Identifying Opportunities to Reduce Water Pollution and Encourage Voluntary Compliance in Windhoek, Namibia

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Identifying Opportunities to Reduce Water Pollution and Encourage Voluntary Compliance in Windhoek, Namibia

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Abstract

The City of Windhoek's water treatment process is threatened by increased pollution from industrial discharges. Our goal was twofold: through interviews, to determine the reasons why local industries failed to comply with water pollution regulations, and, through systematic sampling, to identify sources of water pollution. We developed recommendations to help the City's Department of Infrastructure, Bulk Water and Wastewater Division, increase voluntary compliance among industries to reduce pollution.

Executive Summary

Namibia is one of the driest countries in the world, which makes access to clean water a top priority. Its capital city, Windhoek, faces even more challenges in terms of clean water access as it is located far from any perennial water sources and has little rainfall each year to replenish the water supply. To address this lack of water, the city has developed a direct potable water reclamation process that sends treated wastewater straight to a plant for further cleaning before it is sent back to the local drinking water supply. This reclamation process is threatened by polluted effluent from Windhoek industries which runs into the sewer and to the wastewater treatment plant. The rapid urbanization of Windhoek has exacerbated the pollution to the wastewater treatment facility and has made it very difficult to identify the exact locations that the pollution originates because there are more areas where the pollution could come from. Since the origin of the pollution is difficult to locate, it is more important to examine all of the potential sources and determine the root cause of the contamination.

The goal of our project was to investigate the factors influencing industrial compliance with pollution regulations in Windhoek, Namibia. Furthermore, we sought to locate potential point sources of critical contaminants responsible for operational difficulties at the city's wastewater treatment plant. First, we analyzed past and current data regarding water contamination in Windhoek. We then sought to better understand the reasons why local industries failed to comply with water pollution regulations and the opportunities to increase voluntary compliance. Finally, we identified potential sources of industrial pollution to the Gammams Water Care Works.

The existing data that we analyzed consisted of pollution testing results at the inlet to the Gammams Water Care Works, as well as at the Gammams outlet, at the Goreangab Dam, and at various stages in both the wastewater treatment and water reclamation processes. The process of water reclamation in Windhoek is outlined in *Figure 1*. We focused on analyzing data relating to bromide concentrations because during the ozonation stage of the water reclamation process, bromides react with ozone, a disinfectant, to form cancer-causing bromates in city's drinking water. Through this analysis, we were able to identify trends in the appearances of bromides and other contaminants of concern, which of the three pipelines leading to the Gammams generally had the highest concentrations of pollutants, and how rainfall affects the concentration of bromides in the water coming to the Gammams Water Care Works. The other contaminants of concern identified by the city were ammonia, total Kjeldahl nitrogen, and chemical oxygen demand.

