ALGAL-BASED TERTIARY TREATMENT IN MATURATION PONDS OF THE MOTETEMA WASTEWATER TREATMENT WORKS

Report to the Water Research Commission

February 2017

WATER RESEARCH COMMISSION

TT706/16

science & technology

Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

CSIR
our future through science

UNIVERSITY OF LIMPOPO


our future through

Algal-Based Tertiary Treatment in Maturation Ponds of the Motetema Wastewater Treatment Works

PJ Oberholster[1], M Claasen[1], K Nortje[1], B Genthe[1], M Steyn[1], P McMillan[1], P Cheng[1], L de Klerk[1], M Naidoo[1], W Masangane[1], Y Tancu[1], WJ Luus-Powell[2], JR Sara[2], KD Bal[2], MP Mokgawa[2], and WJ Smit[2]

1 CSIR Department Natural Resources and the Environment | P.O. Box 320, Stellenbosch, 7599
2 University of Limpopo | Private Bag X1106, Sovenga, 0727

Report to the
Water Research Commission

WRC Report No. TT706/16
February 2017

science & technology
Department:
Science and Technology
REPUBLIC OF SOUTH AFRICA

CSIR our future through science

UNIVERSITY OF LIMPOPO

WATER RESEARCH COMMISSION

Obtainable from

Water Research Commission
Private Bag X03
Gezina, 0031

orders@wrc.org.za or download from www.wrc.org.za

The publication of this report emanates from a project entitled *Algal-based Tertiary Treatment in Maturation Ponds of the Motetema Wastewater Treatment Works* (WRC Project No. K5/7050).

ISBN 978-1-43120-876-0
Printed in the Republic of South Africa

EXECUTIVE SUMMARY

Even without considering climate change, we are heading towards an increasingly water insecure world. Globally, water pollution is on the increase as a result of population growth, urbanisation, industrialisation as well as expanded and intensified food production. South Africa is a water scarce country and is currently facing a multi-faceted water challenges.

While South Africa has a strong water sector with a track record in innovation, we have not managed to provide adequate sanitation to all, nor have we managed to effectively treat domestic wastewater. The main issues highlighted for the water and sanitation service delivery in South Africa are: poverty, inequality and unemployment coupled with the lack of capacity (skills) in municipalities; funding challenges; fragmented or incoherent policies; aging infrastructure; lack of long-term planning and the lack of operation and maintenance plans for water and sanitation infrastructure. The Green Drop assessments confirm that WWTW in South Africa in general, and in the study area specifically, are facing significant challenges.

As part of the Department of Science and Technology's (DST) innovation partnership for rural development programme (IPRDP), implemented by the Water Research Commission (WRC), with the Council for Scientific and Industrial Research (CSIR) as the project team, the Motetema Waste Water Treatment Works (WWTW) in the Sekhukhune District Municipality of Limpopo Province, was identified for pilot implementation of the algae-based wastewater treatment system. The Motetema WWTW is a waste stabilisation pond system that consists of two sets of 6 ponds that operate at a time and serves an estimated 1560 households. The effluent discharged from this WWTW mostly do not comply with National and Provincial regulations, posing a high risk to the environment and natural water sources as well as to human and animal health.

Treatment ponds are commonly used in South African rural areas for the decentralized treatment of domestic sewage. These rural treatment ponds are cost effective as they depend mainly on natural processes without any external energy inputs. The need for further assimilation of nutrients before discharging of wastewater in phosphate sensitive rivers using algae provides an environmentally friendly, cost effective option.

The objective of the current study was to investigate nutrient assimilation and proliferation trends of selected cultured microalgae, as a final algal treatment step, when treating effluents to improve water quality and reuse in water scarce areas. The algae-based treatment process utilises a specific consortium of algal species to remove nutrients and create conditions for effective solar disinfection to reduce pathogens. The selected cultured micro algae consortium used was able to remove nutrients in the different saturated ponds below the guidelines set by the South African Department of Water and Sanitation (DWS). The percentage reduction of total phosphorus in unfiltered water (containing algae) after treatment was 74.7, 76.4, and 75.3% for ponds 5, 6 and 7 respectively. The percentage total nitrogen removal in ponds 5, 6 and 7 were 43.1; 35.1 and 30.7% respectively.

There was an increase in the suspended solids associated with the algae biomass and while COD was reduced after treatment, it still did not meet the South African wastewater effluent standards. However, from the study it was evident that the algae biomass needs to be removed on a continuous basis. The feasibility of establishing a fish polyculture at the Motetema WWTW to remove and limit algal production was investigated. Indigenous fish i.e. *Oreochromis mossambicus* and *Coptodon rendalli* that are able to ingest and assimilate algae and aquatic macrophytes were introduced to the ponds but did not survive as the algae treatment system was not yet mature. Thereafter, laboratory tests with Motetema wastewater at different concentrations indicated a 60 – 100% survival rate. Fish mortality was concluded to be due to ammonia and nitrite levels and that aquaculture is not a viable option at Motetema WWTW until such time that the improved algae-based process is operating optimally. The microbial health risk assessment indicates that it is very likely that individuals making use of the receiving water, (even for recreational purposes) is likely to be affected. The health risks associated

with exposure to the wastewater were significantly reduced from the beginning of the wastewater treatment process to the final effluent, and the results illustrate that with proper operations and management of the system, it is expected that health risks to the community can be significantly reduced.

Municipal benefits derived from the project are not merely the tangible technology such as the algal bioreactors that were installed at the Motetema WWTW, but also the positive impact healthy ecosystems have on the population's health and well-being. It highlighted that projects such as this create a conducive environment that allows for social and economic development of the area. The project created awareness amongst various stakeholders about the downstream processes from the Motetema WWTW, which in turn could create more responsible consumption and production behaviour not only by individuals, but also by businesses and industry. Sustainable and timely removal of sludge is very important not only for the proper functioning of the Motetema waste stabilisation pond treatment works, the results showed that sludge removal is critical for the success of phycoremediation. Benefits that can be derived from sludge at Motetema WWTW range from heat generation to nutrient utilisation and extraction of useful constituents such as phosphorous. The most viable option at Motetema WWTW must be based on the classification and corresponding suitability of the sludge for a specific use.

Going forward, pro-active solutions and innovative treatment options are required to improve wastewater management. Instead of being a source of problems, one should look at approaches to change how wastewater is perceived. Well-managed wastewater could be a valuable resource and ultimately, its use can lead to improved food security, societal health and economic development.

REFERENCE GROUP (STEERING COMMITTEE)

The authors would like to thank the Sekhukhune District Municipality, the Motetema community and the Reference Group of the WRC Project for the assistance and the constructive discussions during the project:

Valerie Naidoo	WRC
John Ngoni Zvimba	WRC
Keith Cowan	Rhodes University
Jerrard Muller	BESTCON
Hannes Joubert	Sciencetech
Cliff Jones	Rhodes University
Zinhle Mchunu	Department of Science and Technology
Faizal Bux	Durban University of Technology

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
CRR	Cumulative Risk Rating
CSIR	Council for Scientific and Industrial Research
DM	District Municipality
DO	Dissolved Oxygen
DST	Department of Science and Technology
DWS	Department of Water and Sanitation
IDP	Integrated Development Plan
IPRDP	Innovation Partnership for Rural Development Programme
LM	Local Municipality
PAT	Programme Assessment Tool
QMRA	Quantitative Microbial Risk Assessment
RDP	Reconstruction and Development Programme
RMS	Root Mean Square
SALGA	South African Local Government Association
SDG	Sustainable Development Goals
SDM	Sekhukhune District Municipality
TN	Total Nitrogen
TP	Total Phosphorous
UN	United Nations
WASH	Water Sanitation and Hygiene
WRC	Water Research Commission
WSA	Water Services Authority
WSP	Water Services Provider
WSR	Water Services Regulation
WWTW	Wastewater Treatment Works

CHAPTER 1: INTRODUCTION

CHAPTER OBJECTIVE:

To provide International, national and local context on sanitation and background information about the study area and waste stabilisation ponds.

Project Overview and Outline

The principal objective of the project: ***"The piloting of algae-based wastewater treatment (phycoremediation) to achieve a significant improvement in the quality of effluent discharged at Motetema Wastewater Treatment Works"*** was to:

- Facilitate the effective and efficient removal of nutrients and pathogens in Wastewater Treatment Works (WWTW) effluent, which pose a risk to downstream communities and water resources. These include nutrients such as nitrates and phosphates and pathogens such as protozoa, helminths, bacteria and viruses;
- Utilise an anaerobic microbial process to settle suspended solids and reduce BOD in a modified algae-based tertiary treatment process in existing maturation ponds. The treatment process will make use of a community of algal species which has been isolated and cultured in the laboratory to remove nutrients and create conditions for effective solar disinfection to reduce pathogens;
- Establish biotic communities that consume algae and residual pathogens in the final stage with the added benefit of establishing an aquaculture venture;
- Implement a self-sustaining system that is independent of electricity or expensive chemicals and can be effectively maintained by a semi-skilled workforce. The successful implementation of such a system will be highly relevant to smaller municipalities throughout the country;
- Apply a Quantitative Microbial Risk Assessment (QMRA) to confirm the reduction of health risks; and to
- Improve community awareness, knowledge sharing and capacity development through an associated community and stakeholder programme.

The first part of this report provides background on the critical challenges we face, both internationally but also in the National context in managing wastewater and considers the implications for people and the environment across different sectors, and how these may be influenced by issues such as population growth, urbanisation and climate change, specifically in the study area.

The second part of the report looks at testing and reviewing a possible solution that has been developed and rolled out in Limpopo Province of South Africa. It further discusses the human health risks associated with the treated waste water effluent after the intervention, spin-off treatment options for future job creation (e.g., aquaculture, sludge beneficiation) and other entrepreneurial ideas. The report assesses the impact at municipal level and the importance of engaging with stakeholders throughout the project, from problem identification right through to implementation and monitoring in order to achieve sustainable solutions. Each chapter of the report concludes with key learning points for consideration for future implementation of such an intervention by local municipalities at WWTW.

Global Water Resource Crisis

Even without considering climate change, the world as a whole is heading towards an increasingly water insecure world. Globally, water pollution is on the increase as a result of population growth, urbanisation, industrialisation as well as expanded and intensified food production (WHO/ UNICEF, 2010).

"Our indispensable water resources have proven themselves to be greatly resilient, but they are increasingly vulnerable and threatened. Our growing population's need for water for food, raw materials and energy is increasingly competing with nature's own demands for water to sustain already imperilled ecosystems and the services on which we depend. Day after day, we pour millions of tons of untreated sewage and industrial and agricultural wastes into the world's water systems. Clean water has become scarce and will become even scarcer with the onset of climate change. And the poor continue to suffer first and most from pollution, water shortages and the lack of adequate sanitation."
– Ban Ki-moon, UN Secretary General

The challenges for implementing universal access to water and achieving the sustainable development goals (SDGs) are immense (UN-Water, 2015; WHO, 2016). Worldwide, an estimated 663 million people still lack access to safe water and some 2.4 billion (almost half the population of the developing world), do not have access to adequate sanitation (WHO/UNICEF, 2015; WHO, 2016). Diarrhoeal disease is the third leading cause of death for the under-five age group. Globally, an estimated 340 000 children under the age of five die annually from diarrhoea as a result of poor sanitation, poor hygiene or unsafe drinking water. In addition, lack of Water Sanitation and Hygiene (WASH) and open defecation has been linked to stunting or chronic malnutrition in some 161 million children (WHO/UNICEF, 2015).

It is clear that future demands for water cannot be met unless wastewater management is revolutionised. Inadequate infrastructure (e.g., aged wastewater infrastructure) and management systems for the increased volume of wastewater produced as a result of population increases and predicted climate change, are at the core of the wastewater crisis (Corcoran et al., 2010).

For a healthier and sustainable future, urgent global action is essential. Corcoran and co-authors (2010) called for immediate action and continued investment in improved wastewater management and infrastructure in order to prevent further deaths to people and impacts on ecosystem resilience and biodiversity.

Going forward, improved governance of water resources is key to sustainable human development, growth and poverty reduction. It will be necessary to have pro-active solutions for investment in wastewater treatment infrastructure, draw on existing and new policy approaches and look at alternative funding solutions (UN-Water, 2015). Instead of being a source of problems, one should look at approaches to change how wastewater is perceived. Well-managed wastewater could be a valuable resource and globally its use could lead to improved food security, health and economy.

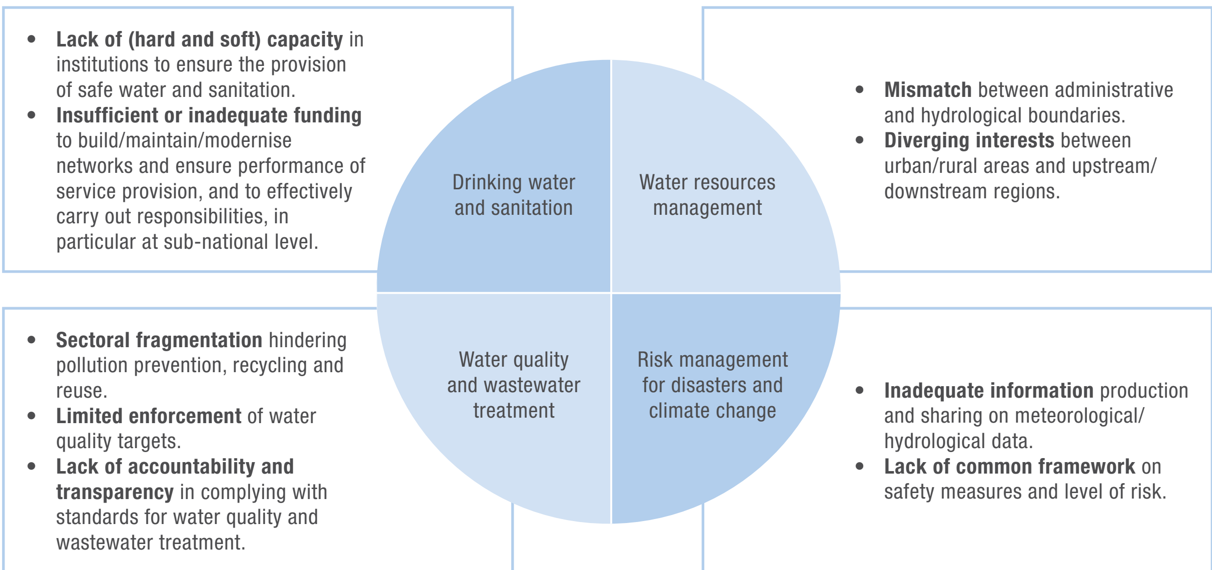


Figure 1: Governance obstacles by water management function (Source: OECD, 2014)

Status of South Africa's Water Resources

The National Water Resource Strategy (DWS, 2013) of South Africa sets out the strategic direction for water resources management over the next 20 years (Figure 3). While it also provides the framework for the protection, use, development, conservation, management and control of water resources, as well as the framework within which water must be managed at catchment level, the state of South Africa's water resources is similar to that found globally. The population of South Africa has increased from 40.6 million in 1996 to 51.8 million in 2011 (28%), just over 11 million people, and is expected to grow to over 60 million by 2050 (World Urbanisation Prospects, 2014).

The country is currently facing a multi-faceted water crisis. The ongoing drought, the mismatch between water supply and water demand, a deteriorating infrastructure, water losses due to theft, vandalism and leaks, the loss of essential skills, a poor and underfunded education system, management failure, and deterioration in the quality of water, are all potential threats and key concerns (SAHRC, 2014).

Water supply and sanitation in South Africa is characterised by both achievements and challenges. While South Africa has a strong water industry with a track record in innovation, little progress has been made with sanitation (Table 1). Access to sanitation services is important, not only for human dignity, but also because of its direct link with disease control and the potential impact on water resources.

Access to sanitation generally improved between 2006 and 2011. Statistics South Africa through their Census 2011 data reported that households that have access to flush toilets connected to a public sewerage system increased from 51.9% in 2001 to 60.1% in 2011 (StatsSA 2012a). The highest provision is in the Western Cape (89.6%) and Gauteng (85.4%) and the lowest is in Limpopo Province (21.9%).

