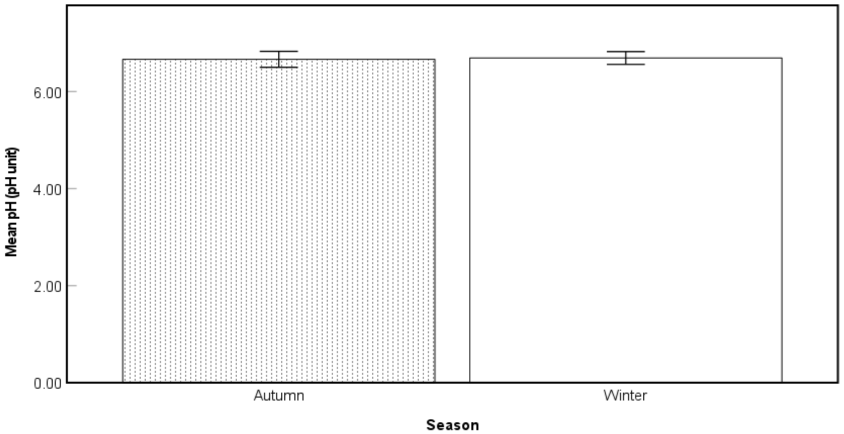

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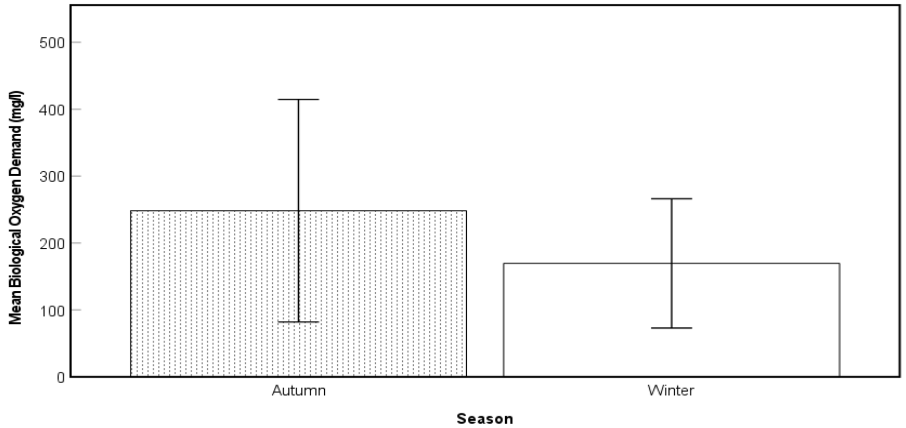