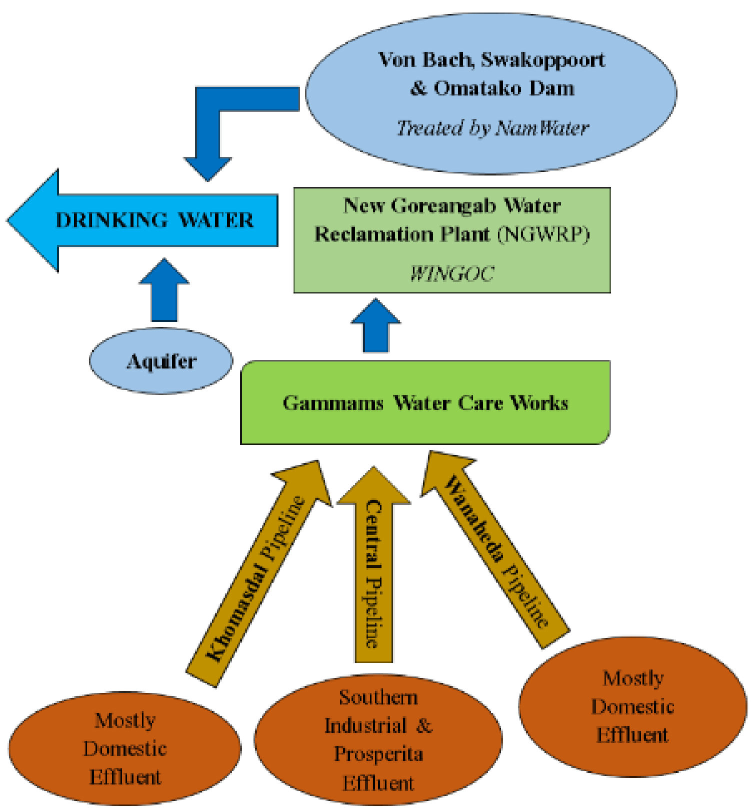

Figure 1 - Windhoek's Water Reclamation Process

To further illuminate pollution trends in the city, as well as to identify point sources of pollution in Windhoek, we began sampling water from the wastewater pipeline system. We used maps provided by the Bulk Water and Wastewater Division (BWWD) to identify sampling locations. Our strategy was to sample multiple manholes upstream of mixing points in order to identify which pipeline carried the highest concentration of contaminants. We identified which of the pipelines was the most polluted and followed that line to the next mixing point to repeat the process. We also decided to take the bulk of our samples from two industrial zones and identified high levels of bromides being discharged from automobile repair shops.

Indirectly, we also discovered that Windhoek's infrastructure is generally lacking maintenance and is in need of proper monitoring. While sampling, we found numerous blockages in the pipeline system and that wastewater in the reticulation was spilling into the nearby river bed. The river that the city's wastewater was entering leads directly to a dam that the city used to use as a source of drinking water. Because of extreme amounts of pollution in the dam, its water can no longer be used for swimming and recreation, let alone be treated up to potable standards. Because of the poor state of the infrastructure in Windhoek, the city itself is greatly contributing to the pollution of its nearby dam.

In addition to sampling for pollution, we conducted in-depth interviews with various Windhoek-based industries to understand their knowledge of pollution regulations, how they currently managed their discharges into the sewer system, and what assistance they need to comply with regulations. From these interviews, we discovered that industries of all sizes in Windhoek were having trouble with compliance.

Larger industries in the area generate high volumes of polluted waste water, and are required by the city to treat their own effluent before it enters the city's sewer system. Some companies may be required to build their own wastewater treatment systems based on what types and what quantities of contaminants they dispose into the pipe system. Some of these industries were able to implement proper wastewater treatment systems that cleaned their wastewater to acceptable standards, thus remaining in compliance with the city's regulations. However, many of the larger industries claimed to have financial issues regarding the implementation and maintenance of the treatment systems. We have found that they are either unable to generate the necessary funding for the treatment facilities, or they are reluctant to adjust their budget to accommodate the systems, instead favoring investments that increase their profit. These industries also need to pay fines to the city based on the volume of wastewater that they discharge into the system in addition to paying the costs of treatment systems. These larger industries commonly asked the city to more frequently communicate with them, either suggesting that a list of pollution testing results from various companies be emailed monthly or that more information regarding how discharge fees are calculated be made available to them.

We have also found that awareness is the main source of noncompliance with smaller industries. Economic issues were found to not have a significant presence in these smaller industries because they produce a smaller amount of waste when compared with larger industries. These small industries are scattered across Windhoek, and their effluent drains to the city's wastewater treatment plant and is eventually used for direct potable reclamation. In contrast, larger industries dispose their wastewater to a different water treatment plant, and their effluent is treated for irrigational purposes. For these smaller industries draining to the wastewater treatment plant, lack of education has been identified as the main barrier of voluntary compliance. For example, numerous automotive repair shops simply did not know how to properly maintain their oil traps, a pollution prevention system that requires monthly draining and cleaning. They were unaware of the proper regulations and therefore were unknowingly not complying with the pollution standards set by the city.

Based on what we discovered with our testing and interviews, we have come up with the following recommendations for the Bulk Water and Wastewater Division.