Table 1: Access to Water and Sanitation services in South Africa (DWS, 2016)

	Access to water supply			Access to sanitation		
	1994	2001	2011	1994	2001	2011
Households (million)	8.66	11.52	14.45	8.66	11.52	14.45
HH below RDP (million)	3.89	3.07	2.16	4.5	4.95	4.52
% HH below RDP	44.9%	26.7%	15%	52%	43%	31.3%
HH equal to or above RDP (million)	4.77	8.44	12.29	4.16	6.57	9.93
% HH equal to or above RDP	55.1%	73.3%	85%	48%	57%	68.7%

Source: DWS and Stats SA data

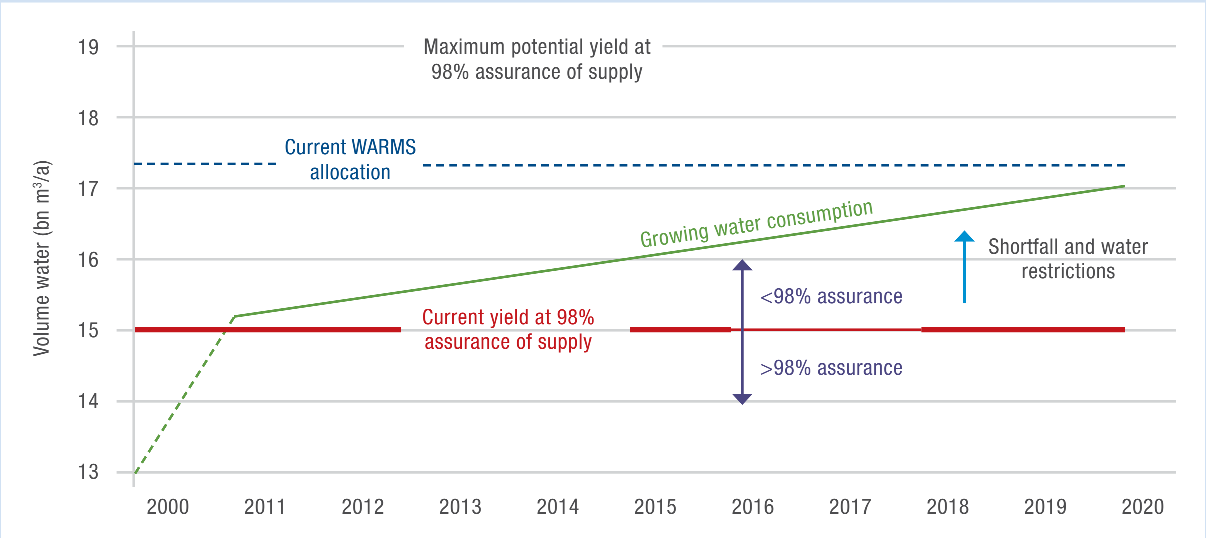


Figure 2: South African Water Supply and Demand Trend (Source: DWS, 2016)

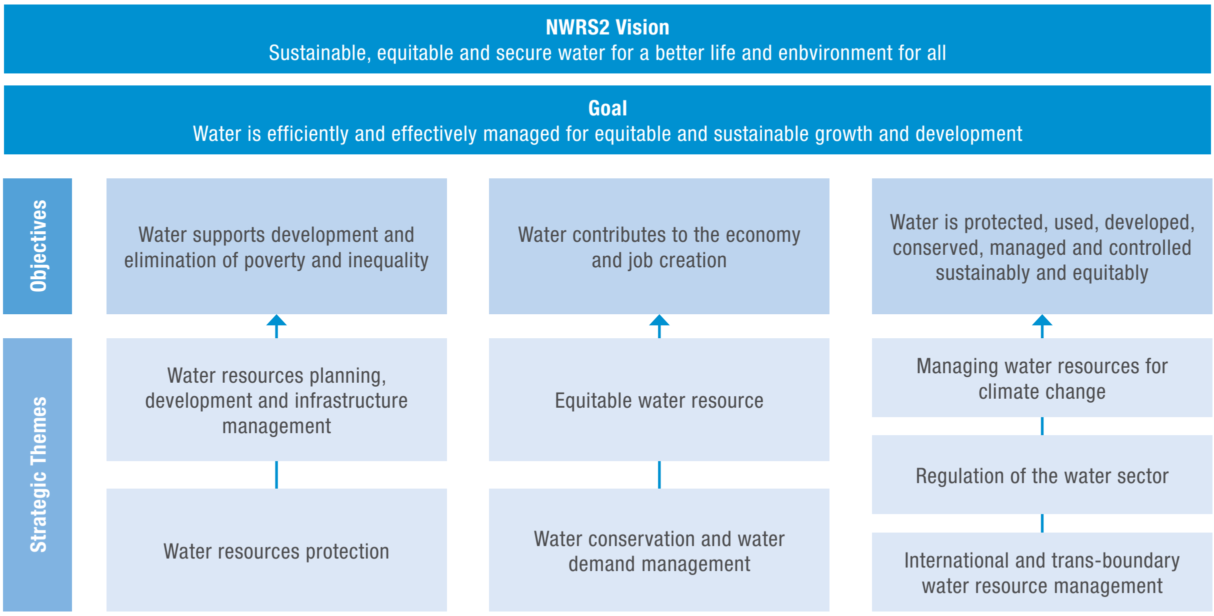


Figure 3: National Water Resources Strategy (Source: DWS, 2016)

"Efforts in alleviating poverty and inequality in South Africa will never be realised unless the municipalities address the issue of service delivery in different communities, particularly sanitation and provision of energy. Since basic sanitation is a human right, it is therefore the responsibility of government to create a better environment which is allowing to all its citizens – the clean environment that remain free of harmful impacts of sanitation systems."

– Community Survey, 2016

According to the Green Drop Assessment Report (2009), when 449 wastewater treatment plants were assessed, according to official government data, 7% were classified as excellently managed, 38% “performed within acceptable standards” and 55% did not perform within acceptable standards (DWS, 2010; DWS, 2009). In 2011, 7 of the 159 water services authorities (WSAs) and 32 of 1,237 wastewater treatment plants were certified with the Green Drop (DWS, 2011). According to the latest Green Drop Assessment report (2014), of the 824 plants assessed, 508 plants digressed. A further cause for concern is the Waste Water Treatment Works (WWTW) in the low risk domain that decreased from 199 to 135. An increase from 235 to 259 for plants in the high risk space is seen, while 212 plants compared to the previous 121 plants were characterised in the critical risk domain (DWS, 2014).

The Water Research Commission (WRC) of South Africa in partnership with the South African Local Government Association (SALGA) reported that in June 2013, 44% of wastewater treatment plants included in a representative sample, made use of inappropriate and unnecessarily expensive technologies. Additional findings were “lack of funding for maintenance because of low tariffs” and municipalities “running assets to failure” through the absence of ring-fencing of revenues for the purpose of maintaining assets.

In a speech to Parliament (Johnson, 2015) the three main issues highlighted for the water and sanitation service delivery problems in South Africa are: 1) poverty, 2) inequality and 3) unemployment. Unfortunately, these three issues define the majority of communities in formal and informal settlements across the country as they remain unable to pay for water and sanitation services. In addition to the abovementioned challenges, “the lack of capacity (skills) in municipalities; funding challenges; fragmented or incoherent policies; aged infrastructure; lack of long-term planning and the lack of an operation and maintenance plan for water and sanitation infrastructure” are further key obstacles (SAHRC, 2014).

South African Legislative Framework and Compliance Monitoring

The government launched a green drop certification for municipal wastewater treatment in 2008. This programme is administered by the Water Services Regulation Directorate (WSR Directorate) within the Department of Water and Sanitation (DWS). The WSR Directorate promotes the protection of consumers and public interest and is responsible for ensuring compliance based on minimum national norms and standards, good performance and the efficient use of resources and good contracting practices (DWA, 2010).

Through environmental regulation, the WSR Directorate aims to ensure that all wastewater discharges from the water services sector meet the specified minimum standards in order to protect human health and the environment (DWA, 2010). It is within the scope of environmental regulation that the Green Drop Programme was established and is currently being implemented.

The Green Drop System

The Green Drop Programme follows a two-legged regulatory approach with the first “leg” being an incentive-based regulatory approach seeking to recognise excellence in the wastewater industry. Wastewater practitioners are encouraged to work towards the achievement of Green Drop certification. The second leg is a targeted risk-based regulation approach, which provides for early warning signs of wastewater treatment plants containing a certain measure of risk, allowing for early identification of risks. It also allows for pro-active targeted intervention necessary to manage and mitigate the identified risks in order to shift towards a more favourable position of compliance and, ultimately, excellence. Where high risks are identified, the regulator applies the Enforcement Protocol in order to ensure that an incremental process is followed which allows for such actions as municipal support, emergency measures and legal action (DWA, 2011a).

With the simultaneous implementation of the above approaches, the Green Drop Programme: (1) enables water services authorities to generate information from effluent data in order to inform the overall improvement of wastewater management; (2) allows DWS, as the regulator, to have access to credible information towards the improvement of regulatory decision making; and (3) allows public access to credible wastewater performance information regarding performance and risk management (DWA, 2011a).

"Efforts in alleviating poverty and inequality in South Africa will never be realised unless the municipalities address the issue of service delivery in different communities, particularly sanitation and provision of energy. Since basic sanitation is a human right, it is therefore the responsibility of government to create a better environment which is allowing to all its citizens –the clean environment that remain free of harmful impacts of sanitation systems."
– Community Survey, 2016

Overview of the Study Area

As part of the Department of Science and Technology's (DST) innovation partnership for rural development programme (IPRDP), implemented by the Water Research Commission (WRC), with the Council for Scientific and Industrial Research (CSIR) as the project team, the Motetema WWTW in the Elias Motsoaledi Local Municipality was identified as the pilot study site for this project. Elias Motsoaledi Local Municipality is one of five sub-districts (Elias Motsoaledi, Ephraim Mogale, Fetakgomo, Makhuduthamaga and Greater Tubatse) that form the Greater Sekhukhune District in the south-eastern part of the Limpopo Province (IDP, 2015).

The Sekhukhune District covers an area of approximately 13 264 square kilometres and comprises a population of 1 122 522. Most of the district is rural with almost 740 villages which are generally sparsely populated (83.0 persons per km^2) and dispersed throughout the District (IDP, 2015).

It is estimated that only 5% of the Sekhukhune population live in urban areas. The district falls in socioeconomic Quintile 1, among the poorest districts (Massyn et al., 2015). According to Census 2011 figures (Stats SA, 2012) Greater Sekhukhune district had the highest unemployment rate (50,9%) in the Limpopo Province (38.9%).

The Greater Sekhukhune District Municipality in the Limpopo Province is experiencing significant challenges in water quality and sanitation services. The Green Drop Report (DWS, 2014) noted a digressive trend at 13 of the 16 waste water treatment works assessed in the Greater Sekhukhune District Municipality with 3 plants in high risk and 13 plants in critical risk positions. Effluent discharged from these WWTW pollutes receiving water bodies, debilitating ecosystem services and presenting a high risk to the health of communities living downstream from these WWTW.

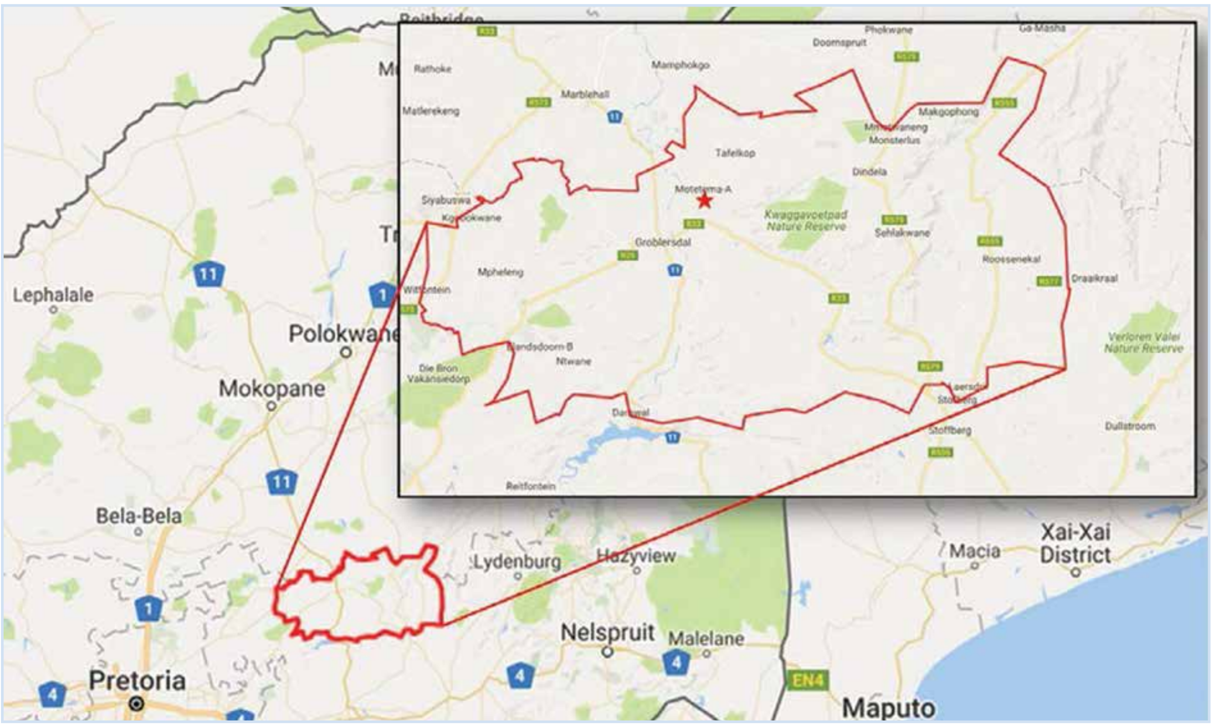


Figure 4: Location map of Elias Motsoaledi Local Municipality within Greater Sekhukhune District, Limpopo Province

Motetema WWTW

The Motetema WWTW is situated outside the town of Groblersdal and serves around 1 560 households. Mostly, the effluent discharged from this WWTW does not comply with National and Provincial regulations and municipal officials are dealing with aging infrastructure, insufficient technical skills and limited resources. Local communities bear the brunt of poor effluent quality, since they often depend on drinking water from the same rivers and streams that are contaminated by these wastewaters. These communities either have no access to safe drinking water or their access is often interrupted.

According to the latest Green Drop progress report (2014), Sekhukhune District failed to make an effort to complete and submit the Green Drop Progress Assessment Tool (PAT). This Water Services Authority, due to the lack of proof of evidence therefore digressed from a high risk position in 2013 (82.4%) to a critical risk state in 2014 at 94.1% for Motetema WWTW specifically (Table 3 and Table 4).

The key risk factors flagged was the lack of effluent monitoring, non-compliant effluent quality, lack of flow monitoring and non-compliance in terms of Regulation 813 in terms of the technical skills requirement. The district showed a digressive state at 13 of the 16 WWTW indicating that the current practice in the district holds a high risk to the environment and natural water sources and well as to human and animal health (DWS, 2014).

Table 2: Cumulative risk rating for WWTW within the Greater Sekhukhune (DWS, 2014)

WSA Name	2014 Average CRR/ CRRmax %deviation	WWTP's in critical and high risk space	
Greater Sekhukhune DM	90.3%	Burgersfort, Elandskraal, Groblersdal, Jane Furse, Leeuwfontein (Mokganyaka), Meckleberg (Moroke), Monsterlus (Hlogotlou), Motetema, Nebo, Phokwane, Tubatse	Denilton, Marble Hall, Roosenekaal
Mogalakwena LM	86.4%	Rebone	Mokopane old and new
Lephalale LM	83.5%	Zongesien	
Mookgophong LM	82.4%	Thusang (Roedtan)	
Thabazimbi LM	80.4%	Thabazimbi	Northam, Rooiberg
Mopani DM	79.5%	Modjadji (Duiwelskloof), Senwamokgope, Namakgale	Lulekani, Giyani, Phalaborwa, Lenyenye
Vhembe DM	78.8%	Mutale, Mhinga, Musina, Nancefiled, Thifulanani	Thohoyandou, Dzanani, Siloam Ponds
BelaBela LM	78.4%	Radium	Pienaarsrivier
Modimolle LM	73.5%		Vaalwater
Capricorn DM	69.4%		Alldays, Lebowakgomo Ponds, Senwabarwana

Medium risk WSA and plants   High risk WSA and plants   Critical risk WSA and plants

Table 3: Cumulative Risk Rating (CRR) for Motetema WWTW (DWS, 2014)

Technology Description	Motetema
Technology (Liquid)	Anaerobic ponds/ Facultative ponds
Technology (Sludge)	Solar drying beds and Composting
Key Risk Areas	
A) ADWF Design Capacity (Ml/d)	0.4
B) Operational flow (% of design capacity	151% (NI)
C) Annual Average Effluent Quality Compliance (2012-2013) 1) Microbiological compliance (%) 2) Physical compliance (%) 3) Chemical compliance (%)	0.0%
D) Technical skills (Reg 813)	Partial
2014 Wastewater Risk Rating (%CRR/CRRmax)	94.1%
2013 Wastewater Risk Rating (%CRR/CRRmax)	82.4%
Risk Abatement Planning	
High Risk Areas based on the CRR	Flow monitoring, technical skill, effluent monitoring
WW Risk Abatement Status	Draft Document (unapproved by Council)
Capital and Refurbishment expenditure for Fin year 2012-2013 (Rand)	None
Description of Projects' Expenditure 20132-2013	None

Waste Stabilisation Ponds

Waste Stabilisation Ponds, amongst the most common and efficient methods of wastewater treatment around the world (Table 4, Table 5), are described in literature as "large, man-made water bodies in which blackwater, greywater or faecal sludge are treated by natural occurring processes and the influence of solar light, wind, microorganisms and algae" (Tilley et al., 2014). Pond treatment systems are especially appropriate for rural communities that have large, open and unused lands, away from homes and public spaces and where it is feasible to develop a local collection system. Since the intensity of sunlight and temperature are key factors for their efficiency, waste stabilisation ponds are particularly well suited for tropical and subtropical countries (IRC, 2004).

The ponds can be used individually, or linked in a series for improved treatment. There are three types of ponds, (1) anaerobic, (2) facultative and (3) aerobic (maturation), each with different treatment and design characteristics.

Anaerobic Ponds

These ponds operate without the presence of dissolved oxygen with high organic loads. In anaerobic ponds, the biological oxygen demand (BOD) is achieved by sedimentation of solids and subsequent anaerobic digestion in the resulting sludge (Mara et al., 1992). A short retention time of one to one and a half days is commonly used.

Facultative Ponds

In these ponds aerobic conditions prevail at the water surface and below, while anaerobic conditions prevail in the bottom sediment (Mara and Pearson, 1998). Facultative ponds can be differentiated into primary and secondary facultative ponds. Primary facultative ponds receive raw water and secondary facultative ponds receive particle-free wastewater. Facultative ponds are designed for BOD removal on the bases to allow for the development of a healthy algal population, since the oxygen for BOD removal by the pond bacteria is generated primarily via algal photosynthesis. The bottom layer of primary facultative ponds includes sludge deposits that are decomposed by anaerobic bacteria.

Aerobic (Maturation) Ponds

These ponds also known as polishing ponds receive their effluent from the secondary facultative ponds. Maturation ponds show less vertical stratification and are well oxygenated throughout the day. These ponds are designed for pathogen removal and the size and number of ponds depends on the bacterial quality of the final effluent (Mara et al., 1992; Tilley et al., 2008). The algal diversity in maturation ponds is much more diverse than in the facultative ponds, with non-motile genera tending to be more widespread. Algae are one of the main driving forces for treatment within maturation ponds by taking up phosphates, carbon dioxide and nitrogen compounds, while it provide oxygen for heterotrophic bacteria to degrade organic material. Tilley et al., (2008) reported that if used in combination with algae and/or fish harvesting, this type of pond is also effective at removing the majority of nitrogen and phosphorus from the effluent.