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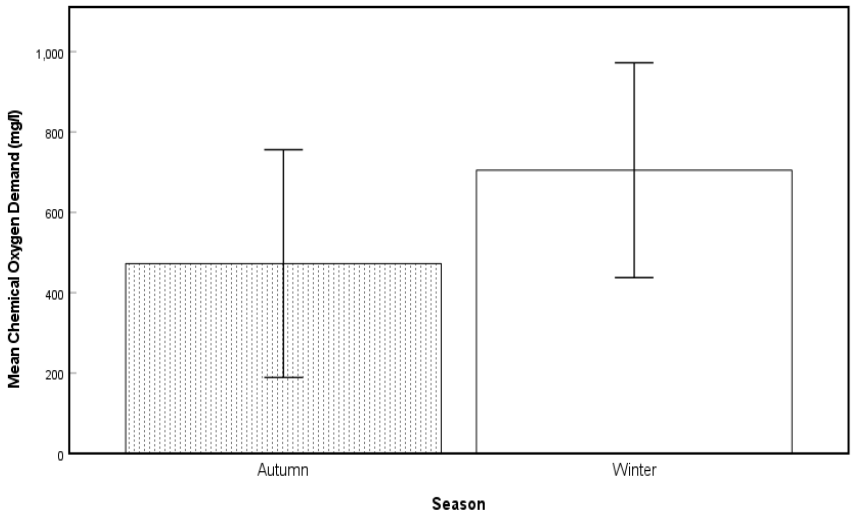
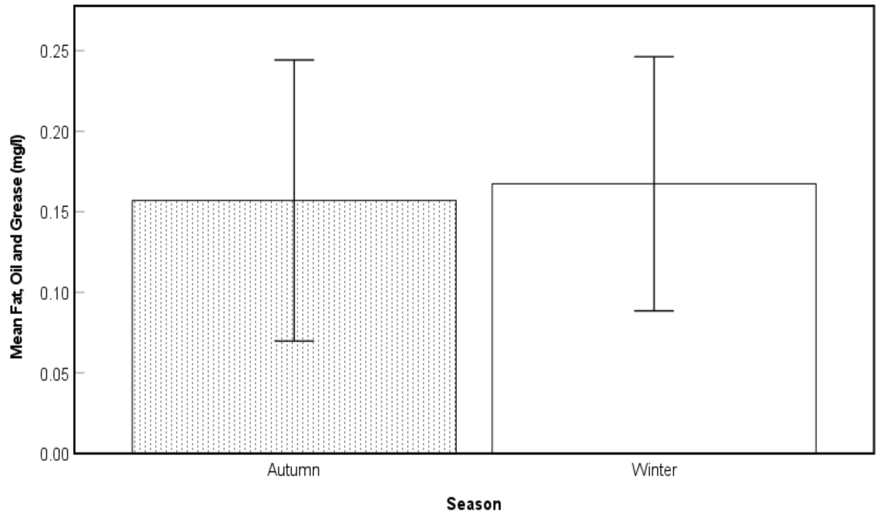


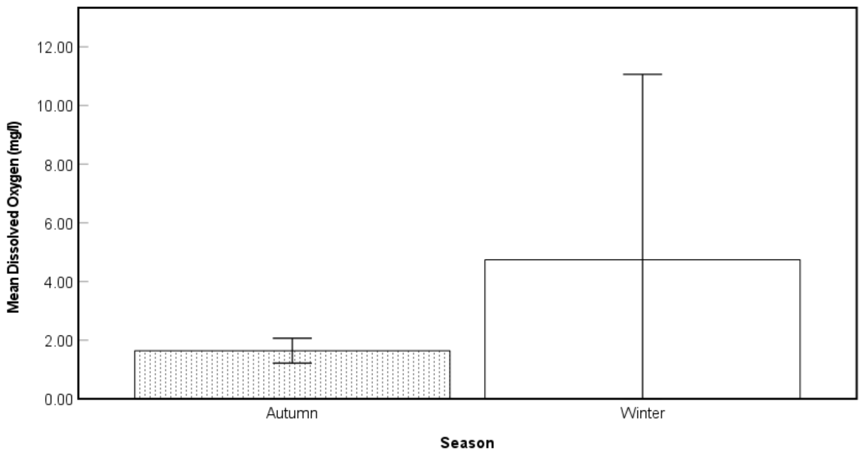
Mean Chemical Oxygen Demand (mg/l)
1,000
800
600
400
200
0
Autumn
Winter
Season

e



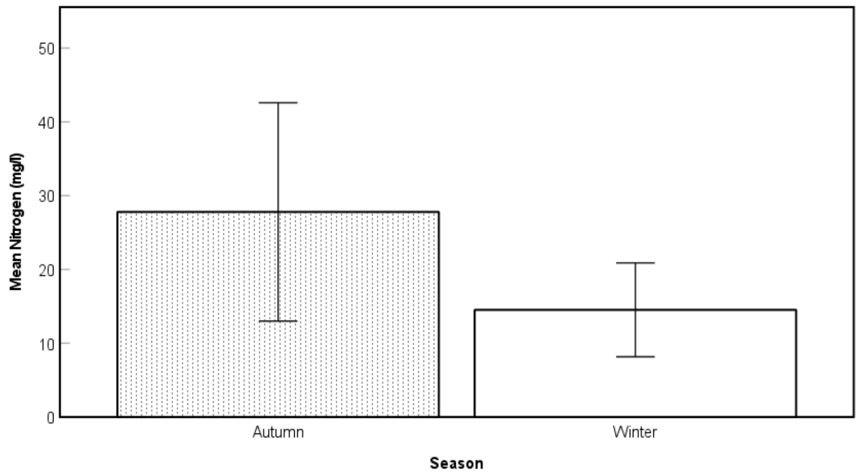
Mean Fat, Oil and Grease (mg/l)
0.25
0.20
0.15
0.10
0.05
0.00
Autumn
Winter
Season