- The BWWD should expand its inspection staff to enhance pollution monitoring and enforcement of regulations in the city.
- The BWWD should continue sampling the wastewater in the pipe systems to further identify areas in the city of high contamination.
- The BWWD should conduct monthly walks along the river bed in order to ensure the infrastructure is functioning properly.
- The BWWD should explore opportunities for encouraging companies to voluntarily comply with regulatory standards, including education and expanded outreach.
- The BWWD should make posters or diagrams to industries that illustrate best practices for managing their pollution control measures. These posters should be made mandatory to have in their businesses in order to create awareness of city standards and proper pollution management.
- The BWWD should communicate with industries more, beginning with providing industries with results from effluent testing as well as how effluent charges are calculated.
- When voluntary compliance is not working with a company or a sector, the BWWD should more strongly enforce pollution standards against industries that knowingly pollute.
- The BWWD should engage in monthly meetings with the Business Registry of Windhoek.
- The BWWD should further encourage people to report damaged infrastructure and leakages in the pipe system.

If the city's water reclamation plant experiences operational difficulties due to high loads of pollution, it will be unable to provide enough drinking water to its rapidly increasing population. In order to ensure this facility works properly, the pollution stemming from industries in Windhoek has to be reduced. Small industries must be made aware of the city's standards for wastewater contamination, and larger industries must allocate the proper resources for the construction and maintenance of wastewater treatment facilities. Understanding the factors that affect industrial compliance and working with industries to reduce their pollution loads is essential to the provision of the City of Windhoek's drinking water.

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Authorship

This paper represents the equal, combined efforts of every group member. However, the following is a list of the major contributors to each section of the report. Additionally, any pictures that are not cited were taken by this project team with the intent of using them in this report.

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List of Acronyms

BAC – Biological Activated Carbon Filtration

BOD – Biological Oxygen Demand

BWWD – Bulk Water and Wastewater Division

CARS - Corporaciónes Autónomas Regionales (Colombian Environmental Regulatory Authority)

COD – Chemical Oxygen Demand

DBP – Disinfection By-Product

EMS – Environmental Management Systems

FEEMA - Fundacao Estadual de Meio Ambiente (Brazilian Environmental Regulatory Authority)

ISO – International Organization for Standardizations

NGWRP – New Goreangab Water Reclamation Plant

OGWRP – Old Goreangab Water Reclamation Plant

OKACOM – Okavango River Basin Water Commission

TKN – Total Kjeldahl Nitrogen

TSS – Total Suspended Solids

WHO – World Health Organization

WINGOC – Windhoek Goreangab Operating Company

List of Definitions

Catchment – The water in a given geographical area that flows to a series of low points, such as rivers or lakes

Chemical Oxygen Demand (COD) – The amount of oxygen required to breakdown organic solids in water

Contaminants of Concern – Bromides, Ammonia (NH_3), COD & TKN

Direct Potable Reclamation – Process by which wastewater or sewage is recycled and treated up to quality standards to be used as drinking water

Enlighten – Software program utilized by the city that contains detailed maps of the city's reticulation system

Effluent – Outflow of water

Gammams Water Care Works – The main wastewater treatment facility for the City of Windhoek that treats domestic wastewater

Goreangab Reclamation Plant (NGWRP) – Facility that recycles wastewater to be reused as drinking water

NamWater – Company that treats and distributes the water from the Von Bach, Swakoppoort and Omatako Dams

Non-Point Source – Pollution linked to indirect contaminants, such as those picked up from stormwater runoff

Point Source – Pollution linked to direct discharges from industries and other facilities

Potable – Of a quality suitable for drinking

Reticulation – Network of pipes that transport water

Total Kjeldahl Nitrogen (TKN) – A measurement of the nitrate, nitrite, and ammonia levels in water

Ujams Wastewater Treatment Facility – Wastewater treatment facility located in the Northern Industrial region of the city that treats industrial wastewater

Windhoek Goreangab Operating Company (WINGOC) – Private company that runs the Goreangab Reclamation Plant (NGWRP).

1 Introduction

The most essential resource to sustain human life is potable water, yet an estimated one billion people living in developing countries do not have access to it, making water scarcity one of the most significant issues in the world (The United Nations, 2010). Namibia is one of the driest countries in sub-Saharan Africa and, with few surface water resources, must obtain most of its water from underground aquifers (FAO, 2010). The country is likely to face challenges meeting demand for drinking water from a rapidly growing population, though Windhoek has been able thus far to provide adequate drinking water for its citizens.