Table 4: Advantages and Disadvantages of Waste Stabilisation Ponds (Adopted from: IRC, 2004)

Advantages	Disadvantages
• Resistant to organic and hydraulic shock loads • High reduction of solids, BOD and pathogens • High nutrient removal if combined with aquaculture • Low operating cost • No electrical energy required • No real problems with flies or odours if designed and maintained correctly • Can be built and repaired with locally available materials • Effluent can be reused in aquaculture or for irrigation in agriculture	• Requires large land area • High capital cost depending on the price of land • Requires expert design and construction • Sludge requires proper removal and treatment • De-sludging (normally every few years) • Mosquito control required • If the effluent is reused, salinity needs to be monitored • Not always appropriate for colder climates

Table 5: Relevance of waste stabilisation ponds in removal of the main constituents in wastewater and stormwater (Adopted from: IRC, 2004)

Constituents	Representative parameters	Source/ Relevance			Possible effect of the hazard
		Wastewater		Urban stormwater	
		Domestic	Industrial		
Pathogens	• *E. coli* • Coliforms	High	Variable	Medium	Waterborne diseases
Suspended solids	Total suspended solids	High	Variable	Medium	• Sludge deposits • Hazard adsorption • Shielding of pathogens
Biodegradable organic matter	Biochemical oxygen demand	High	Variable	Medium	• Oxygen consumption • Death of fish • Septic conditions
Nutrients	• Nitrogen • Phosphorus	High	Variable	Medium	• Excessive growth of cyanobacteria and algae • Toxicity to fish (ammonia) • oxygen consumption • Illnesses in new-born infants (nitrate) • Pollution of groundwater (nitrate)
Poorly biodegradable organic matter	• Some pesticides • Some detergents • Pharmaceuticals	Medium	Variable	Low	• Toxicity (various) • Foam (detergents) • Reduction of oxygen transfer (detergents) • Reduced or non-biodegradability • Offensive odours (e.g. phenols)
Heavy metals	Specific elements (e.g. arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc)	Medium	Variable	Low	• Inhibition of biological sewage treatment • Contamination of groundwater
Inorganic dissolved solids	• Total dissolved solids • Conductivity	Medium	Variable	Not relevant	• Excessive salinity – harm to plantations (irrigation) • Toxicity to plants (some ions) • Problems with soil permeability (sodium)

Key Learning Points

- South Africa is a water scarce country
- WWTW impact on ecosystem and human development
- Robust technologies with inclusive implementation processes are required

CHAPTER 2: STAKEHOLDER ENGAGEMENT

CHAPTER OBJECTIVE:

To acquire an understanding of the local socio-economic context, stakeholders affected by the project outcomes, as well as their knowledge and capacity needs.

Stakeholder Engagement

The purpose of stakeholder engagement for this project has been to firstly develop a general understanding of the stakeholders in the area that would be affected by the project as well as their immediate socio-economic context. And, secondly to develop and implement a capacity building and knowledge sharing plan based on actual stakeholder needs. Initial assessment was based on desktop research, utilising the insights and information gained through other projects the CSIR has had in the area; and lastly, introductory scoping visits to the area and offices of the Sekhukhune District Municipality (SDM). This was followed by a needs assessment which was conducted with the SDM, and semi-structured interviews with key stakeholders and local leaders. There are mainly two stakeholder groups identified as related to this project, i) residents both up- and downstream from the WWTW and ii) the Municipalities, namely the SDM as well as Elias Motsoaledi Local Municipality (Motetema) and Ephraim Mogale Local Municipality (Leeuwfontein).

From the outset of the project it was acknowledged that stakeholder engagement activities needed to be kept focussed on specific stakeholder needs, so as to avoid the engagement turning into a 'water and sanitation campaign'. In order to do this the team sought guidance from a stakeholder reference group. This reference group consisted of representatives from the SDM, specifically the Operations and Maintenance Department and the Water Quality Department, as well as representatives from the two local municipalities, youth organisations, and local leadership.

Stakeholder engagement for this project then consisted of three components namely, capacity building; knowledge sharing; and knowledge gathering.

Capacity Building

The primary objective for capacity building has been to support the district municipality with regards to specific needs relating to waste water treatment and the management thereof. Capacity building events usually took the form of workshops where experts in the field were invited to speak on and workshop specific issues with the SDM (e.g., sludge treatment and handling).

The team also developed and implemented an intensive capacity building programme at the Motetema WWTW with the site controller in order to learn how to operate the new technology.

Figure 5: Dr Marius Claassen from the CSIR during a capacity building workshop in Groblersdal with SDM representatives

"Our indispensable water resources have proven themselves to be greatly resilient, but they are increasingly vulnerable and threatened. Our growing population's need for water for food, raw materials and energy is increasingly competing with nature's own demands for water to sustain already imperilled ecosystems and the services on which we depend. Day after day, we pour millions of tons of untreated sewage and industrial and agricultural wastes into the world's water systems. Clean water has become scarce and will become even scarcer with the onset of climate change. And the poor continue to suffer first and most from pollution, water shortages and the lack of adequate sanitation."
– Ban Ki-moon, UN Secretary General

Knowledge sharing

Knowledge sharing activities focussed on both of the SDM and the local community. As a part of knowledge sharing, representatives from the SDM were provided with a number of opportunities to learn more about the science behind the project's technology intervention. For example, one such opportunity was a field trip to the CSIR's Pretoria campus where representatives from the SDM, the local municipalities, youth forums and traditional leadership were treated to a tour of the CSIR laboratories and where CSIR scientists showed the participants how the algae were cultivated in the lab.

The team also held a schools event where learners from the Ramohloko Secondary School were given the opportunity to observe and participate in scientific experiments at their own school. Here the objective was to broaden the horizons of the learners so that they too can not only dream of becoming scientists but also realise those dreams.

Knowledge gathering

Gathering of knowledge has been mainly to gain better insight to the socio-economic context of people living in the case area. This has included (as previously mentioned) desktop studies, literature review, and scoping visits. In addition, two social science masters students are basing their research on related social issues in the area. The qualitative methodologies employed has provided an opportunity to obtain community perspectives on a range of issues (focus groups and semi-structured interviews) including water and sanitation governance, especially at local and district level, community perspectives on waste water, and gender and decision making processes in water at district and local levels.

Figure 6: Mr David Mailula, site controller at the Motetema WWTW demonstrates to an audience how the system works

Figure 7: Learners from the Ramohloko Secondary School learning about water borne disease from CSIR scientists

Student dissertations are as follows:

- **Mr. Robson Masaraure (University of Pretoria):** MSc Water Resource Management – *"The development of an approach for the production and use of algae to treat urban wastewater."*
- **Ms. Winile Masangane (University of Johannesburg):** MA Development Studies – *"Barriers to Women Initiating Change: the Case of Key Water Services Structures in Sekhukhune District Municipality."*
- **Mr. Paseka Pharumele (University of Johannesburg):** MA Anthropology – *"Local knowledges on changing climate and water in Leeuwfontein (Limpopo Province)."*
- **Ms. Makubu Priscilla Mokgawa (University of Limpopo):** MSc Zoology – *"Assessing the health and survival of different fish species exposed to and reared in waste water treatment ponds in a temperate region in Greater Sekhukhune District Municipality."*

Significant findings

From the start it was made clear that this project cannot attempt a large scale social survey of the local perceptions with regards to waste water treatment as this was beyond the scope of the project. As such, much of the focus has been on capacity building and understanding the needs of the SDM. However some important findings did emerge as significant which influenced the trajectory of the stakeholder engagement and additionally informed the technical side of the project. These findings are as follows:

- The SDM are facing significant capacity, governance and budgetary challenges that require deep and significant changes, not only in processes, but also in attitude and behaviour. While not surprising to the project team, it is significant to note that the SDM representatives spoke freely about the challenges they face and how it has been a never-ending battle. Some SDM representatives even went as far to say that the reason municipalities such as the SDM are failing is because of corrupt and lazy officials. Additionally, it was not uncommon for junior officials to insist that capacity building should be aimed at those in managerial positions as these were the people who do not have the necessary capacity to perform their jobs. This is important learning for future projects that seeks to make a difference in governance structures.
- Despite these significant challenges, it was heartening to find a group of municipal officials who were committed to the project from start to finish. Making up the bulk of the local reference group, they were instrumental in the project team being able to develop capacity building and knowledge sharing events that were tailor made to their needs. This is important for any project that wishes to truly make a difference on the ground.
- Blame shifting between local and district municipality was common place. During discussions it became clear that there is an uneasy and distrustful relationship between district and local municipal officials dealing with water and sanitation. As such, it was often difficult to find consensus on the causes of the current state.
- Staff working on site at the WWTW felt isolated and abandoned, especially at the start of the project we were informed that no-one from the district municipality had visited the site in the last year or so. Once the project started more attention was given to not only the site but also the staff on site. It is also a point of concern for this project and others like it, but maybe even more importantly funders of research. When the project is completed, to what extent can we (the team, the funder etc.) truly be satisfied that the difference that was made during the project life span will continue.
- Local people engaged with had very little knowledge relating to WWTW and their operations. This was clear both through conversations with locals and WWTW staff. Locals often had no idea what a WWTW is, where it is, or what it does. WWTW staff also commented on the types of waste and goods that find their way through the system to their treatment site. On more than one occasion staff noted that aborted foetuses were found, as well as dead animals, blankets and old television sets. Clearly there is a lot of scope for more capacity building in communities such as these, not only with regards to waste water but also personal health and hygiene, and social welfare.
- Conversations with locals also revealed that people were generally uncomfortable talking about human faeces. Also, locals were quite unwilling to accept the notion that technology can clean water in the later ponds to a sufficient extent so that fish can thrive in it. They were also exceedingly negative with regards to the idea that one could eat the fish from such ponds.

Key Learning Points

Municipalities are facing significant capacity, governance and budgetary challenges that require deep and significant changes not only in processes but also in attitude and behaviour.	The status of co-operative governance between local and district municipality is a significant factor of concern for project works at multiple governance scales.	Local knowledge around WWTW and human health requires more investment in capacity building.

"It was heartening to find a group of municipal officials who were committed to the project from start to finish. Making up the bulk of the local reference group, they were instrumental in the project team being able to develop capacity building and knowledge sharing events that were tailor made to their needs. This is important for any project that wishes to truly make a difference on the ground."

CHAPTER 3: PHYCOREMEDIATION

CHAPTER OBJECTIVE:

To investigate nutrient assimilation and proliferation trends of selected cultured microalgae, as a final algal treatment step, when treating domestic effluents to improve water quality and reuse of water.

Phycoremediation is an environmentally friendly and cost effective alternative treatment option for rural areas.

Conventional treatment processes such as activated sludge and biofilms are seldom used in rural South Africa due to lack of electricity and financial resources. Therefore, it is important to search for possible alternative options to improve the effluent of WWTP in Southern Africa since classic ponds (waste stabilisation ponds) have been used as wastewater treatment option in most of the rural areas of Southern Africa.

Characteristics of the Motetema WWTW

The Motetema WWTW consist of 12 earth ponds organised in two series of six each, parallel to one another, without any algae treatment or mechanical aeration. Only 6 ponds are operated at a time, while the other 6 ponds are dried to remove sludge (Figure 8). The maturation pond 7 always acts as the final pond in both parallel series since it is the only pond connected with the Olifants River for release of effluent (Figure 8). The pond system is based on natural overflow from one pond to another (Figure 8). The average total effluent that needs to be treated (for a population of 11 400) by the Motetema WWTW is ~ 2.5 Ml/ day. The Motetema WWTW consists of four types of stabilisation ponds, namely (1) anaerobic ponds, (2) primary facultative ponds, (3) secondary facultative ponds and (4) aerobic (maturation) ponds. The current study was done just after the system was switch to a new series of six ponds without reaching maturity. In the new series of six ponds, the dried bottom sludge was not removed and it took up to six months for the new series of ponds to fill up with domestic waste water. Therefore, data presented in the current study may have been influenced by the rewetting of the ponds and the possible diffusing of phosphorus from the dried bottom sludge into the water column.

Figure 8: Layout of the Motetema WWTW

The pond dimensions are presented in Table 6.

Table 6: Dimensions of the 7 different ponds at the Motetema WWTW

Pond	Depth (m)	Area (m^2)	Volume (m^3)
1	2.5	38571.43	96428.57
2	2	9183.67	18367.35
3	2	5969.39	11938.78
4	1.5	4336.73	6505.10
5	1.5	4132.65	6198.98
6	1.5	10204.08	15306.12
7	2	16836.73	25255.10

Culturing Process

Two species of microalgae from the phylum, Chlorophyte, were previously cultured in the laboratory under different environmental conditions. These specific species namely *Chlorella vulgaris* and *Chlorella protothecoides* were selected during laboratory trails with the following criteria: (1) the potential to take up maximum phosphates (b) the fastest exponential growth, and (c) the largest temperature range. The latter species were used for mass culturing and inoculation at the Motetema WWTW.

The algae raceway was constructed on the Pretoria CSIR campus for the purpose of microalgae mass cultivation to be introduced at the Motetema WWTW. The raceway is 5 x 6 m, consisting of 8 channels, with sluices to control algae movement and a motorised paddle wheel. Laboratory cultures of *Chlorella vulgaris* and *Chlorella protothecoides* were added together and introduced in the middle section of the raceway.

Figure 9: The algae raceway on the CSIR campus in Pretoria

The raceway algae were transported to the Motetema WWTW (Ten x 25 litre containers) where the Motetema WWTW operator used it to start the mass culturing of algae in a step-wise procedure using onsite algal reactors. Five algae bioreactor tanks (Semi-transparent tanks with a capacity of 5 000 ℓ each) was installed at the WWTW. The mass algal culturing process was initiated by adding 20 g of fertiliser to each algal reactor.

Only maturation ponds 4 and 5 were inoculated with algae on a 3 to 4 week basis with the selected consortium of algae (10 000 cells/mℓ). Due to the fact that the pond system is based on natural overflow from one pond to another, it was assumed that the inoculated algae will move from one pond to another by natural flow.

All samples for physical, chemical and biological analyses were collected at the outlet of each pond, in the morning between 9h00-11h00 a.m. Samples were taken before algae inoculation and once a month over a period of 6 months during continuous inoculation. Sampling was conducted during the autumn and winter months (March 2016 to August 2016). Dissolved oxygen (DO), temperature (°C), pH and electrical conductivity (EC) were measured *in situ* in the water column using a Hach HQ 40d multiparameter (USA, Hach, Loveland, Colorado). Surface water column samples (top 5 cm) were collected using a grab sampler and kept in polyethylene bottles (1 litre) that had been pre-rinsed with dilute sulfuric acid (to pH 2.0) for the analysis of dissolved nutrients. The samples were kept cool whilst transported to the laboratory in a dark container. All water analyses were carried out according to standard methods (APHA, 1992). Water samples before and after algae treatment of ponds 5, 6 and 7 was filtered through 0.22 µm pore size Whatman GF/filters to separate the algae from the treated water for the determination of algae uptake of Total Nitrogen (TN) and Total Phosphorous (TP). Both filtered and unfiltered data were used in the analyses.

Figure 10: Layout of the ponds at the Motetema Wastewater Treatment Works, indicating the piping from the reactor tanks and the ponds to be dosed

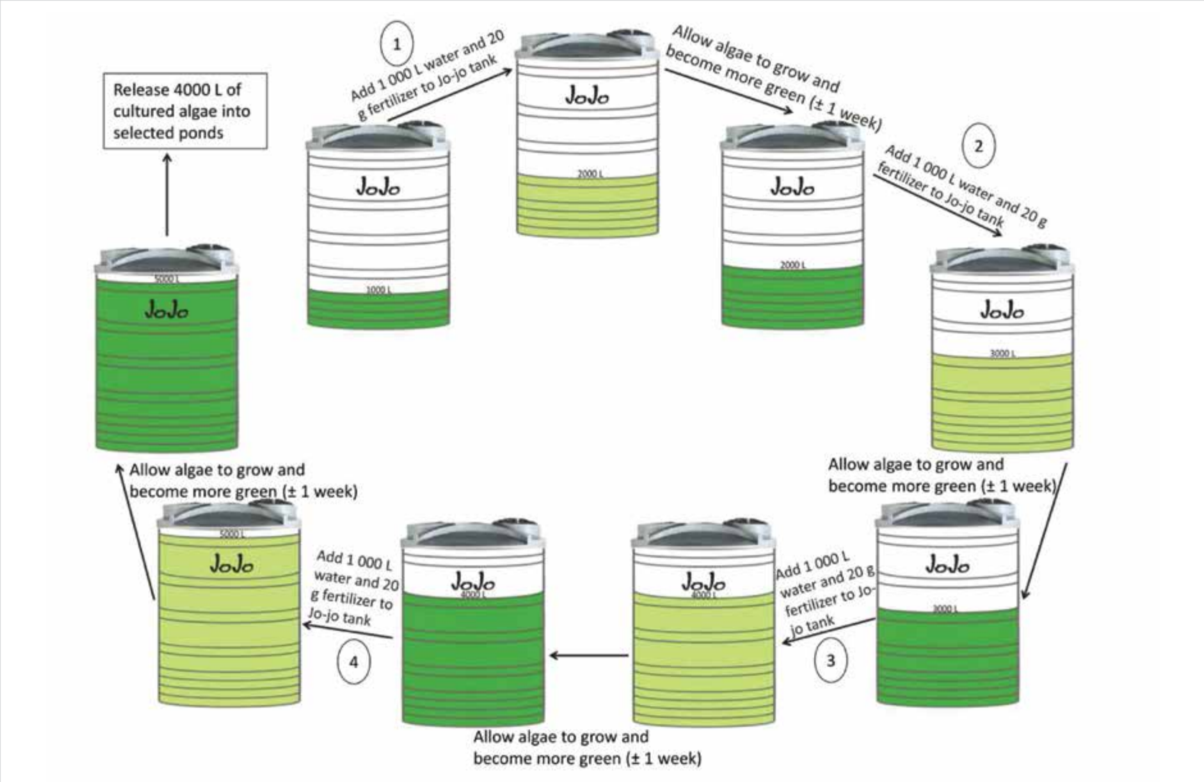


Figure 11: The step-wise procedure for algae mass culturing at the Motetema WWTW. Steps one (1) to four (4) indicate the addition of water and fertiliser for the growth of cultured algae.

Phytoplankton identification

One sample (1 litre bottle) at the outlet of each pond was taken on a monthly basis over a period of 6 months and divided in three sub-samples for (a) soft algae identification, (b) diatom identification and (c) suspended chl-a analyses. For the determination of suspended chl-a (mg/ℓ) in the water column, the protocol of Porra et al., (1989) was followed. The samples for algae identification were preserved in the field by adding 2.5% (v/v) calcium carbonate-buffered glutaraldehyde.

The diatom sub-sample of each pond was cleared of organic matter by heating it in a potassium dichromate and sulphuric acid solution and the cleared material was rinsed, diluted and mounted in Pleurax medium for microscopic examination. Algae were identified up to species level using a compound microscope at 1250 times magnification (Van Vuuren et al., 2006; Taylor et al., 2007b; Truter, 1987, Wehr and Sheath, 2003). The samples were sedimented in a Sedgewick-Rafter sedimentation chamber and were analysed using the strip-count method (APHA, AWWA and WPCF, 1992). The numerical numbers for general grouping of abundance of algae taxa at each sampling site was categorised according to Oberholster and Botha (2011): 1 = ≤ 250, 2 = 251-1000, 3 = 1001-5000, 4 = 5001-25 000 cells/ℓ. The Berger-Parker dominance index (Berger and Parker, 1970) was used to measure the evenness or dominance of each algae species at each sampling site using actual algae cell numbers: $D = N_{max}/N$ Eqn 1

Where N_{max} = the number of individuals of the most abundant species present in each sample, and N = the total number of individuals collected at each site.