f



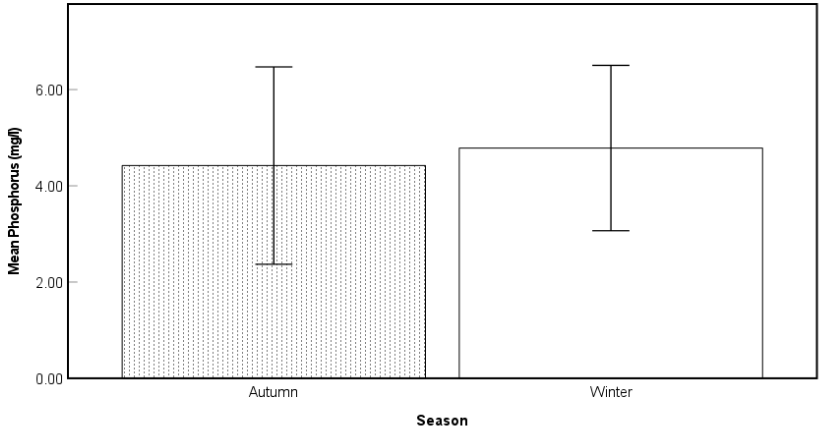
Mean Dissolved Oxygen (mg/l)
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Autumn
Winter
Season