To make up for the lack of water in Namibia, the City of Windhoek has adopted the practice of direct potable water reclamation. This process utilizes a variety of water treatment techniques to bring wastewater to drinkable standards immediately after the initial wastewater treatment process. After treatment, the water is combined with surface water to be used for drinking and for replenishing underground aquifers. Though this method has been advantageous in the past, it is currently becoming far less effective because although there will generally be wastewater to treat and reuse, there are a limited number of clean surface water resources that the city can tap into. Because the dam closest to Windhoek, the Goreangab Dam, has become too polluted for drinking, the city now has to mix its reclaimed water with water piped in from great distances away, from other reservoirs in Namibia.

The water contamination in Windhoek has been exacerbated by the rapid industrialization of the city. Due to the increase in industrial activities, higher amounts of industrial waste have been introduced into the city's water. Before a new industry is allowed to locate in Windhoek, the city analyzes the potential impacts that the business may have on the environment and water supply. The problem is that even when the business is determined to be a threat to the water supply, the city has little power to halt the construction of the facilities because of the promise of job creation. Ramatex, a textile manufacturer that formerly operated in the Otjimuise region of Windhoek, is an example of one of these industries that pose a threat to the water supply but are still allowed to locate in the city. The Namibian government offered Ramatex major benefits, including reduced water usage and power usage rates, to locate in Namibia over South Africa even though the company would be one of the most water intensive industries in the area. Currently, in the eyes of the government, the promise of employment from foreign investments is outweighing the negative environmental impact that new industries impose on Windhoek. Water intensive industries such as Ramatex, Namib Poultry, and South African Breweries are continuously being introduced into the Windhoek region and are locating themselves in areas that are sensitive to wastewater pollution as they lie in the catchment of Windhoek's reservoirs. This has created a need for research to be done regarding how the city can ensure that new industries comply with pollution regulations once they are allowed to locate near the very limited clean water supply.

Currently, the city is having trouble identifying and monitoring all of the sources of industrial pollution from both compliant and noncompliant industries. This is a major problem because industrial pollution is a large source of the contaminants that cause Windhoek's wastewater treatment plant to experience operational difficulties. In addition to causing the treatment processes to work less effectively, high loads of industrial pollutants also raise the cost of treating the water at the treatment plant, thus making it more expensive and time consuming to produce potable water for the city. The lack of information regarding what can be done to encourage industries to voluntarily comply with city pollution regulations and reduce their pollution loading on the wastewater treatment plant is the foundation for our project.

The goal of our project was to investigate the factors influencing industrial compliance with regards to water pollution regulations in Windhoek, Namibia. By collaborating with local experts, we determined which pollutants were causing the most harm at the wastewater treatment plant as well as the most effective method of identifying sources of pollution in the city. We took samples from various locations throughout the city starting from the wastewater treatment plant and moving outward with the intent of locating areas in the city that had high concentrations of pollutants. In addition to identifying sources of pollution, we also interviewed a number of local industries and businesses in Windhoek regarding their contributions to water contamination, their wastewater management practices, and their ability to abide by pollution limitations put in place by the city. We then provided the city with recommendations regarding how to increase industrial compliance with the hope of reducing pollution to Windhoek's water supply.

2 Background

In this chapter, we discuss difficulties that dry, Southern African countries have with providing their citizens with adequate drinking water. We then consider the effects of water contamination on these already water-scarce countries. General pollution sources and prevention methods are outlined, with a concentration on point sources. We then discuss the difficulties regulatory agencies face in improving compliance with water pollution regulations by examining four regulatory models that are used to improve industrial compliance in developing countries. We conclude by describing the water provision system in Windhoek, Namibia.

2.1 Water Scarcity and Provision

Water is the basis for all life. The deep involvement of water in life processes makes living matter vulnerable to changes in the quantity and quality of the water (Falkenmark, 1990). Many cities and towns throughout Africa are struggling to meet basic urban infrastructural needs such as clean water, waste management disposal, and drainage systems (Helena Molina-Valdes, 2014). In the developing world, finding a reliable source of safe water is often times consuming and expensive, and in other areas, the lack of water is a more profound problem (The Water Project, 2014). As demonstrated in *Figure 2*, all of Africa is facing the problem of water scarcity, especially the Southern African region including the countries Botswana, Lesotho, Namibia, South Africa, and Swaziland. Lack of sufficient water and lack of access to safe, clean water can cause water borne diseases, limit people's potential, and hinder the progress of educational and economic development, leading to further issues of food insecurity and poverty (The Water Project, 2014).