The density of the most abundant species (cell/ℓ) was calculated using the following formula: Density = Xn / M x 44 µl

Where Xn = number of individuals in species X; M = number of drops observed under the microscope. A drop of the sampled water taken up by a micropipette = 44 µl (Moser et al., 2004).

Findings

The results of the quantitative changes in algal biomass before and after treatment are presented in Table 7. The average pH of the pre-treated water (ponds 4, 5, 6 and 7) was 8.0 and changed to 8.7 after treatment with the algae (Table 8 on page 20). The higher pH values were possibly attributed to higher photosynthetic rates of the inoculated algae biomass drawing more CO_2 from the water column (Madhab et al., 2013). Total nitrogen and phosphorus varied from one pond to another before treatment, but decreased along the treatment system after algae treatment.

The reduction of total phosphorus in the unfiltered water (contain algae) after algae treatment was 74.7%, 76.4% and 75.3% for ponds 5, 6 and 7. There were two possible explanations for the reduction of phosphorus concentration during the algae treatment. The first is the incorporation of phosphorus into the algae biomass as shown in Table 3, while the second is the precipitation of phosphorus at high pH values in calcium rich water. The latter is known to occur at pH values greater than 8.5 (Mesple et al., 1995; Moutin et al., 1992).

The reduction of total nitrogen was much less than total phosphorus after treatment. The total nitrogen removal in ponds 5, 6 and 7 were 43.1%, 35.1% and 30.7% respectively. The suspended solids increased from before to after algae treatment. The latter can possibly be related to the dense suspended algal solids after treatment of ponds 5, 6 and 7. The increase of suspended solids after algae treatment was also reported by Madhab et al., (2013).

Although the system displayed a reduction of COD after treatment, it was unable to reduce COD levels in the unfiltered samples to meet the South African effluent discharge standard of 75 mg/ℓ. However a large portion of this residual COD was possibly related to the algae biomass that increased dissolved oxygen levels. This phenomenon was evident from the filtered water samples where algal cells were separated from the treated pond water (Table 9 on page 21).

Chlorophytes were the dominant algal group throughout the pre-algae treatment sampling period in ponds 4, 5, 6 and 7. The chlorophyte *Micractinium pusillum* was the dominant algae at ponds 4, 5, 6 and 7 before treatment. These results are similar to those observed by Madhab et al., (2013) who reported dominance of chlorophytes in maturation ponds.

The maximum algae abundance was 2.7×10^4 cells/mℓ in pond 4 before treatment, while the maximum chl – a concentration of 242 µg/ℓ coincided with the maximum algae biomass in this pond. Algae abundance of 3.1×10^4 cells/mℓ was measured in pond 5 before treatment, with a maximum chl – a concentration of 341 µg/ℓ.

Diatoms were present in low numbers before and after treatment throughout the study and can possibly be related to our sampling technique, since Bartel et al., (2008) reported that diatoms preferred the bottom of ponds. After treatment with 10 000 cells/mℓ the dominant algae was *Chlorella protothecoides* in ponds 4, 5, 6 and 7 (Table 7). The maximum algae abundance was 4.6×10^6 cells/mℓ in pond 4 and 6.1×10^6 cells/mℓ in pond 5 after treatment, while the maximum chl – a concentration of 783 µg/ℓ was measured in pond 5 after two months of inoculation. The average chl – a in ponds 4 and 5 before algae inoculation was 176 µg/ℓ, which changed to an average of 611 µg/ℓ after four months of algae treatment.

Table 7: Composition of algal communities before algae treatment (b) and after algae treatment (a) during the winter month at ponds 5, 6 and 7 (+ = rare, + + =scarce, + + + = common, + + + + = abundant, + + + + + = predominant). The relative abundance of each algal taxa was grouped into: 1 = ≤ 50 (rare) 2 = 51- 250 (scarce), 3 = 251-1000 (common), 4 = 1001-5000 (abundant), 5 = 5001-25 000 (predominant) cells/mℓ

Phylum/Class	Major species	Pond 4 (b)	Pond 4 (a)	Pond 5 (b)	Pond 5 (a)	Pond 6 (b)	Pond 6 (a)	Pond 7 (b)	Pond 7 (a)
Bacillariophyta									
Bacillariophyceae	*Nitzchia palea*	+		+					
	Craticula ambigua	++		+					
	Navicula viridula	+	+	++	+				
	Melosira varians		++	+	+	+		++	
Chlorophyta									
Chlorophyceae	*Micractinium pusillum*	++++	+	++++	++	+++	+	++++	++
	Scenedesmus chlorelloides	+++	+	+			++		
	Scenedesmus ovalternus	+	+		+	++		++	+
	Scenedesmus quadricauda	+++	+	+++	+				
	Eudorina elegans	+++	+		+	+			
	Pediastrun dubplex	++		++		++		+++	
	Pandorina morum	++		+		++			
	Desmodesmus armatus	++		+	+				
	Chlorella vulgaris		++++		++++		++++		++++
	Chlorella protothecoides		++++		+++++		+++++		++++
Euglenophyta									
Euglenophyceae	*Euglena viridis*	+++		+					
	Trachelomonas hispida	++		+		+			
	Phacus pleuronectus	+++	+						
Cyanophyta									
Cyanophyceae	*Oscillatoria limosa*	+++	+	+					

Way forward

By improving rural sewage pond systems to be self-sufficient, there will be a reduction of operator responsibilities to manage treatment, a reduction in labour costs, reduction in electricity requirements and an increase in the potential fiscal returns from the tangible products generated by the treatment unit in the form of aquaculture breeding of ornamental fish or production of fertiliser from the algae biomass. However, from the study it was evident that the algae biomass needs to be removed through either aquaculture or flocculation to reduce COD and Total Phosphorus below DWS effluent standards on a continuous basis. Nonetheless, it must be taken into account that the test trail was performed during the winter months when green algae productivity is generally low due to lower surface water temperatures (Ras et al., 2013). Furthermore, bottom sludge was not removed from the dry ponds prior to the study, possibly causing phosphorus concentrations to increase due to diffusion from the previous dried bottom sludge when the ponds was rewetted over a period of six months.

Table 8: Trend analyses of selected physical and chemical parameters (mean and standard deviation values) for monitoring the efficiency of algae remediation at Motetema wastewater treatment works over a period of six months (n=6). Only ponds 4 and 5 were inoculated with algae for treatment.

Parameters	Before treatment (unfiltered)							After treatment (unfiltered)							% Removal after treatment		
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 5	Pond 6	Pond 7
Total Nitrogen (mg/ℓ)	34 ±17	30 ±13	2 7±4	23 ±5	58 ±11	3 1±7	26 ±4	47 ±13	33 ±9	36 ±7	36 ±2	33 ±7	20 ±4	18 ±3	43.1	35.1	30.7
Total Organic Carbon (mg/ℓ)	99 ±19	61 ±15	57 ±11	47 ±10	181 ±18	45 ±11	37 ±7	117 ±17	58 ±18	77 ±11	67 ±14	55 ±9	35 ±8	31 ±5	69.6	22.1	16.4
Total Chemical Oxygen Demand (mg/ℓ)	378 ±81	238 ±69	224 ±61	157 ±43	567 ±83	230 ±39	103 ±41	379 ±76	228 ±84	276 ±70	272 ±67	142 ±23	92 ±11	93 ±9	59.4	35.2	2.0
Total Phosphorus (mg/ℓ)	11 ±5	10.3 ±3	8.7 ±3	9.5 ±6	9.1 ±4	8.9 ±3	7.3 ±2	14 ±5	12 ±4	10 ±3	3.3 ±1	2.3 ±0.9	2.1 ±0.3	1.8 ±0.4	74.7	76.4.	75.3
Suspended Solids (mg/ℓ)	229 ±17	117 ±12	115 ±11	65 ±10	224 ±14	54 ±7	76 ±11	259 ±21	118 ±19	76 ±11	120 ±19	123 ±11	82 ±7	89 ±11			
Sulphate as SO_4 Dissolved (mg/ℓ)	87 ±15	89 ±11	106 ±19	109 ±13	71 ±10	167 ±13	153 ±7	210 ±19	150 ±11	155 ±13	159 ±17	103 ±21	122 ±11	117 ±10	39.7	63.3	23.5
Chloride as Cl (mg/ℓ)	60 ±9	61 ±5	62 ±7	60 ±6	76 ±13	76 ±7	74 ±11	89 ±12	83 ±9	82 ±11	84 ±7	66 ±10	61 ±5	60 ±9	13.1	19.7	18.9
ortho Phosphate as P (mg/ℓ)	2.7 ±1.5	2.4 ±1.3	1.0 ±0.5	1.1 ±02	4.8 ±1.1	3.4 ±0.8	2.0 ±0.7	2.5 ±1.2	2.8 ±1.1	1.7 ±0.5	1.8 ±0.3	1.1 ±0.6	0.44 ±0.4	0.28 ±0.6	81.0	87.1	86.0
Ammonia as N (mg/ℓ)	20 ±4	17 ±8	19 ±3	18 ±5	37 ±11	24 ±9	27 ±6	33 ±10	22 ±9	21 ±6	22 ±4	21 ±7	20 ±8	18 ±3	43.2	16.6	33.3
Electrical Conductivity (mS/m)	104 ±19	102 ±21	102 ±9	98 ±17	112 ±11	100 ±10	116 ±7	132 ±21	116 ±9	120 ±15	115 ±8	120 ±21	116 ±9	94 ±11			
pH (Lab) (20°C)	8.1 ±1.2	8.1 ±1.5	8.1 ±1.3	8.1 ±1.2	7.8 ±1.5	8.1 ±1.3	8 ±1.1	8.0 ±1.3	8.3 ±1.2	8 ±1.4	8.7 ±1.0	8.9 ±1.4	8.6 ±1.3	8.2 ±0.9			

Table 9: Pond 5-7 after algae is removed through filtering (0.22 µm pore size Whatman GF/filter) to determine algae uptake of nutrients during month 6 of algae inoculation

Parameters	Before treatment (filtered)			After treatment (filtered)			% Removal after treatment		
	Pond 5	Pond 6	Pond 7	Pond 5	Pond 6	Pond 7	Pond 5	Pond 6	Pond 7
Total Nitrogen water (mg/ℓ)	32	20	20	20	14	13	37.5	30.0	35.0
Total Organic Carbon (mg/ℓ)	83	27	25	20	27	19	75.9	7.4	24.0
Chemical Oxygen Demand (mg/ℓ)	282	72	68	52	71	49	81.6	1.4	27.9
Total Phosphorus (mg/ℓ)	7.0	0.3	0.6	0.1	0.1	0.1	99.0	72.1	88.3

Key Learning Points

Algae *(Chlorella vulgaris* and *Chlorella protothecoides)* can be easily cultured in the lab and scaled up in raceways or open tanks. These cultured algal species are more effective in nutrient assimilation than algal species that occur naturally.

The introduction of the two algal species in three ponds at Motetema led to the reduction of 74.7%, 76.4% and 75.3% in total phosphorus and 43.1%, 35.1% and 30.7% in total nitrogen respectively.

Bottom sludge must be removed from the dry ponds prior to rewetting.

CHAPTER 4: AQUACULTURE

CHAPTER OBJECTIVE:

The focus of the aquaculture component was to improve nutrient removal in WWTW by introducing fish in the final pond to consume the algae.

Implementation of polyculture in waste water treatment ponds

When establishing a small and sustainable fish culture in waste water treatment works, one needs to consider that essentially all aquatic organisms are poikilothermic such that when climate and water temperatures decrease the metabolic rate/ activities of fish also decrease to that of the surrounding environment. The implication is that a point may be reached under extreme cold conditions whereby all feeding behaviour ceases entirely resulting in the increase of wastewater loads and the further deterioration in water quality.

In conjunction with temperature, knowledge of the diurnal content of oxygen levels is crucial as high algal densities result in a drastic decrease of oxygen levels at night. Minimum oxygen, in turn, will dictate the permissible stocking density with low stocking densities due to low oxygen concentrations equating to low fish yields. Should dissolved oxygen (DO) levels be depleted due to an increase in the biological oxygen demand (BOD) the bulk of the fish stocked could die. This is especially true at night when DO levels are known to decrease substantially due to the respiration of algae at high densities. A means to circumvent and prevent the occurrence of low levels of oxygen is to use paddle wheels designed to agitate the surface water. Moreover, temperature and oxygen levels are known to influence water pH, which in turn will have an effect on free ions associated with ammonia and ammonium in solution (Spotte, 1970).

However, with the facilities at Motetema WWTW being rudimentary and void of electricity supply the use of artificial heating and paddle wheels was not an option and hence, for all intents and purposes, principles governing extensive aquaculture practises were therefore considered in this study.

Field based experiments

To assess if water conditions in Motetema (WWTW) would allow for the growth and survival of fish, 66 *Oreochromis mossambicus* and 73 *Coptodon rendalli* were introduced into the system. These fish were captured from the nearby Flag Boshielo Dam and transported in well aerated holding tanks to Motetema (WWTW) where they acclimatised by slowly introducing pond water into the holding tanks. The fish were then removed from the tanks and placed into floating cages/ microcosms (Figure 12) that were built to house them in the system. However, the fish died just hours after being placed into the system. Although unionized ammonia (NH_3) levels was not measured when introducing the fish, fish mortality was inferred to be caused by the system not being in a mature state due to the fact that the parallel system was switched to a new set of six ponds during our field experiment and that levels reported in Table 8 (previous chapter) far exceeds < 2.0 mg/ℓ NH_3 reported by Alabaster and Lloyd (1980) to be toxic to fish.

Figure 12: A) Microcosms being set out in pond 6 by Mr Willem Smit. B) Microcosms being retracted and removed from pond 6 for final inspection by Mr Smit and Dr Kris Bal.

Laboratory based experiments

Based on the unsuccessful field-based studies, laboratory based studies focusing on conducive conditions for fish survival were conducted. A preliminary investigation was undertaken involving two sets of laboratory trials wherein *O. mossambicus* were placed in glass aquaria (10 specimens per tank) and exposed for 24 hours to wastewater collected from Motetema WWTW that was diluted with clean municipal water (matured for 36 hours) using ratios of 100:0; 50:50 and 0:100 (Figure 13).

One set of trials involved all three treatments be well aerated whilst the other set of treatments was not. Water temperature was kept constant at 29°C, with the use of submersible heaters. Results revealed that a 100% mortality occurred amongst fish exposed to wastewater that was void of aeration whilst survival for fish exposed to water treatments supplied with air were 60 – 100%, see Figure 14. Fish deaths were inferred to be due to the high levels of ammonia (NH_3) and nitrite (NO_2^-) present in the water (see Table 10), attributed to the system not being mature at the time the wastewater was collected. Alabaster and Lloyd (1980) report that for the safe culture of fish it is crucial that unionized ammonia (NH_3) and NO_2^- should be kept as low as possible and never exceed levels of 2 mg/ℓ and 5 mg/ℓ, respectively. For each treatment, oxygen levels were shown to have a considerable effect on water pH, see Figure 15 on page 24. A change in pH can account for the change in NH_3 and NO_2^- reported (Table 10). Similar trials involving periods of longer exposure and different species of fish are underway at the University of Limpopo. Results of these studies will be published elsewhere in the future.

Figure 13: Experimental Laboratory facilities at the University of Limpopo

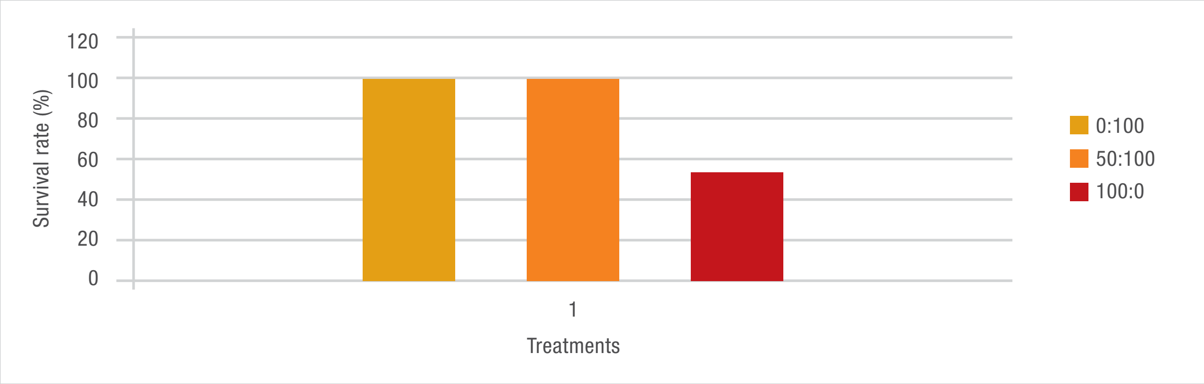


Figure 14: The survival rate expressed as percentage (%) of fish exposed to different treatments

Table 10: The nutrient content in water samples taken from the various treatments

Nutrients (mg/ℓ)	Treatment						Effluent water
	Non-aerated water			Aerated water			
	Control	0:50	0:100	Control	0:50	0:100	
Ammonium as NH_4	0.45	8.28	19.1	0.4	9.45	18.1	20.7
Ammonia as NH_3	0.42	7.81	18.02	0.38	8.92	17.08	19.53
Nitrate as NO_3	0.1	0.12	0.13	0.16	0.09	0.12	0.07

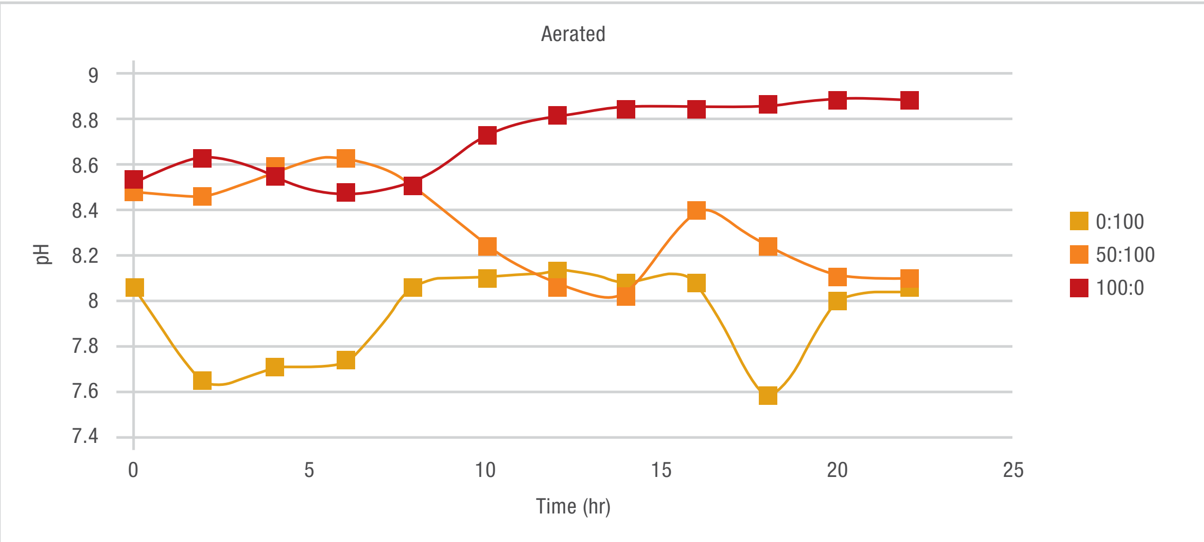


Figure 15: The pH recorded over a 24 hour period for tanks containing 0%, 50% or 100% effluent water with aeration

Way forward

Given the water quality readings elucidated in this document and based on the field and laboratory trials, the conditions at Motetema WWTW at the time did do not allow for successful aquaculture. The fish should only be introduced once the phycoremediation process has been established and the water quality in the final pond is suitable for fish culturing. In addition, only two fish species were introduced and more research on additional more robust species should be investigated. Future research should investigate alternatively options such as methods for algae harvesting for bio-fertiliser production.