g

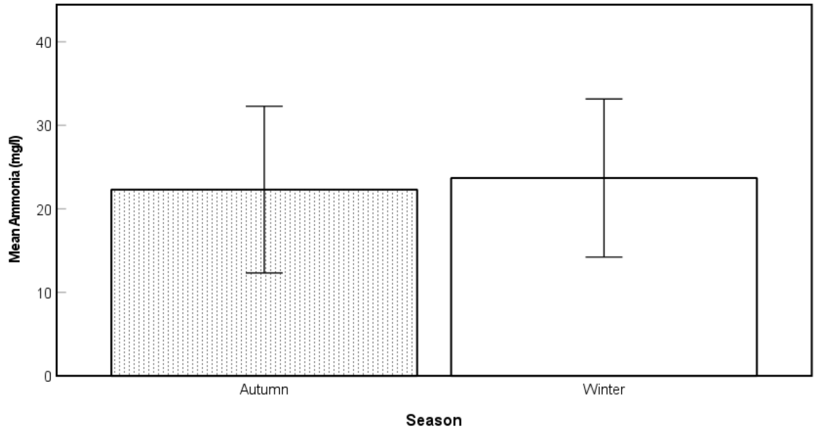


Mean Nitrogen (mg/l)
50
40
30
20
10
0
Autumn
Winter
Season

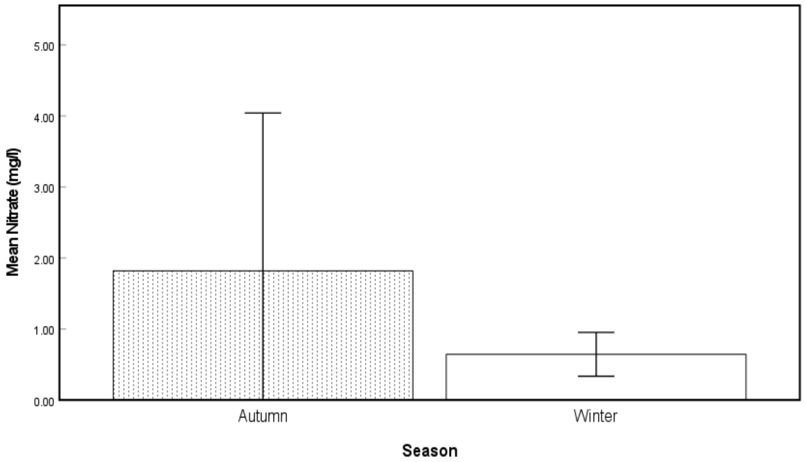
h


6.00
4.00
2.00
0.00
Mean Phosphorus (mg/l)
Autumn
Winter
Season

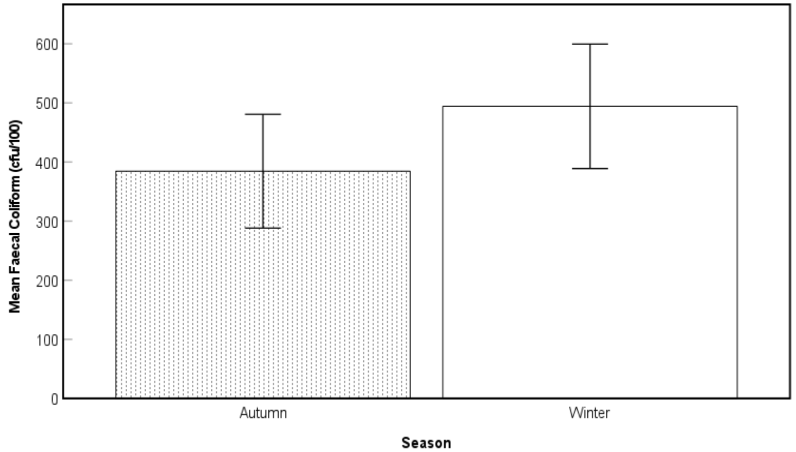
i


40
30
20
10
0
Mean Ammonia (mg/l)
Autumn
Winter
Season

j


5.00
4.00
3.00
2.00
1.00
0.00
Mean Nitrate (mg/l)
Autumn
Winter
Season

k


600
500
400
300
200
100
0
Mean Faecal Coliform (cfu/100)
Autumn
Winter
Season

l

APPENDIX F - THE PARAMETERS DESCRIBING SEASONAL DIFFERENCES AT THE OLD AND NEW SITES

		Old DAF		New DAF		Old BW		New BW		Old CT		New CT	
		Autumn	**Winter**	**Autumn**	**Winter**	**Autumn**	**Winter**	**Autumn**	**Winter**	**Autumn**	**Winter**	**Autumn**	**Winter**
TDS	**Mean**	32525	32942	32346	34022	36083*	36888	32047*	34094	36569*	35629	32518*	35329
	SE	2691	931	690	609	742	595	457	793	568	1213	1109	925
PH	**Mean**	7	6.4	6	7	7*	7	6*	6	7	7	6	7
	SE	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.1
BOD	**Mean**	1338	782	159	150	4*	209	64*	127	12	42	6	5
	SE	431	324	58	40	0.8	123	12	58	4	31	0.7	1
COD	**Mean**	974	1335	1130	1384	274	582	69	561	343*	507*	28*	32*
	SE	333	603	698	408	4	209	11	273	139	218	8	4
NH_3	**Mean**	73	33	34	45	0.7*	3	30*	54	3	9	0.4	0.4
	SE	20	21	14	11	0.2	2	8	14	2	8	0.1	0.1
NO_3	**Mean**	1*	0.4	1*	0.5	0.5	0.5	0.5	0.5	0.5	1	7	0.5
	SE	0.4	0.1	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.9	6	0.0
FC	**Mean**	967*	1001	440*	692	358	567	111	252	339	393	112	227
	SE	87	99	125	122	111	143	1	96	120	124	1	80

*Significant