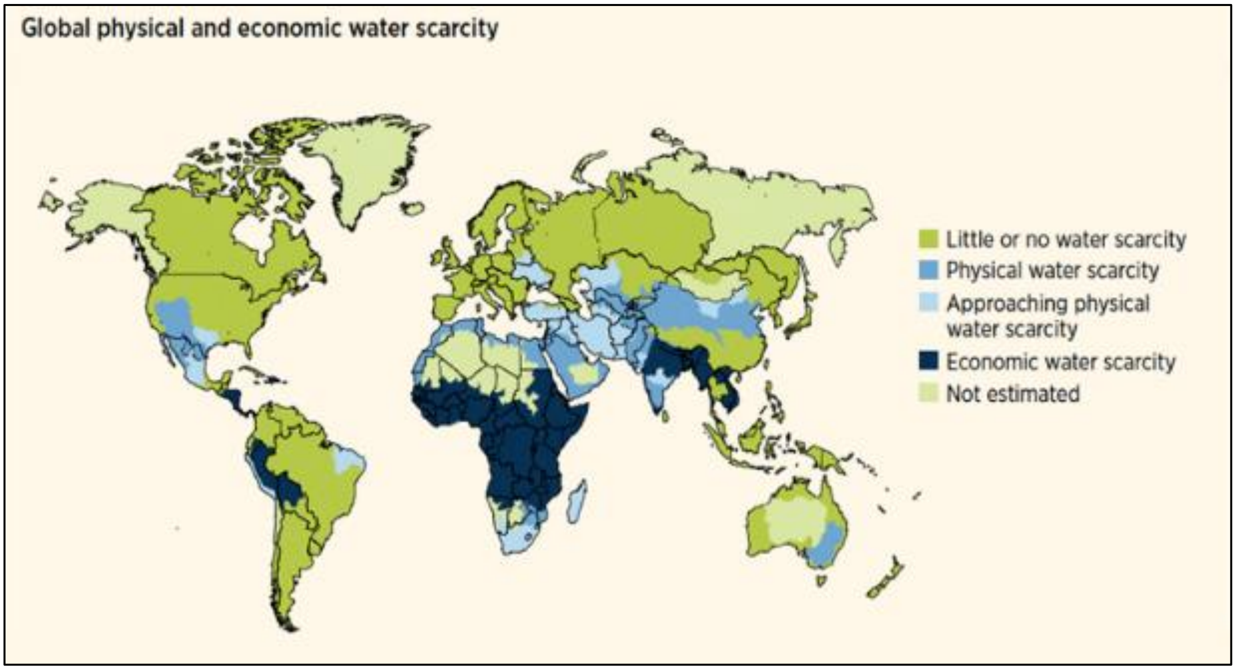

Figure 2 - Global physical and economic water scarcity (World Water Assessment Programme, March 2012.)

2.1.1 How Water Scarcity Affects Southern Africa

Clean and safe water is essential to healthy living. In Africa, about 80% of illnesses are linked to poor water and sanitation conditions (The Water Project, 2014). Every hour, 115 people in Africa die from diseases linked to poor sanitation, poor hygiene and contaminated water (United Nations Department of Economic and Social Affairs, 2014). The sickness caused by dirty water saps people's energy to perform daily activities, and students who suffer from waterborne illnesses fail to remain in class. These students are deprived of the chance to learn, and the cycle of poverty continues (2030 Water Resources Group, 2013). Additionally, when one person is sick, someone else has to take care of them, which means that the second person cannot work or study either. If the sick person needs medicine, that money cannot be used for other things, like food or school supplies (Falkenmark, 1989). Relieving hunger in Africa has to begin with access to clean water, for without access to a reliable source of water, food is hard to grow and even more difficult to preserve and prepare (2030 Water Resources Group, 2013). Without clean water, the possibility of breaking out of the cycle of poverty is slim, and people living in Southern Africa consume much of their day meeting basic water needs. It is necessary to identify what causes water scarcity and create a plan to deal with the concerns.