Key Learning Points

- Various fish species may be suitable for introduction in WWTW, with indigenous species such as *Oreochromis mossambicus* and *Coptodon rendalli* being good candidates.
- The fish should only be introduced once the phycoremediation process has been established and the water quality in the final pond is suitable for fish culturing.
- Alternative methods for algae harvesting for bio-fertiliser production and introduction of more robust fish species should be investigated.

CHAPTER 5: ECOSYSTEM AND HUMAN HEALTH RISK ASSESSMENT

CHAPTER OBJECTIVE:

To use a quantitative microbial risk assessment to determine the potential health risks posed to humans from exposure to microbial pathogens in the effluent discharged from the Motetema WWTW. The probability of infection is calculated assuming a probable exposure from activities ranging from, for instance, playing or wading in the water.

Introduction

The release of untreated or inadequately treated municipal wastewater effluents may pose a public health risk due to the presence of pathogenic bacteria, enteric viruses, and protozoa (such as *Giardia* and *Cryptosporidium spp*.) into receiving waters (Toze, 1997). Bacteria are the most common of microbial pathogens found in wastewater. A wide range of bacterial pathogens and opportunistic pathogens associated with wastewater are enteric in origin and have been reported in literature (Simpson and Charles, 2000). Gastrointestinal infections are amongst the most common diseases caused by bacterial pathogens in wastewater (LeChevailler and Au, 2004). Wastewater associated infections generally include diarrhoea, dysentery, dysentery-like infections, *Leptospira interrogans* infections, typhoid, human enteritis, legionellosis, melioidosis, stomach ulcer and cancer (Liang et al., 2006).

The contamination of food by water organisms such as *Staphylococcus aureus*, *Salmonella spp*., *E. coli*, or *Clostridium perfringes* can cause outbreaks of food poisoning (often severe and widespread) (Toze, 1997). Viruses are generally more resistant to treatment, more infectious, more difficult to detect in environmental samples such as wastewater and require smaller doses to cause infection than most of the other pathogens (Gomez et al., 2006). The public are at risk through the direct ingestion of untreated or inadequately treated water, engaging in recreational and domestic activities in contaminated waters, consuming contaminated fish and through unintentional exposure through splashes. The effects of contamination can be experienced 30 - 40 km downstream of a source (Oberholster et al., 2013) illustrating the importance of adequate treatment of wastewaters to protect public health.

Water Quality Analysis

Physicochemical analysis of the wastewater samples included the following parameters: ammonia, ortho-phosphate, nitrate and nitrite, chloride and fluoride, potassium, sodium, magnesium, sulphate, calcium, and hardness as $CaCO_3$, electrical conductivity, pH, chemical oxygen demand (COD), Kjedahl nitrogen and total phosphate.

Wastewater was initially analysed for a number of microbial faecal indicator bacteria and various pathogens, namely, *E.coli,* coliphage and clostridium, two protozoan parasites (*Giardia* and *Cryptosporidium*) and the enteric virus, Norovirus, using methods previously described (Le Roux et al., 2012). Due to costs of pathogen analysis, the indicator organisms *E. coli*, coliphages and clostridium were used to assess water quality following the initial assessment. These organisms are used as surrogates for pathogens in microbial risk assessments. As the World Health Organisation (WHO, 2011) states discussing water quality guidelines, “it is rarely possible or appropriate to directly measure pathogens on a regular basis”.

Quantitative Microbial Risk Assessment

In assessing risks associated with exposure to water it is important to judge the level of safety of the water. Quantitative Microbial Risk Assessment (QMRA) is a method developed to calculate the probability of infection from particular pathogens. The process of QMRA is derived from the chemical risk assessment paradigm that encompasses the 4 steps of risk assessment which are hazard identification and characterisation; exposure assessment; dose-response assessment and lastly risk characterisation.

Hazard identification

Many infectious causes of gastrointestinal symptoms can occur as a result of contaminated water. These may be parasitic, bacterial or viral agents with examples of water-borne diseases including cholera, typhoid, giardiasis, cryptosporidiosis, hepatitis and polio. Both faecal indicator organisms and specific pathogens were tested for in the ponds of the wastewater treatment works in the 2 study sites. With exposure to microorganisms the consequence may include infection (not necessarily with apparent illness), morbidity (the development of symptoms) and finally mortality (death).

In general, the tendency in water microbiology is to consider infection in the population as the particular hazard for which protection is needed (WHO, 2001). Bacterial indicators of faecal contamination and enteric viruses are usually present in high concentrations in raw wastewater. For example, typical concentrations of faecal coliforms in untreated sewage are 10^6 –10^8 /100 mℓ (Feachem et al., 1983; George et al., 2002; Miescer and Cabelli, 1982; Hu and Gibbs, 1995). According to Hu and Gibbs (1995) *Salmonella sp*. in wastewater typically range from 100 –10 000 cells per 100 mℓ. According to studies looking at the occurrence of pathogenic *E. coli*, 53% found in wastewater treatment works and environmental waters were of the pathogenic IPEC variety (Anastasi et al., 2012). In a study monitoring pathogenic types of *E. coli* used to irrigate lettuce, Castro-Rosasa et al., (2012) found 7% of *E. coli*'s to be pathogenic.

Exposure assessment

There are several ways in which an individual can acquire disease from wastewater: direct ingestion of the wastewater or aerosols created during spray irrigation may result in infection. In addition, infection may occur from ingestion of pathogens on contaminated vegetation, oysters or other surfaces.

To calculate microbial risk, the density of pathogens (number of micro-organisms per litre) in the source water must be quantified and entered into the risk model. The main sources of information for quantifying pathogen density in source waters are either water samples collected from the site and analysed directly for the presence of pathogens; or through modelling based on presence of indicator organisms. In this study indicator organisms and pathogenic viruses and parasites were initially analysed followed by indicator organisms only.

Doses can be calculated based on the volume used for assessment and assuming a hypothetical volume of ingestion (accidental or deliberate) of effluent from the pond systems was consumed.

Exposure assessment is a predictive activity and therefore contains uncertainty. Variability must also be taken into account, as water quality will vary over time in addition to spatially. Literature studies have shown that ingested volumes ranged from 1 to 50 mℓ from accidental exposure through splashing, playing, wading, fishing, boating and swimming (Table 11). Assumptions were made on the volume of water ingested directly without treatment. In the risk assessment presented in this report it was assumed that between 1 and 10 mℓ volume of untreated water was ingested. It is unlikely that larger volumes associated with active unrestricted swimming will be ingested. According to the studies mentioned in the earlier section, pathogenic *E. coli* varied from 53% to 7%. In this quantitative microbial health risk assessment, it was assumed that the lower, more conservative value of 7% of *E. coli* bacteria were pathogenic.

Table 11: Volumes of water associated with specific recreational activities according to exposure studies

Activity	Volume ingested	Reference
Boating and canoeing	1-4 mℓ/h	
Fishing	1 mℓ/h	Sunger and Haas
Wading	10 mℓ/h	
Playing	12 mℓ/h	
Swimming	25 mℓ/h	
Swimming	18-51/event	Schets et al., 2011
Swimming – children	47 mℓ/event	Evan's et al., 2006
Swimming males	30 mℓ/event	
Swimming females	19 mℓ/event	Dorevitch et al., 2011
Children	37 mℓ	Dufour
Adults	16 mℓ	
Wading	10 mℓ/h	US-EPA, 2000

Dose-Response

Dose-response modelling is one of the most important steps in microbial risk assessment as it illustrates the link between exposure dose and the probability of infection. Previously, dose-response relationships were based on human feeding experiments and were used to estimate infectious doses. It became clear that infection is possible from exposure to a single organism, and the use of models based on the 'single-hit' theory of dose-response evolved (Regli et al., 1991; Haas et al., 1993; Gerba et al., 1996).

Quantitative dose-response models were developed to estimate the probability of infection based on the average pathogen dose (Haas et al., 1983). The calculation of probability of infection is a two-step process, being the combined probability of exposure and probability of infection, including some simplifying assumptions to the relationship between numbers of organisms ingested and infection.

Table 12: Daily risk of infection formulae

Daily risk of infection	Daily risk of infection
(WHO, 2001) $P_i = 1 - \left[1 + \frac{d}{N_{50}}(2^{\frac{1}{\alpha}} - 1)\right]^{-\alpha}$	Exponential model (Haas, 1996) $Pi = 1 - \exp(-rN)$

P_i = probability (risk) of infection
d = dose or exposure (number of organisms ingested based on consumption of water per day)
α = parameter characterised by dose-response relationship
N_{50} = median infectious dose
r = parameter characterised by dose-response relationship

1 The root-mean-square (or quadratic mean) is calculated using the formula: $\sqrt{\frac{x_1{}^2 + x_2{}^2 + \cdots \ldots x_n{}^2.}{n}}$

Long-term probability of infection or multiple exposures

Multiple (or long-term) exposures are calculated using the following formula:

$P(n) = 1-((1-Pi))^n$

Where n is the number of times exposure occurs.

For example annual exposure, n =365, monthly exposure, n=12 and weekly exposure, n=52.

The organism specific parameters used within the risk calculations are presented in Table 13, with corresponding references.

Table 13: Parameters used in the quantitative microbial risk assessment and references

Organism	α	N_{50}	r	Reference
E. coli pathogenic	0.395	2.473		Strachan et al., 2005
Giardia sp.			0.0198	Teunis et al., 1996
Cryptosporidium sp.			0.00419	Teunis et al., 1996
Norovirus	0.040	0.055		Teunis et al., 2008

Findings

Microbial Quality

The microbial water quality represented by faecal indicators in the pond systems is presented in Table 14 and Figure 16a and 16b on page 30.

Averages (presented by Root Mean Squares –RMS) based on monthly tests from May to August 2016 are used as the measure of central tendency.[1] The general *E. coli* limit for wastewater effluent is 1000 / 100 mℓ. The final pond water quality was below the general limit on one occasion with average *E. coli* counts more than 7 times this limit.

The *E. coli* and other faecal indicator numbers decreased significantly from the inflow to the final pond, with the highest numbers occurring in Pond 1 and lowest numbers in the final effluent (M7). No enteric viruses or protozoan parasites were isolated in the wastewater samples, as only low volumes (4 ℓ) could be processed for analysis due to high levels of suspended solids present in the wastewater. Surrogate analyses were used in the quantitative microbial risk assessment with coliphages representing Noroviruses and clostridium counts used to represent *Giardia* and *Cryptosporidium*. A ratio (0.032%) was used based on earlier studies of wastewater treatment works in a similar area (data not shown) where both *Giardia* cysts and clostridia were detected. A ratio of 1% of coliphage counts was used to represent norovirus concentrations based on studies carried out on norovirus concentrations in oysters (Flannery et al., 2012).

Table 14: Average (Root Mean Square) microbial quality of wastewater ponds

Pond	E. coli *2 n = 4	Phage / 100 mℓ	Clostridium / 100 mℓ
M1	1 688 094	118 474	355 528
M2	612 115	11 777	63 547
M3	192 345	12 900	53 233
M4	202 165	7 290	29 182
M5	102 951	7 790	30 321
M6	25 115	2 306	11 571
M7	7 381	1 852	13 055

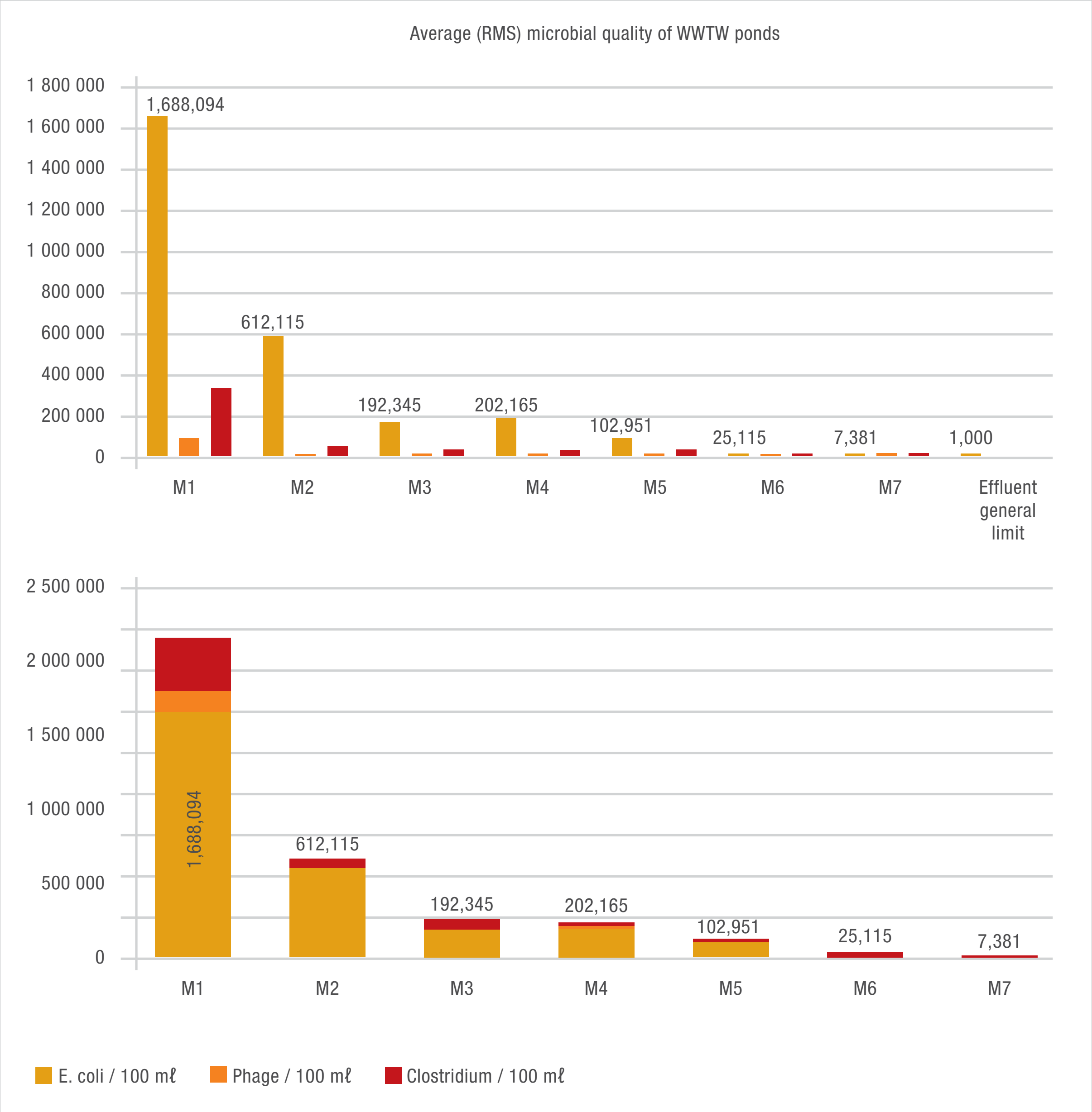


Figure 16a and b: Microbial quality of wastewater ponds

2 *General limit for *E. coli* WW 1,000/100 mℓ

Chemical and physical water quality

The primary operational efficiency effluent constituents considered in the baseline assessment of wastewater collected from the maturation ponds at Motetema are given in Table 15.

The effluent parameters determined for the samples collected from the maturation ponds at Motetema are given in Table 16. The electrical conductivity (EC), chemical oxygen demand (COD), ammonia and suspended solids measured in all the maturation ponds exceeded the general and specific limits for municipal wastewater (DWAF, 2003).

Table 15: Operational monitoring constituent parameters considered in the baseline assessment

Suspended solids	Suspended solids can lead to the development of sludge deposits and anaerobic conditions when untreated wastewater is discharged in the aquatic environment.
Biodegradable organics (BOD and COD)	Composed principally of proteins, carbohydrates, and fats, biodegradable organics are measured most commonly in terms of BOD (biochemical oxygen demand) and COD (chemical oxygen demand). If discharged untreated to the environment, their biological stabilisation can lead to the depletion of natural oxygen resource and to the development of septic conditions.
Microbial indicators and Pathogens	Communicable diseases can be transmitted by pathogenic organisms that may be present in wastewater.
Nutrients	Both nitrogen and phosphorus, along with carbon, are essential nutrients for growth. When discharged to the aquatic environment, these nutrients can lead to the growth of undesirable aquatic life. When discharged in excessive amounts on land, they can also lead to the pollution of groundwater.