2.1.2 Factors Affecting Water Scarcity in Namibia

The situation in southern Africa with regard to water scarcity is particularly acute (Ali, 1999). As seen in *Table 1*, Namibia has a very limited total sustainable water supply (0.740 km^3) compared to other countries in southern Africa.

Country	*Total Demand 1993*	*Irrigation Demand 1993*	*Total Demand 2020*	*Total Irrigation 2020*	*Total Sustainable Supply*
Angola	1.335	0.350	2.757	0.750	78.000
Botswana	0.129	0.020	0.336	0.047	0.230
Lesotho	0.118	0.070	0.268	0.160	2.490
Malawi	1.125	0.795	2.578	1.820	4.240
Mozambique	1.967	1.308	3.210	3.000	132.000
Namibia	0.265	0.108	0.538	0.248	0.740
South Africa	19.295	9.615	30.168	12.674	28.470
Swaziland	0.454	0.310	0.511	0.331	1.160
Tanzania	5.374	4.560	12.220	10.450	44.000
Zambia	0.994	0.690	2.192	1.580	60.000
Zimbabwe	2.524	2.175	5.737	4.980	7.860
Total	33.590	19.981	60.515	36.130	359.190

Table 1 - Current and Projected Water Demand and Supply in Southern Africa (km^3/yr) (Heyns, 1994)

There are many reasons that contribute to this growing water crisis in Namibia. Climate variability, such as the changing frequency of rainfall, has affected water supplies within the region. For example, in Windhoek, the dams were 20% lower in 2012 than they were at the start of 2010 (Malisawa & Rautenbach, 2012). In Namibia, the average annual rainfall is about 250 mm, but nearly 83% evaporates immediately and is lost back into the atmosphere. This is mainly due to the sparse vegetation and the relatively large land areas exposed to sun, heat and wind. Only 14% of the rainfall is available for sustaining the vegetation, and most of it is lost through evapotranspiration, which is the sum of evaporation directly from surface water bodies and evaporation from the leaves of plants after water has passed through the plant (transpiration). The remaining 3% is available as surface runoff (2%) and groundwater (1%) (du Pisani, 2006).

The water resources in Namibia are unevenly distributed, as perennial rivers are only found on the southern and northern borders (Hulme, Conway, Kelly, Subak, & Downing, 1995). Due to the erratic rainfall conditions, the flow in the rivers in the interior of the country is ephemeral, irregular and unreliable. The potential of the surface water sources is therefore very limited, and the water can only be used when harnessed in storage impoundments (Conway et al., 2009).

Namibia's rising population is driving demand for water and accelerating the degradation of water resources. By mid-2011, Namibia's population was around 2.178 million, and the average natural rate of population increase was 2.6% per year, compared to the world average of 1.2%. By one estimate, its population will grow to 2.8 million by 2025 and to 3.7 million by 2050 (United Nations Department of Economic and Social Affairs, 2014). *Table 2* shows the large projected increase of consumer demands on the water resources in Namibia from the year 1995 to the year 2020 due to the rapid increase of population.

	Demand on water resources (MCM)							
	Perennial rivers		Ephemeral surface		Groundwater		Total	
Consumer	1995	2020	1995	2020	1995	2020	1995	2020
Domestic	19.4	100	20.6	30	40.0	90	80	220
Stock	4.0	10	*	*	63.0	65	67	75
Mining	7.1	25	1.6	5	9.3	15	18	45
Irrigation	76.5	180	29.8	50	23.7	30	130	260
Total	107.0	315	52.0	85	136.0	200	295	600

Table 2 - Demand on Water Resources in Namibia (Lloyd's, 2008)

2.1.3 Constraints to Expanding Namibia's Water Supply

One of the major challenges of finding a sustainable water source for a growing population is determining how one water source can be evenly distributed across borders. In Southern Africa the Okavango River runs through Angola, Botswana, and Namibia. The river is a sustainable water resource that is currently used as such for the regions in the immediate surroundings of the river. The Permanent Okavango River Basin Water Commission (OKACOM) determines the allocation of the Okavango River to Angola, Botswana, and Namibia.