Table 16: Physicochemical properties of Motetema ponds (highlighted values exceed the general and/or specific limit) (Section 39 of the National Water Act no 36 of 1998)

Parameters	Before treatment (unfiltered)							After treatment (unfiltered)							% Removal after treatment		
	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 1	Pond 2	Pond 3	Pond 4	Pond 5	Pond 6	Pond 7	Pond 5	Pond 6	Pond 7
Total Nitrogen (mg/ℓ)	34 ±17	30 ±13	2 7±4	23 ±5	58 ±11	3 1±7	26 ±4	47 ±13	33 ±9	36 ±7	36 ±2	33 ±7	20 ±4	18 ±3	43.1	35.1	30.7
Total Organic Carbon (mg/ℓ)	99 ±19	61 ±15	57 ±11	47 ±10	181 ±18	45 ±11	37 ±7	117 ±17	58 ±18	77 ±11	67 ±14	55 ±9	35 ±8	31 ±5	69.6	22.1	16.4
Total Chemical Oxygen Demand (mg/ℓ) [75]	378 ±81	238 ±69	224 ±61	157 ±43	567 ±83	230 ±39	103 ±41	379 ±76	228 ±84	276 ±70	272 ±67	142 ±23	92 ±11	93 ±9	59.4	35.2	2.0
Total Phosphorus (mg/ℓ) [10]	11 ±5	10.3 ±3	8.7 ±3	9.5 ±6	9.1 ±4	8.9 ±3	7.3 ±2	14 ±5	12 ±4	10 ±3	3.3 ±1	2.3 ±0.9	2.1 ±0.3	1.8 ±0.4	74.7	76.4.	75.3
Suspended Solids (mg/ℓ) [25]	229 ±17	117 ±12	115 ±11	65 ±10	224 ±14	54 ±7	76 ±11	259 ±21	118 ±19	76 ±11	120 ±19	123 ±11	82 ±7	89 ±11			
Sulphate as SO_4 Dissolved (mg/ℓ)	87 ±15	89 ±11	106 ±19	109 ±13	71 ±10	167 ±13	153 ±7	210 ±19	150 ±11	155 ±13	159 ±17	103 ±21	122 ±11	117 ±10	39.7	63.3	23.5
Chloride as Cl (mg/ℓ)	60 ±9	61 ±5	62 ±7	60 ±6	76 ±13	76 ±7	74 ±11	89 ±12	83 ±9	82 ±11	84 ±7	66 ±10	61 ±5	60 ±9	13.1	19.7	18.9
Ortho Phosphate as P (mg/ℓ) [10]	2.7 ±1.5	2.4 ±1.3	1.0 ±0.5	1.1 ±02	4.8 ±1.1	3.4 ±0.8	2.0 ±0.7	2.5 ±1.2	2.8 ±1.1	1.7 ±0.5	1.8 ±0.3	1.1 ±0.6	0.44 ±0.4	0.28 ±0.6	81.0	87.1	86.0
Ammonia as N (mg/ℓ) [3]	20 ±4	17 ±8	19 ±3	18 ±5	37 ±11	24 ±9	27 ±6	33 ±10	22 ±9	21 ±6	22 ±4	21 ±7	20 ±8	18 ±3	43.2	16.6	33.3
Electrical Conductivity (mS/m) [100]	104 ±19	102 ±21	102 ±9	98 ±17	112 ±11	100 ±10	116 ±7	132 ±21	116 ±9	120 ±15	115 ±8	120 ±21	116 ±9	94 ±11			
pH (Lab) (20°C) [5.5-9.5]	8.1 ±1.2	8.1 ±1.5	8.1 ±1.3	8.1 ±1.2	7.8 ±1.5	8.1 ±1.3	8 ±1.1	8.0 ±1.3	8.3 ±1.2	8 ±1.4	8.7 ±1.0	8.9 ±1.4	8.6 ±1.3	8.2 ±0.9			

Health Risk Assessment

Health risks presented as probability of infection is based on accidental or intentional ingestion of both 1 mℓ and 10 mℓ wastewater are shown in Table 17 and Figure 17.

The probability of infection is reduced from almost certain (95% or 0.95) in wastewater that enters the pond system at M1, to a probability of infection of ~6 in 10,000 in M7, from exposure to pathogenic *E. coli*, assuming a single exposure event of 1 mℓ. For *Giardia*, the probability of infection is reduced from 2% at the start of the wastewater treatment process to 0.08% in the final effluent. Risks for exposure to viruses in effluent started at 64% and reduced to 55%. This low reduction in probability of infection estimated is predicted even though a far larger (2 log) reduction in viral concentrations is observed, as well as assuming that only 7% of coliphages detected are considered to represent norovirus (Flannery et al., 2012; Ulbricht et al., 2014). The risk of infection does not decrease accordingly to the decrease in virus numbers, as the dose-response curve of viruses characteristically follow an exponential model. The overall risks are higher than the recommended 0.01% or 1 in 10,000 annual risk of infection (WHO, 2001) with both parasites and viruses posing the greatest risk.

Table 17: Probability of infection resulting from a single or monthly exposure to pathogens in 1 mℓ or 10 mℓ wastewater

Organism	Site	Pi (1mℓ single)	Pi (1mℓ monthly)	Pi (10mℓ single)	Pi (10mℓ monthly)
E. coli pathogenic	M1 first pond	0.9529	1.0	0.9810	1.0
	M4 middle of process	0.0149	0.1645	0.1173	0.7763
	M7 final effluent	0.0006	0.0067	0.0055	0.0644
Giardia	M1 first pond	0.0223	0.2367	0.2016	0.9329
	M4 middle of process	0.0018	0.0219	0.0183	0.1989
	M7 final effluent	0.0008	0.0099	0.0082	0.0944
Cryptosporidium	M1 first pond	0.0047	0.0553	0.0463	0.4339
	M4 middle of process	0.0004	0.0047	0.0039	0.0456
	M7 final effluent	0.0002	0.0021	0.0017	0.0207
Norovirus	M1 first pond	0.6409	1.0	0.7276	1.0
	M4 middle of process	0.6078	1.0	0.7025	1.0
	M7 final effluent	0.5595	0.9999	0.6658	1.0

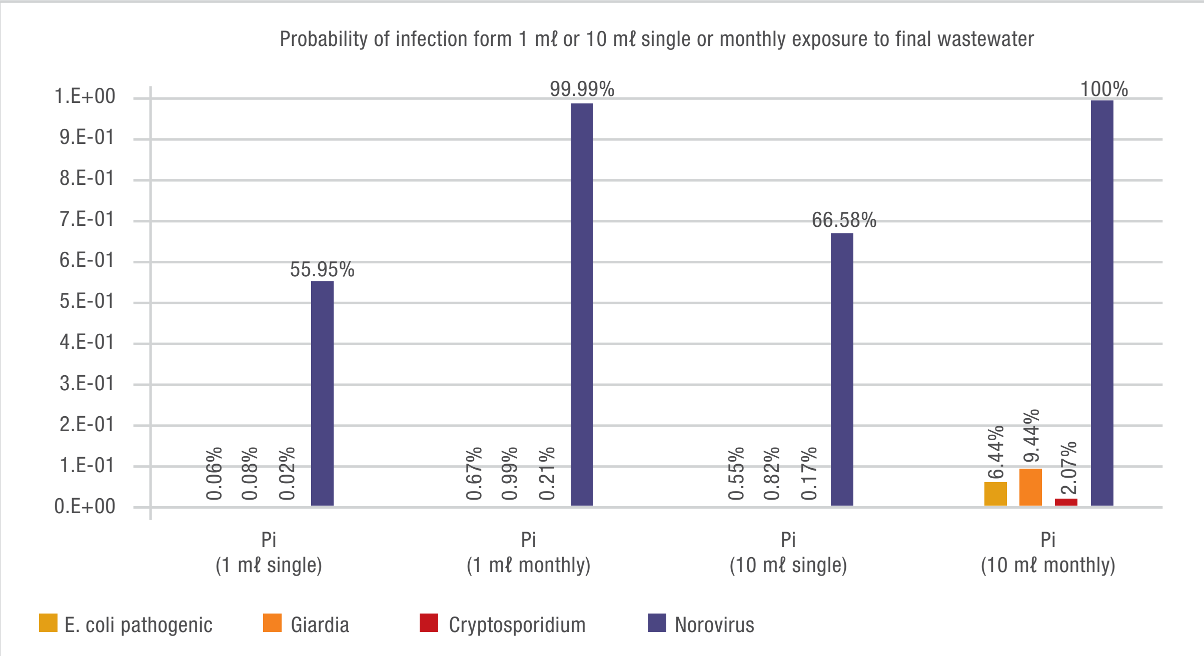


Figure 17: Probability of infection from pathogens in wastewater – single and monthly exposure to 1 mℓ and 10 mℓ final wastewater

As it is unlikely that a person living in the community will be exposed to the water on only a single occasion, repeated exposures were also calculated (Table 17 and Figure 17). It was assumed that a possible repeat exposure would be on a monthly basis, to the same quality of water. The amount of 1 mℓ - 10 mℓ volume of wastewater that is assumed that people might be exposed to represents a realistic exposure, resulting from splashing and playing in the receiving water, i.e. the river that receives the effluent. This results in probabilities of infection from *E. coli* of 1% to 6%, from *Giardia* of 1% to 10%, from *Cryptosporidium* of 0.2% to 2% and from norovirus 100% probability of depending on whether 1 mℓ or 10 mℓ is assumed as the volume of exposure.

These results reflect probability of infection, which differs from probability of illness (disease). Infection occurs when bacteria, parasites or viruses enter your body and begin to multiply, and is not related to the severity or outcome of symptomatic illness. Disease occurs when signs and symptoms of an illness appear.

Way forward

The health risks associated with exposure to the wastewater were significantly reduced from the beginning of the wastewater treatment process to the final effluent, and the results illustrate that with proper operations and management of the system, it is expected that health risks to the community can be significantly reduced. Health risks are greatest from possible exposure to viruses such as norovirus, and cryptosporidium presenting the lowest risks. The risk assessment presented here relates to probability of infection. Each pathogen may have a different health impact, and therefore a different disease burden. Differences may be due to disease severity, disease immunity or vulnerability, age and disease sequelae[3]. Studies in England reported asymptomatic norovirus infections at 12% of healthy individuals (Gibney et al., 2013). This is useful in understanding the high probability of infection predicted in this quantitative microbial risk assessment. Many uncertainties exist, however it is very likely that individuals making use of the receiving water, (even for recreational purposes) is likely to be infected. Any reductions in pathogen numbers in the wastewater effluent will provide a health benefit to the community.

Key Learning Points

The Health Risk Assessment process showed that any reductions in pathogen numbers in the wastewater effluent will provide a health benefit to the community.

Although health risks associated with exposure to the wastewater was significantly reduced from the beginning of the wastewater treatment process to the final effluent, the results still illustrated a significant risk of infection.

Health risks were greatest from possible exposure to viruses such as norovirus, while cryptosporidium presented the lowest risk.

3 Disease sequela is defined as an after effect of a disease, condition or injury; or a secondary result. An example of a disease sequela is where campylobacter results in a sequela of Guillain Barre Syndrome, a form of paralysis

CHAPTER 6: MUNICIPAL BENEFITS

CHAPTER OBJECTIVE:

To illustrate the approaches' support to municipalities by providing a technical solution and associated governance guidance to achieve greater treatment efficacy with existing wastewater treatment infrastructure.

People's constitutional rights and provisions as contained in the relevant legislation and regulations establish the policy context and legal instruments for wastewater treatment. The implementation of these provisions has proved difficult due to governance and technical constraints. Pond systems are ideally suited for sewage treatment in rural communities and towns, because they are simple and economical to operate and maintain. The algae-based treatment process utilises a specific consortium of algal species to remove nutrients and create conditions for effective solar disinfection to reduce pathogens. The intention of this project is to implement a self-sustaining system that is independent of electricity or expensive chemicals and that can be effectively operated within financial and capacity constraints. The algae-based treatment process will limit the impact on the country's scarce water resources and reduce health risks associated with wastewater discharge. The approach provides a technical solution and associated governance guidance to achieve greater treatment efficacy with existing wastewater treatment infrastructure and thereby support more effective policy implementation.

Sekhukhune District Municipality Context

The SDM is a Category C municipality which was established in December 2000. Until early 2006, the District was a cross-border municipality, straddling the Limpopo and Mpumalanga provinces. The District is made up of 5 local municipalities (LMs) – Elias Motsoaledi Local Municipality (formerly the Greater Groblersdal Local Municipality), Fetakgomo Local Municipality, Ephraim Mogale Local Municipality (formerly the Greater Marble Hall Local Municipality), Greater Tubatse Local Municipality and Makhuduthamaga Local Municipality. The main towns are Marble Hall, Groblersdal, Apel, Burgersfort, and Jane Furse.

According to the 2014/2015 IDP, the SDM has a number of powers and functions which it is legally mandated to "render efficient and professional services delivery" on. These are:

- Water Services
- Sanitation
- Electricity
- Municipal Roads
- Municipal Health Services
- Waste Management and Refuse Removal
- Cemeteries and Crematoria
- Firefighting
- Municipal Abattoirs
- Local Tourism
- Markets
- Municipal Airports except for Marble Hall and Groblersdal
- Municipal Public Transport
- Municipal Planning
- Storm Water for Tubatse, Makhuduthamaga and Fetakgomo

According to the growth point analysis of the SDM, the two local municipalities, Elias Motsoaledi and Ephraim Mogale are expected population growth points for the SDM; specifically the area of Motetema is also mentioned as a local municipal area of population growth (SDM, 2014). These growth points hold particular challenges for the SDM in terms of sustainable development and service delivery. Some of these challenges are for example an increase in the number of informal settlements and housing backlogs due to an increase in mining and agricultural activities; competing land uses which is causing spatial, social, environmental and economic constraints; lack of adequate environmental management; and, a lack of water supply to all settlements (SDM, 2014).

Sekhukhune District Municipality is both a Water Services Authority (WSA) and Water Services Provider (WSP). Its 740 villages are supplied with water from 43 schemes and sub-schemes. The SDM is a water scarce area, especially during low rainfall periods and water availability is thus a major concern for the SDM. In addition, due to a number of challenges the IDP notes that the SDM experiences more below RDP standard services[4] than they do above RDP standard services. According to the IDP for the SDM (2014/2015), there are a number of issues related to their role as WSA and WSP (SDM, 2014):

1) **Skills shortage within the SDM:** According to the SDM IDP for 2014/2015 the SDM lacks essential skills in the areas of engineering, IT, legal and municipal finance.
2) **Free basic water:** Many SDM households can be defined as poor indigent where their total income is below R1500 per month. Free Basic Water must be supplied to these households.
3) **Access to piped water:** At least 25% of the households in the SDM do not have access to piped water. Similarly, 75% of the households in the district do have access to piped water in the yard or through communal tap. Focused investment and delivery on water infrastructure development is essential for the SDM.
4) **Electric motors as energy soured for water supply:** often residents use electric motors instead of diesel motors as energy source to pump water. This has an impact on the SDM in that they need to implement operations and maintenance programmes to support this trend.
5) **Irregular water supply:** 415 villages report that although there is water supply, it is irregular. Thus water may only be available up to three times a week and not every day. While emphasis of effort should be placed upon those households without any water, attention should also be given here.
6) **Co-ordination of pump operators:** 61% of all villagers have pump operators for water pumps. However, the nature of these operators varies as some are employed by the municipality whilst others work on a voluntary basis. There is however no clear understanding of the pump operators and the nature of their employment and whether they are doing the job they are employed for. Investigation is needed by the SDM.
7) **People without water:** Many residents still travel long distances to obtain water. Attention should be given to improving yard connections. The SDM faces many challenges here such as limited water sources available in some areas, budgetary constraints; contamination of boreholes; vandalism and theft of electric and diesel engine pumps; and breakdown of machines, illegal connections and extensions of settlements.

Sanitation in the SDM faces considerable challenges. According to the SDM IDP (2014/2015) only 22% of the SDM households receive above RDP standards sanitation services[5]. The sanitation backlog is also very high particularly in the rural areas where 78% of households are without adequate sanitation services (see Table 18). According to the SDM IDP the situation is so dire that the SDM will not be able to meet the national targets as set out by the Millennium Development Goals.

Table 18: Sanitation level in 2013 (Infrastructure and Water Services Department at SDM, 2013 in SDM IDP 2014/2015)

Municipality	Total number of households	% Access RDP and above	% Backlog
Elias Motsoaledi	62829	26%	74%
Ephraim Mogale	57855	34%	66%
Fetakgomo	25642	30%	70%
Greater Tubatse	80879	25%	75%
Makhuduthamaga	66330	20%	80%
Sekhukhune	293535	25%	75%

4 Water at RDP standard: Water sources from pipes/tap/boreholes in the dwelling or yard or 200 metres or less from the dwelling (Stats SA, 2011a).

5 Sanitation at RDP standard: Flush toilet with on-site or off-site disposal as well as pit latrine with ventilation pipe regardless of location dwelling (Stats SA, 2011a).

Access to sanitation remains a challenge in the SDM as pit latrines are still the main source of sanitation in the district. Only 2% of villages in the district make use of sewer borne sanitation systems – these areas are mainly located in the urban centres of the district such as existing towns or townships (SDM, 2014). Greater Tubatse Local Municipality has recorded the highest number of villages/suburbs that are using sewerage systems (7); followed by Elias Motsoaledi Local Municipality (5); Ephraim Mogale Local Municipality (4); and Makhuduthamaga (1). Fetakgomo Local Municipality is the only municipality that reports no sewerage systems in use in any of its settlements. The SDM IDP 2014/2015 suggests the following measures taken to address these sanitation challenges:

- Measures to reduce the number of pit latrines as many households rely on groundwater (which may become contaminated by the pit latrines) for daily consumption.
- SDM needs to develop and implement a programme that will improve sanitation access throughout the entire district.
- SDM needs to develop standards regarding sanitation supply in the district in line with required standards.
- Concerted effort to migrate households in the district from pit latrines towards safer sanitation options even if it is not sewer borne sanitation.

According to Funke et al., (2014) their research in the SDM revealed a number of important challenges facing the SDM with regards to the management of their WWTW, these challenges are:

- Lack of mainstreaming wastewater treatment in municipal decision-making: refers to the ability of water managers to secure municipal budget in order to carry out their functions, in competition with other departments.
- Lack of planning and budgeting: links to the development and implementation of Green Drop ratification plans which needs budget and long term planning to be in place. Funke et al., (2014) note that officials often face having to develop ratification plans without having adequate financial resources to support the endeavour.
- Lack of capacity and reliable service provision at WWTW: Skills of workers at WWTW are often not up to standard and treatment plants often tend to be operated by workers who are not trained to do so (Funke et al., 2014). In addition, contractors employed to upgrade the plants and infrastructure often lacks the necessary experience for such a job (Funke et al., 2014).
- Lack of community buy-in and understanding of issues related to waste water treatment: Funke et al., (2014) argues that their research revealed that if the linkages between communities and municipalities are strengthened, communities are more able to be involved and informed regarding wastewater treatment issues.