A project was proposed in the 1990's that involved building a pipeline, *Figure 3*, to withdraw water from the Okavango River and send the water to be integrated into the Windhoek water supply, but this proposal was never put into action (Mbaiwa, 2004). The river flows through the Caprivi Strip of Namibia and is one of the only perennial water sources available in the country. This means that the river is the only water source in Namibia that is available in all seasons. The pipeline was intended to be a safety net in the event that existing water resources failed. It is also predicted that 250,000 people of all classes in central Namibia will eventually need access to this water to sustain their current ways of life (Pinheiro, Gabaake, & Heyns, 2003). The pipeline project raised major environmental concerns that damming the river at the point seen in *Figure 3* would prevent precious sediment from reaching the Okavango Delta where the sediment is a key life force for the ecosystem (Mbaiwa, 2004). Due to the environmental concerns, the OKACOM has declared that a full environmental impact assessment must be performed before any plans for the pipeline are ever discussed. Any potential river diversion plans by Namibia must also be approved by Angola and Botswana, the other two countries that are part of the commission (Ashton, 2010).

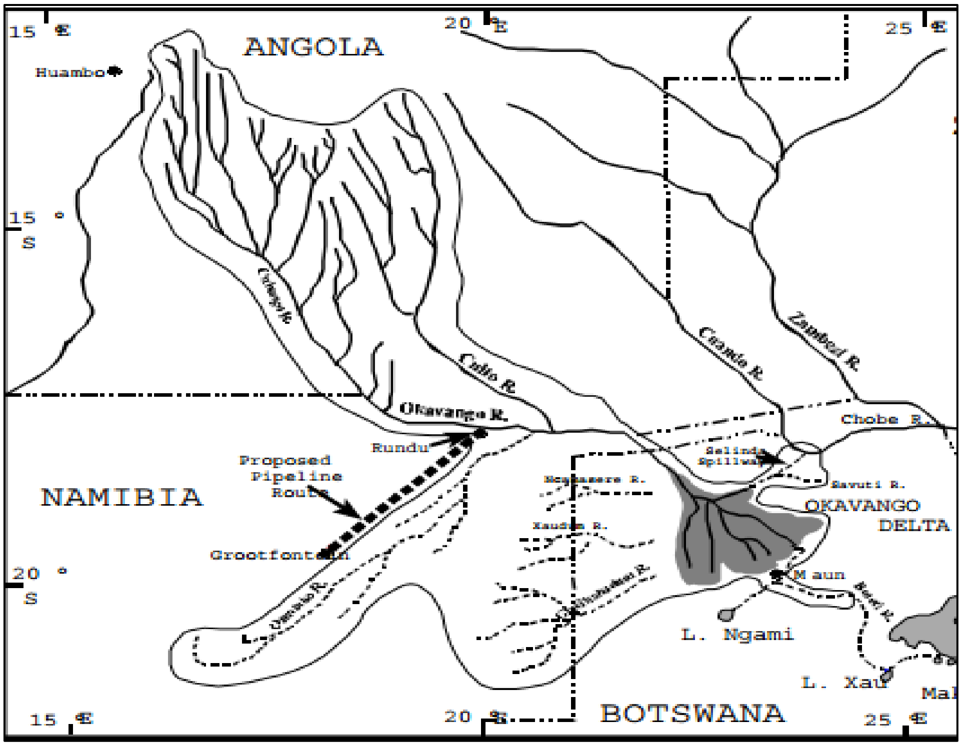

Figure 3 - Illustration of the proposed 260km pipeline project and the Okavango Delta it would impact (Ashton, 2010)

Reaching an agreement with the other countries is the major force holding back the pipeline project and is the main reason the Okavango River is not viable as a water source for Windhoek. This inaccessibility makes managing the provision and expansion of water sources that are located solely in Namibia extremely important for the future growth of the country.