These challenges were also echoed in a recent workshop held in the SDM, facilitated by the CSIR and hosted by the SDM. In this workshop the participants (including representatives from the national and provincial offices of the Department of Water Affairs, Lepelle Northern Water, the Sekhukhune District Municipality and local communities) identified the desired future state of the SDM in terms of WWTW (Ntombela et al., 2013). The following points were highlighted:

"Capacity of the Municipality and WWTW Operators

- The municipality's top management needs to give the necessary support to WWTW in terms of providing skilled personnel.
- All vacant positions related to WWTW need to be filled.
- Skilled operators/process controllers who have a broad knowledge and understanding of processes and operation procedures in their respective treatment plants are required. These operators/process controllers will also assist with the performance of their respective WWTW to thereby improve the receiving water quality.

WWTW and Infrastructure

- It is important to start looking at the upgrading of existing infrastructure.
- It is necessary to efficiently remove phosphates and nitrates in WWTW in the Sekhukhune District Municipality.
- An effective and efficient WWT system is required.
- It is important to have a sewerage works with a design capacity to accommodate the surrounding population.
- Well-functioning and reliable wastewater treatment infrastructure is needed.
- Infrastructure needs to be improved/developed otherwise we will have a challenge in the future because inadequate infrastructure can affect everyone in the district.
- All treatment works need to be completed so that all people and communities around this municipality will get clean water in their yards.
- All treatment works that are not properly constructed should be identified and urgently repaired to render them functional. This may be less expensive than constructing new WWTW to replace dysfunctional ones.

- The municipality should treat the effluent before discharging it into the system
- A practical maintenance and operational system is needed for all existing WWT infrastructure (O&M).
- Barricade dam and reservoir security to pumps and house connection be free for all"

(Ntombela et al., 2013)

Small, Medium and Micro Enterprise (SMME)

The project identified and tested options for economic opportunities from WWTW. Although it was not an explicit objective to establish an SMME, various beneficiation opportunities have been identified. It has become clear in the project that the sludge removal at small WWTW take place irregularly or not at all. Deactivated sludge has significant potential value and an SMME can be established for the collection and sale or use of sludge for approved agricultural products. The research into aquaculture options for beneficiation at WWTW bas been proven in the project. Although this is being evaluated as an entrepreneurial opportunity in the project this could be taken further in future through the establishment of SMMEs to implement similar beneficiation at other WWTW in the province and elsewhere.

Youth

The project involved the youth in two ways. Firstly, the project facilitated a focus group which specifically sought the views of the youth and the elderly (please see the next discussion on 'community" for more details).

Secondly, the project has made a concerted effort to include four young researchers in the team and to promote their research through the development of research opportunities within the scope of the project. Each of the young researchers involved are working towards a Masters Degree at a South African university.

Community

The project has contributed to the development of the community at various levels and through a number of different interactions. The nature of these outcomes cannot be (and should not be) quantified, as their value lies beyond numbers and percentages. However, if numbers are required, we would direct our attention to the latest Census data. According to Census (2011) data, it is calculated that there are 2382 households in Motetema alone. That is 8422 people that reside in Motetema – 8422 people that live and work in the general vicinity of the WWTW and whose immediate natural environment is impacted on a daily basis by the WWTW and its operations. Through the efforts of the project and team we are contributing to a healthy living environment for 8422 people so that they can pursue a variety of livelihood opportunities. The project contributes to a healthy natural environment for 8422 people directly (not to mention communities living further downstream of the WWTWs) by taking into consideration the positive impact healthy ecosystems can have on the population's health and well-being. Moreover, by improving the governance and maintenance system that is responsible for the WWTW, the project contributes to ensuring better quality water that is discharged from the WWTW into their streams and rivers.

Lastly, the project created a conducive environment that allows for social and economic development of the area that will provide more opportunities for decent work and economic growth for these 2382 households. Such economic growth may be dependent on an effective WWTW that is able to accommodate additional in-flows.

Looking at specific activities that have taken place during the life of the project, we argue that peer-to-peer discussion, co-learning, capacity building and empowerment through knowledge sharing are methods that contribute to the development of communities in ways that cannot be measured. These methods offer opportunities for people to hear, see and experience new ideas; test, evaluate, challenge and even reform old ideas; share personal experiences and learn from others; change attitudes and endeavour to change personal held beliefs and eventually also behaviour.

Employment

The beneficiation of WWTWs through aquaculture options is being investigated in the project and has the potential to provide employment opportunities through entrepreneurial ventures. An entrepreneur can utilize the final ponds for fish culture and gain economic benefits through the sale of fish for stocking ponds for end users. The entrepreneurship should be in combination with the phycoremediation intervention and can also be linked with sludge removal and beneficiation. The project scope includes the development of a business plan and training for potential entrepreneurs, which will be completed in the last stage of the project.

The project achievements through the lens of the UN's Sustainable Development Goals

There are a number of development outcomes that speak directly to the needs of the municipality. Some of these achievements are overt in that they are tangible outcomes such as innovation around infrastructure, for example the new algae bioreactor. There are however other development goals that are less tangible, yet certainly as important, for example community upliftment. A useful way to understand the various development outcomes of the project is to look at the UN's Sustainable Development Goals (https://sustainabledevelopment.un.org/sdgs). The UN defines seventeen goals towards changing the world in a way that is more sustainable and this project attained some of these through its research and stakeholder engagements.

1 NO POVERTY	**No poverty** The project creates an environment that is conducive to healthy lives and productive people. While the project does not pursue poverty reduction directly, the poverty alleviation is a secondary, yet related outcome of the project's research and innovation activities. Through improving service provision in sanitation, the project helps to reduce human health costs that might arise due to water resources and people being exposed to untreated sewerage.
3 GOOD HEALTH AND WELL-BEING	**Good health and well-being** The project contributes to a healthy natural environment by taking into consideration the positive impact healthy ecosystems can have on the population's health and well-being. Moreover, by improving the governance and maintenance system that is responsible for the WWTW, the project contributes to ensuring better quality water that is discharged from the WWTW into our streams and rivers. Related capacity building and overall awareness raising by the project's social component, both at local and municipal level contributes to better health and well-being of the surrounding communities to the WWTW.
5 GENDER EQUALITY	**Gender equality** Student research linked to this project looked specifically at the gender imperative bound up in the everyday activities of women who occupy decision making positions related to water and sanitation within the SDM. By better understanding the challenges they face, but also the unique perspectives they bring to the job governance systems can be better informed and tailored to include gender sensitive structures and management styles. Capacity building events both at community and municipality levels have been geared towards including women in discussions and knowledge sharing activities.
6 CLEAN WATER AND SANITATION	**Clean water and sanitation** Cleaner water and sanitation goals are overtly dealt with in the project. Research and innovation developed in relation to the algae bioreactor speaks directly to this development goal.
8 DECENT WORK AND ECONOMIC GROWTH	**Decent work and economic growth** The project creates a conducive environment that allows for social and economic development of the area that provides more opportunities for decent work and economic growth. Such economic growth may be dependent on an effective WWTW that is able to accommodate additional in-flows.
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE	**Industry, innovation and infrastructure** The project provides further research and entrepreneurial opportunities as outcomes from current research and innovation activities.
11 SUSTAINABLE CITIES AND COMMUNITIES	**Sustainable cities and communities** The project encourages capacity building and empowerment through knowledge sharing at different levels within the local community and the municipal governance structure which will create momentum within communities and individuals to live more sustainably.
12 RESPONSIBLE CONSUMPTION AND PRODUCTION	**Responsible consumption and production** The project creates better awareness about downstream processes from the WWTW, and that in turn will create more responsible consumption and production behaviour not only with individuals but also business and industry.

Figure 18: Project achievements through the lens of the UN's Sustainable Development Goals

Key Learning Points

The project contributed to a healthy natural environment of the municipality by taking into consideration the positive impact healthy ecosystems can have on the population's health and well-being.	The project created a conducive environment that allows for social and economic development of the area that will provide more opportunities for decent work and economic growth.	The project created better awareness about downstream processes from the WWTW, and that in turn will create more responsible consumption and production behaviour not only with individuals but also business and industry.

CHAPTER 7: SLUDGE BENEFICIATION

CHAPTER OBJECTIVE:

To identify viable options for Motetema WWTW based on known sustainable sludge management options and viable entrepreneurship option.

In pond-based Wastewater Treatment Works, sludge is the material removed from wastewater treatment ponds. There are three ways in which sludge can be managed on a sustainable basis.

- Utilising the energy value of the sludge (e.g. generating heat);
- Utilising useful constituents such as carbon and nutrients (e.g. agricultural use); and
- Extracting useful constituents from the sludge (e.g. phosphorus).

Utilising the constituents such as carbon and nutrients in the sludge, particularly in support of agricultural practices, is the most viable management option for South Africa. Since not all sludge generated in South Africa is suitable for agricultural use, the other two sustainable options may also be considered. Sludge would be unsuitable for use in agricultural applications if the sludge is compromised by contaminants such as heavy metals or organic contaminants, if agricultural land is not available within a viable distance; and/or if there is community resistance against such practices.

To determine what options are suitable for the sludge generated at Motetema WWTW, the different sludge streams need to be classified. The classification system is based on the microbiological content (A, B or C), the sludge stability (1, 2 or 3) and the pollutant content (a, b or c). The classification process and suitability of different classes for specific management options are described in detail in Snyman and Herselman (2006), which describes the different uses as follows:

Agricultural use

- Using stabilised sludge as a soil conditioner at an application rate designed to provide the amount of nitrogen needed by the crop and therefore minimise the amount of nitrogen leaching
- Manufacturing compost not destined for use by the general public

Disposal

- Stockpiles
- Operating existing dedicated land disposal sites
- Rehabilitation and phasing out of dedicated land disposal sites
- Off-site disposal of sludge in a general or hazardous landfill site
- On-site disposal of sludge in a mono disposal landfill or lagoon
- Marine disposal

Beneficial use

- Rehabilitation of mine deposits
- Using sludge to aid remediation of contaminated soil
- Using sludge as adsorbents
- Using sludge as a nursery growth medium
- Once-off high-rate land application
- Ameliorate degraded soils
- Capping of landfills
- Beneficial land application at high loading rates

Thermal treatment

- Incineration in dedicated incinerators
- Incineration in furnaces, cement kilns etc.

Saleable products

- Manufacturing pellets from sludge
- Manufacturing compost to sell to the general public
- Manufacturing bricks, paving, artificial rocks and other products

The suitability of different classes of sludge for different beneficiation options at Motetema WWTW are summarised in Table 19.

Table 19: Suitability of different classes of sludge for different beneficiation options (Snyman and Herselman, 2006)

		Agricultural use	Disposal	Beneficial use	Thermal treatment	Saleable products
Microbiological class	A	Yes	Maybe	Yes	No	Yes
	B	Qualified yes	Maybe	Maybe	Qualified no	Qualified no
	C	Qualified no	Yes	Qualified no	Yes	No
Stability class	1	Yes	Yes	Qualified yes	Maybe	Yes
	2	Qualified yes	Qualified yes	Maybe	Qualified yes	Qualified no
	3	No	Qualified no	Qualified no	Yes	No
Pollutant class	a	Yes	Qualified no	Yes	Yes	Yes
	b	Qualified yes	Maybe	Maybe	Qualified yes	Maybe
	c	No	Maybe	Qualified no	Qualified yes	Maybe

Key Learning Points

Sustainable management at Motetema WWTW requires the timely removal of sludge.

Benefits that can be derived from sludge at Motetema WWTW range from heat generation to nutrient utilisation and extraction of useful constituents such as phosphorous.

The most viable option at Motetema WWTW must be based on the classification and corresponding suitability of the sludge for a specific use.

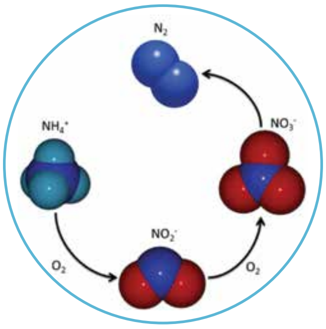
CHAPTER 8: ENTREPRENEURSHIP

CHAPTER OBJECTIVE:

The establishment of entrepreneurial options at WWTW holds much promise and the study identifies different options and outlines a broad approach.

The elements of the entrepreneurship plan are summarised in Figure 18 below, with each section being discussed in the text that follows.

Figure 19: Elements of the entrepreneurship plan



The Resource

Waste water treatment works (WWTW) has an abundance of nutrients. The nitrogen or phosphorous originating from sewage collection systems are assimilated through various biological processes. While some of the nitrogen is released to the atmosphere through the nitrification/denitrification process (shown on the right-hand side), the phosphate is assimilated, but not removed from the system. In properly functioning pond systems, the sludge that settle at the bottom of the ponds are removed, which does remove a significant proportion of phosphorous and nitrogen. The sludge that is removed contains high levels of nutrients, which can be used in various ways if classified correctly. A part of the nitrogen and phosphorous is contained in algae growing in the treatment ponds and can be removed by either harvesting the algae directly, or through harvesting other organisms that consume the algae.

Aquaculture

Aquaculture' refers to the production of aquatic organisms such as fish, crustaceans, molluscs and plants. The aquaculture implementation was not successful at Motetema WWTW because the improved treatment process has not stabilised sufficiently, but it will be an option in the future (and at other WWTW). The fish can serve to consume algae, macrophytes and other organisms and in that way remove nutrients from the system. When fish are harvested, the nutrients are prevented from being discharged in the final effluent. It is also possible to grow and harvest other organisms mentioned above, but since caution should be taken regarding the consumption of such organisms, the culturing of fish for ornamental and stocking purposes is preferred.

Sludge

Sludge that is removed from treatment ponds can be used in a number of applications, depending on the results of the sludge classification procedure (discussed in Chapter 7). Municipal sludge consists of appreciable amounts of macro and micro nutrients and beneficial use of treated municipal sludge in agricultural lands is a well-known practice around the world. This is because of sludge's soil conditioning effect and it is a source of low-grade fertiliser. It has also been tested for fruit trees and agroforestry.

Other Beneficiation Options

Whereas the effluent from wastewater treatment systems may contain acceptable levels of nutrients and may be safe to discharge, it will still contain sufficient nutrients to justify high value uses. These uses can include the production of cut flowers or the generation of biogas.

Alignment with Waste Water Treatment Process

Since the beneficiation of resources from the WWTW should support the treatment process, these options should either directly remove nutrients from the system, or remove plants or animals that have already taken up the nutrients. The beneficiation options should also protect the health of operators and beneficiaries throughout the process.

Business Concept

The first step in the process of establishing an entrepreneurship is the development of the business concept. This should include the product or service that will form the basis for the venture, the resources and facilities, the expertise and staff capacity, the production or value added service process, the clients of the products or services, the capital and cash flow requirements and the transport logistics. During consultative engagements with the Sekhukhune District Municipality and local community members, it was clear that the aquaculture option would only be acceptable for uses other than food production. The options then include producing fish for the ornamental market and producing fish to provide for stocking in other dams. Fish could also be used to add to animal feed, but it would be a challenge to achieve a positive cost-benefit ratio for that application.

Fish selection

According to the detailed description in Chapter 4, the specific species that have been evaluated for aquaculture in the Motetema WWTW is the Mozambique Tilapia and Red Breasted Tilapia (*Oreochromis mossambicus* and *Coptodon rendalli*). *C. rendalli* can tolerate a wide range of temperatures (8-41°C), consume plant material and algae, and is popular for stocking dams where such plants are a nuisance. Studies have shown that *C. rendalli* is an opportunistic feeder that diversifies its diet when resources are scarce, which qualifies it as the aquaculture species of choice for emerging fish farmers who cannot afford highly priced fishmeal as a supplementary protein source.

Skills Requirements

The skills required to establish a sustainable entrepreneurship in aquaculture are broad-ranging. The rearing of fish requires sound knowledge of biophysical processes, including water quality and fish biology. It also requires financial knowledge regarding capital expenditure, budgets, income and expenditure and cash flow. A functional understanding of legal systems will be an advantage regarding compliance to regulations, laws related to financial transactions and compliance regarding employees. The entrepreneurship will also require good interpersonal skills in interactions with suppliers, clients, regulators and stakeholders. The person leading the venture should have tertiary education in at least one of the above fields and an aptitude for the other fields. Further training courses can be used to build capacity in the relevant fields.

Markets

The marketing plan is often the most neglected aspect of the business plan, with most feasibility studies focusing on production. However, the most successful aquaculture ventures are those that have a market orientation, that spend time with their customers, and that diversify their markets. The markets for the products do not need to be limited to the local area, since live fish can be transported for long distances. A marketing strategy should be developed to ensure that there is uptake of the market-ready fish. Some of the key elements that should be included in the strategy are (Engle and Neira, 2005):

- Historical prices paid
- Losses from total delivery for damaged or out-of-size fish
- Transportation charges
- Payment frequency to growers
- Delivery volume requirements
- Quality standards, procedures and requirements
- Delivery quotas and scheduling patterns
- Availability of delivery contracts

Financial Plan

Capital equipment requirements for aquaculture ventures can be extensive, with the Camdeboo Satellite Aquaculture Project in the Eastern Cape (Water Wheel, 2016) requiring an initial investment in excess of R35 million. An aquaculture venture at Motetema WWTW would be at a much smaller scale and would not require extensive capital equipment. Some investment would however be required to establish holding tanks for incoming and outgoing fish, as well as nets and other equipment to collect and handle fish. The entrepreneur would need some basic equipment to monitor water quality and would also need the basic information and communication infrastructure to run a small business.

The economic analysis for an aquaculture venture at Motetema WWTW is provided as an example, which can be updated with site-specific information for other treatment works, adapted for different species or implementation scenarios. The pond at Motetema is 6 400 m^3. At a stocking density of 200 fish/m^3 (for fish between 100 and 250 grams, or 15-20 cm length) (http://www.thefishsite.com/articles/136/tank-culture-of-tilapia/), the pond can theoretically hold 1 280 000 fish. Even if the pond is stocked at only 10% of the theoretical density, it will hold 128 000 fish. If the fish are bought at a market rate of R4.00 per individual (at a length of 4-6 cm) and sold at a market rate of R45 per individual when they reach 15-20 cm, the gross profit will be R5 248 000. Since Tilapia can grow to 450 grams in 12 months, the target weight of 250 grams will easily be reached within a year. Accounting for 50% losses through mortality and other causes and taking a conservative market view by assuming sales at R22.50 per fish, the gross profit (estimated conservatively) can still be R1 184 000. If we assume a R1M initial capital investment that is depreciated over 5 years, the annual depreciation will be R200 000. With an estimated operational expenditure of R300 000/annum, the balance of R684 000 will be available to pay staff salaries. Since the production estimates above are very conservatives, there should be excess funding that can be reinvested to expand the venture to other WWTW.

Although the feasibility of an aquaculture venture has been demonstrated at a concept level, a detailed feasibility study will be required to provide a detailed assessment of the technical and financial components of the entrepreneurship. This will serve as input to an impact assessment or any other regulatory requirements that need to be met. It will also provide the basis for applications to finance institutions such as government departments, development banks or the private sector. The feasibility study should include (but not be limited to):

- Sources of stock fish
- The conditions for culturing fish
- The market for the products
- The facilities and equipment required
- The technical expertise
- Regulatory requirements
- Financial investment required
- Sustainable finance plan
- Identified risks and risk management options
- Societal and cultural perspectives
- The size of the market and competition

The feasibility study could require significant investment, with the Camdeboo Satellite Aquaculture Project in the Eastern Cape investing R780 000 towards the business plan development.

Recruiting Entrepreneurs

The venture will require a good balance of multidisciplinary skills, but moreover commitment and resilience. The opportunity should be announced in neighbouring communities, with a preference for unemployed members of the community that have relevant tertiary education. An introductory course should be offered to selected candidates to develop a baseline of appropriate knowledge, but also to evaluate the aptitude and potential of the candidates. A shortlist of promising candidates should participate in the pre-feasibility and feasibility process and in the process of meeting the regulatory requirements. The venture will require several individuals to tend to the facilities on a rotational basis, but also to engage with suppliers and clients.

Alternative Ventures

Beneficiation opportunities at WWTW include various applications of sludge, including the use as soil conditioning agent, providing it as a fertilizers supplement, using it as a fuel to heat water or generate electricity, and digesting the sludge in a bioreactor to generate biogas that can be used as a fuel in various applications. The effluents from WWTW are rich in nutrients and can therefore also be used to irrigate plants. Cut flowers would be a good option in this case, since irrigation of edible crops with WWTW effluent could have health impacts. These options can be implemented with a similar approach to the aquaculture option discussed in this document.

Photo credits

Organic: http://www.centerforfoodsafety.org/issues/1050/sewage-sludge/how-do-i-know-if-my-food-was-grown-in-sewage-sludge#
Fishing net: http://inspired-progress.com
Group of women: CSIR
T. rendalli: http://www.fisherieshbp.com
WWTW operator: CSIR
People at WWTW: CSIR

Key Learning Points

The WWTW at Motetema can provide various resources to support entrepreneurships, including sludge beneficiation, effluent use and aquaculture once the treatment process has stabilised.

Aspects that should be considered at Motetema WWTW include the expertise and staff capacity, the production or value added service process, the clients of the products or services, the capital and cash flow requirements and the logistics.

The Motetema WWTW can also support other opportunities, such as cut flowers, for entrepreneurs.

CHAPTER 9: Concluding Remarks

Phycoremediation has been demonstrated to be an effective means of improving the effectiveness and treatment capacity of existing WWTW, without significant upgrades to the facilities. Specific learning points from the pilot scale implementation include:

1. **Phycoremediation is a valuable treatment option for the Motetema waste stabilisation treatment works. Successful removal of nutrients at the Motetema WWTW was obtained through cultured algae. Better results are expected if bottom sludge is removed on a regular basis.**

2. **The aquaculture implementation was not successful at Motetema WWTW because the improved treatment process has not stabilised sufficiently, but it will be an option in the future (and at other WWTW).**

3. **A QMRA also indicated a reduction in risk from the final effluent.**

4. **The stakeholder engagement played a valuable role in creating awareness and building trust in training WWTW operators at Motetema.**

The stainability of the pilot implementation has been secured through the following actions:

- The Municipal Manager issued a letter of support for the Motetema pilot implementation, which shows the commitment of the municipality to the the implementation on operatrional phase of the technology.
- The pilot implementation phase included various training sessions, ranging from technical demonstrations on site, a visit to the CSIR facilities in Pretoria and training sessions and workshops in Groblersdal to build technical and management capacity to effectively operate the technology and improve associated management processes.
- Various communication products were produced throughout the project, and together with the meetings, workshops and individual engagements, it served to create awareness and buy-in from the community, municipality, DST, WRC and DWS.
- The process and supporting documents that were developed for the Motetema pilot study can serve as baseline for rolling out implementation in the SDM and beyond.

REFERENCES

ALABASTER JS and LLOYD R (1980) Water quality criteria for freshwater fish. London, Butterworths: 297 pp.

ANASTASI EM, MATTHEWS B, STRATTON HM and KATOULI M (2012) Pathogenic Escherichia coli Found in Sewage Treatment Plants and Environmental Waters. *Appl Environ Microbiol.* 78(16) 5536–5541.

APHA (2006) Standard Methods for Examination of Water and Wastewater, 20th ed. American Public Health Association, Washington, DC.

BARTHEL L, OLIVEIRA PAV, and DA COSTA RHR (2008) Plankton biomass in secondary ponds treating piggery waste. Brazilian Archives of Biology and Technology 51(6) 1287-1298.

BERGER WH, and PARKER FL (1970) Diversity of planktonic Foraminifera in deep sea sediments. Science 168(3937) 1345-1347.

BRITZ PJ, HARA MM, WEYL OLF, TAPELA BN and ROUHANI QA (2015) Scoping Study on the Development and Sustainable Utilisation of Inland Fisheries in South Africa Volume 1: Research Report. WRC Report No TT 615/1/14

CASTRO-ROSASA J CERNA-CORTÉS JF, MÉNDEZ-REYESA E, LOPEZ-HERNANDEZ D, GÓMEZ-ALDAPAA CA, and ESTRADA-GARCIA T (2012) Presence of faecal coliforms, Escherichia coli and diarrheagenic E. coli pathotypes in ready-to-eat salads, from an area where crops are irrigated with untreated sewage water. *Int J Food Microbiol* 156(2) 176–180.

CORCORAN EC, NELLEMANN E, BAKER R, BOS D, and OSBORN H. (2010) Sick Water? The central role of wastewater management in sustainable development. A Rapid Response Assessment. United Nations Environment Programme, UN-HABITAT, GRID-Arendal. URL: http://www.grida.no ISBN: 978-82-7701-075-5 Printed by Birkeland Trykkeri AS, Norway.

CSIR (2010) A climate change handbook for the North-Eastern South Africa, Pretoria, Climate change Research Group.

DEPARTMENT OF WATER AFFAIRS (DWA) (2012) Green Drop Progress Report 2012

DEPARTMENT OF WATER AFFAIRS AND FORESTRY (DWAF) (2003) The management of complex industrial wastewater discharges: Introducing the Direct Estimation of Ecological Effect Potential (DEEEP) approach. A discussion document. 15pp.

DEPARTMENT OF WATER AND SANITATION (2009) Green Drop Report 2009. URL: https://www.dwa.gov.za/Documents/GreenDropReport2009_ver1_web.pdf. (Accessed 18 June 2011)

DEPARTMENT OF WATER AND SANITATION (2010) Statement by the Minister of Water and Environmental Affairs, Ms Buyelwa Sonjica, release of the Green Drop Report, 29 April 2010. URL: https://www.dwa.gov.za/Communications/PressReleases/2010/GreenDropstatement.pdf (Accessed 18 June 2011)

DEPARTMENT OF WATER AND SANITATION (2011) Green Drop Certification. URL: https://www.dwa.gov.za/Documents/GD/GDIntro.pdf (Accessed 18 June 2011)

DEPARTMENT OF WATER AND SANITATION (2013) National Water Resources Strategy. Water for an Equitable and Sustainable Future. 2nd Edition. June 2013. URL: https://www.dwa.gov.za/documents/Other/Strategic%20Plan/NWRS2-Final-email-version.pdf (Accessed November 2015)

DEPARTMENT OF WATER AND SANITATION (2014) Green Drop Progress Report. Introduction to Green Drop PAT 2014 / National Overview. URL: http://greencape.co.za/assets/Sector-files/water/Department-of-Water-and-Sanitation-DWS/DWS-2014-Green-Drop-progress-report-introduction-2016.pdf (Accessed 1October 2016)

DEPARTMENT OF WATER AND SANITATION (2016) Strategic Overview of the Water Services Sector in South Africa 2016. Version 1.7 March 2016. DWS Directorate: Water Services Macro Planning.

ENGLE CR, and NEIRA I (2005) Tilapia farming business management and economics: A training manual. Aquaculture/ Fisheries Center. University of Arkansas. Pine Bluff, Arkansas FAO (2012) International Guidelines for Securing Sustainable Small-scale Fisheries. FAO, Rome.

FLANNERY J, KEAVENEY S, RAJKO-NENOW P, O'FLAHERTY V, and DORÉ W (2012) Concentration of Norovirus during Wastewater Treatment and Its Impact on Oyster Contamination *Appl. Environ. Microbiol.* 78(9) pp3400-3406

FUNKE N NTOMBELA C AND MASANGANE W (2014) A Policy and Practice Guideline for Local, Provincial and National Government to Improve the Operations at Wastewater Treatment Works. CSIR Report Number: CSIR/NRE/WR/IR/2014/0027/A

GIBNEY K, SINCLAIR M, O'TOOLE J, and LEDER K (2013) Using disability-adjusted life years to set health-based targets: A novel use of an established burden of disease metric. *Journal of Public Health.* 34(3) 439-446.

GOMEZ M, DE LA RUA A, GARRALON G, PLAZA F, HONTORIA E, and GOMEZ MA (2006). Urban wastewater disinfection by filteration technologies. Desalin. 190 16-28.LE ROUX, W, SCHAEFER L and GENTHE B (2012) Microbial water quality in the upper Olifants River catchment: Implications for health. *African Journal of Microbiology Research* 6 (36) 6580-6588.

HLOPHE SN, and MOYO NAG (2013) The aquaculture potential of Tilapia rendalli in relation to its feeding habits and digestive capabilities. Physics and Chemistry of the Earth 66: 33–37

INTEGRATED DEVELOPMENT PLAN (2015) Sekhukhune District Municipality (SDM) Final 2015/2016 Integrated Development Plan (IDP) 2015/ 2016. URL: http://www.sekhukhunedistrict.gov.za/sdm-admin/documents/Sekhukhune%202015-16%20FINAL%20IDP.pdf (Accessed 15 October 2016)

JOHNSON L (2015) "Perspectives on the Improvement of Water and Sanitation Delivery at Municipal Level". Address by Member of Parliament: Water Services Municipal Benchmarking Report Release. 2015. URL: http://www.parliament.gov.za/live/content.php?Item_ID=8768 (Accessed 15 October 2016)

LIANG JL, DZIUBAN EJ, CRAUN GF, HILL V, MOORE MR, GELTING RJ, CALDERON RL, BEACH MJ, and ROY SL (2006). Surveillance for waterborne disease and outbreaks associated with drinking water and water not intended for drinking. CDC/ MMWR 55(SS12) 31-58.

MADHAB D, MAHAPATRA H, and CHANAKYA N (2013) Treatment efficacy of algae-based sewage treatment plants. Environmental monitoring assessment 185(9) 7145-7164.

MARA DD, ALABASTER GP, PEARSON HW, and MILLS SW (1992) Waste Stabilization Ponds: A Design Manual for Eastern Africa. Leeds: Lagoon Technology International

MARA DD, and PEARSON H (1998) Design Manual for Waste Stabilization Ponds in Mediterranean Countries. Leeds: Lagoon Technology International Ltd.

MASSYN N, PEER N, PADARATH A, BARRON P, and DAY C (Eds) (2015) District Health Barometer 2014/15. Durban: Health Systems Trust; October 2015.

MESPLE F, TROUSSELLIER M, CASELLAS C, and BONTOUX (1995) Difficulties in modelling phosphate evolution in a high-rate algal pond. Journal of Water science and Technology. 31 (12) 45-54.

MOSER GAO, SIGAUD-KUTNER TCS, CATTENA CO, GIANESELLA SMF, BRAGA ES, SCHINKE KP, and AIDAR E (2004). Algal growth potential as an indicator of eutrophication degree in coastal areas under sewage disposal influence. Aquatic Ecosystem Health and Management 7(1) 115-126.

MOUTIN T, GAL JY, El HALOUANIH, PICOT B, and BONTOUX J (1992) Decrease of phosphate concentration in a high rate pond by precipitation of calcium phosphate: Theoretical and experimental results Water Research. 26(11) 1445-1450.

NTOMBELA C MASANGANE W FUNKE N, AND NORTJE K (2013) Sekhukhune District Municipality Workshop Proceedings Wastewater Treatment: Towards Improved Water Quality to Promote Social and Economic Development' CSIR Report Number: CSIR/NRE/WR/EXP/2013/0152/A

OBERHOLSTER PJ, and BOTHA AM (2011) Dynamics of phytoplankton and phytobenthos in lake Loskop (South Africa) and downstream irrigation canals. Fundamental Apply Limnology 179(3) 169-178

PORRA RJ, THOMPSON WA, KRIEDEMANN PE (1989) Determination of accurate extinction coefficient and simultaneous equations for assaying chlorophylls a and b extracted with four different solvents: verification of the concentration of chlorophyll standards by atomic absorption spectrometry. Biochimica et Biophysica Acta 975 384-394.

RAS M, STEYER J, and BERNARD O (2013) Temperature effects on microalgae: a crucial factor for outdoor production. Reviews in Environmental Science and Bio/Technology 12(2) 153-164.

SEKHUKHUNE DISTRICT MUNICIPALITY (SDM) (2014) Integrated Development Plan (IDP) 2014/2015.

SNYMAN HG and HERSELMAN JE. (2006) *Guidelines for the Utilisation and Disposal of Wastewater Sludge Volume 1: Selection of Management options.* WRC Report No. TT 261/06.

SOUTH AFRICAN HUMAN RIGHTS COMMISSION (2014) Report on the Right to Access Sufficient Water and Decent Sanitation in South Africa: 2014. Water is Life. Sanitation is Dignity: Accountability to People who are Poor. Pp.80

SPOTTE SH (1970) Fish and invertebrate culture. Wiley-Interscience, New York. 145 pp.

STATISTICS SA (2014) Census 2011 Provincial Profile: Limpopo. Report No. 03-01-78 (2011). Published by Statistics South Africa, Private Bag X44, Pretoria 0001. ISBN: 978-0-621-43217-6

STATISTICS SA (2016) Community Survey 2016, Statistical release P0301 / Statistics South Africa. Pretoria: Statistics South Africa. Pp. 107

STATISTICS SOUTH AFRICA (STATS SA) (2011) GHS Series Volume III: Water and sanitation 2002–2010. In-depth analysis of the General Household Survey data. Pretoria: Statistics South Africa.

TAYLOR JC, HARDING WR, and ARCHIBALD CGM (2007) An illustrated guide to some common diatom species from South Africa. – WRC Report, No. TT 282/07. Water Research Commission, Pretoria, South Africa, plates 1-178.

TEUNIS PFM, MOE CL, LIU P, MILLER SE, LINDESMITH L, BARIC RS, LE PENDU J and CALDERON RL. (2008) Norwalk virus: how infectious is it? *J. Med. Virol.*, 80 (8), 1468–1476.

TILLEY E, ULRICH L, LÜTHI C, REYMOND PH and ZURBRÜGG C (2014) Compendium of Sanitation Systems and Technologies. 2nd Revised Edition. Swiss Federal Institute of Aquatic Science and Technology (Eawag). Dübendorf, Switzerland.

TOZE S (1997) Microbial pathogens in wastewater. CSIRO Land and Water Technical Report 1/97.

TRUTER E (1987) An aid to the identification of the dominant and commonly occurring genera of algae observed in some South African impoundments. Pretoria, South Africa: Department of Water Affairs. 1-97.

ULBRICHT K, SELINKA HC, WOLTER S, ROSENWINKEL KH, and NOGUEIRA R (2014) Mass balance of viruses in a municipal wastewater treatment plant. *Water Science & Technology* 69(2) 364-371.

UN-WATER (2015) Water and Sustainable Development. From Vision to Action. Means and Tools for Implementation and the role of different actors. Report of the 2015 UN-Water Zaragoza Conference. www.un.org/waterforlifedecade/waterandsustainabledevelopment2015/index.shtml

VAN VUUREN S, TAYLOR JC, GERBER A, and VAN GINKEL C (2006) Easy identification of the most common freshwater algae. – North-West University and Department of Water Affairs and Forestry, Pretoria, South Africa. 1-200.

WANG H, WANG T, ZHANG B, LI F, TOURE B, OMOSA IB, CHIRAMBA T, ABDEL-MONEM M, and PRADHAM M (2014) Water and Wastewater Treatment in Africa-Current Practices and Challenges. Clean-Soil, Air, Water 42(3) 1029-1035.

WATER WHEEL (2016) Farming with fish – Community finds new hope through aquaculture project. The Water Wheel March/ April 2016.

WEHR JD, and SHEATH RG (2003) Freshwater habitats of algae. In: Wehr, J.D., Sheath, R.G. (eds.), Freshwater Algae of North America: Ecology and Classification. Academic. 11-57

WHO (WORLD HEALTH ORGANISATION) (2016) Protecting surface water for health. Identifying, assessing and managing drinking-water quality risks in surface-water catchments. World Health Organization. ISBN 978 92 4 151055 4.Retrieved 18 October 2016.

WHO, 2001. Water Quality Guidelines, Standards and Health. Assessment of risk and risk management for water-related infectious disease. World Health Organization, Geneva.

WHO, 2011. Guidelines for drinking-water quality. Fourth Edition. World Health Organization, Geneva.

WHO/UNICEF (2010) Joint Monitoring Programme for Water Supply and Sanitation: Data table South Africa, 2010. Retrieved 3 November 2012.

WHO/UNICEF (2015) Progress on sanitation and drinking water – 2015 update and MDG assessment. Retrieved 17 October 2016.

WORLD URBANISATION PROSPECTS (2014) United Nations: Department of Economic and Social Affairs. Population Division. Country Profile: South Africa. https://esa.un.org/unpd/wup/Country-Profiles/. Retrieved: 18 October 2016.

WRC (WATER RESEARCH COMMISSION) (2013) Inappropriate wastewater technology choices compromise quality and sustainability of service delivery in municipalities, 13 June 2013

9781431208760