2.2 Water Pollution

Water pollution can further limit the availability of potable water. Consumption of unsafe drinking water is currently a large cause of disease and sickness in the world, especially in the underdeveloped, sub-Saharan countries of Africa. Water becomes polluted in a variety of ways, and remediating drinking water can be costly and time-consuming. Numerous methods of pollution prevention have been attempted in Southern Africa, but the region is still susceptible to the harmful effects of drinking contaminated water

2.2.1 Sources of Water Pollution

The main causes of drinking water pollution can be broken into two categories: natural contamination and pollution due to human activity (Goel, 2006). Some natural sources of water pollution are rainwater that is both bringing pollutants from the atmosphere and collecting pollutants from the ground, animals defecating near drinking-holes, and certain rocks and minerals that lie beneath water bodies that add excess salts into the water (Goel, 2006). The sources of drinking water pollution from human activity include, but are not limited to, domestic, agricultural, and industrial waste (Wang et al., 2013). In an online article, the United Nations Population Information Network notes that "Most human activities contribute to the pollution of surface and ground water, either directly (by returning dissolved effluents to water bodies) or indirectly (because waste deposited on solid ground finds its way to water bodies)" (du Guerny, 1994, p. 13).

Urbanization is a human activity that is a large, indirect source of water pollution (World Health Organization, 2010). Urbanization occurs when large numbers of people relocate from a rural location to a city or town. This process can lead to water pollution problems if the existing sewer system is undersized and poorly maintained. Specifically in Sub-Saharan Africa, due to the increasing population and growing economy, a large amount of pollution is being generated as a direct result of the increased consumption of clean water and the similarly increased discharge of wastewater (Wang et al., 2013).

Effects of Contaminated Drinking Water

Specifically, in sub-Saharan Africa, poor water supply, improper sanitation, and bad hygiene account for 10.7% of all mortality (Bordalo & Savva-Bordalo, 2007). When drinking water, an already scarce resource, becomes polluted, the problems induced by scarcity multiply.

Diseases are spread easily to people ingesting polluted water, resulting in a wide variety of symptoms. In developing countries, 6 million deaths and roughly 1 billion cases of debilitating diarrhea result from water borne diseases per year (Njemanze, 2009). Diarrhea is the most common effect of drinking polluted water in this region, and the effects of such are greatest among children under five years old (Bordalo & Savva-Bordalo, 2007). The Center for Disease Control and Prevention has determined that 11% of child deaths worldwide are caused by diarrhea-related diseases, many of which occur in underdeveloped countries (Centers for Disease Control and Prevention, 2009). Access to clean and unpolluted water is essential for proper sanitation and well-being.

A recent example in Bangladesh shows that contaminated drinking water can have adverse effects on an entire population. Drinking water in this region was contaminated with arsenic, exposing millions to polluted water and resulting in the largest poisoning of a population in history (Smith, Lingas, & Rahman, 2000). It is estimated that roughly 80 million people were affected by this contamination (Uddin & Huda, 2011). This widespread contamination caused numerous cases of lung, bladder, and skin cancer, of which 1 in 10 people who drank water with 500 micrograms of arsenic per liter died (Smith et al., 2000).

2.2.2 Pollution Due to Human Activity.

Human activity is a large cause of direct water contamination. Human actions that cause pollution range from day to day activities such as cleaning or using the bathroom to large scale industrial activities such as mining and manufacturing. In general, sources of direct water pollution due to human activity can be split into two categories: point source pollution and nonpoint source pollution.

Point Sources

Point sources of water pollution are defined as originating at singular locations. An example of a point source of pollution is a pipe that discharges chemically contaminated water from sewage treatment plants or other industrial facilities. (Winter, Harvey, Franke, & Alley, 2013). Every business or industry that produces any form of waste that enters into the sewer system is a point source of pollution. These sources of contamination contain chemical byproducts and waste generated during the process of manufacturing whatever it is that the certain industry produces. Different forms of industry contribute to water pollution in a variety of ways. For example, a paint factory will produce paint sludge and pigments in its waste (Environmental Protection Agency, 1990), but a slaughterhouse will discharge blood, feces, and other potentially harmful organic matter (Bazrafshan, Mostafapour, Farzadkia, Ownagh, Mahvi, 2012). Generally, developed countries with larger industrial sectors contribute more to point source water pollution than do smaller, underdeveloped countries. The more developed countries generally have more industries, and thus more pollution, while underdeveloped countries generally have more agriculture and less industry. Less developed countries often experience more issues with non-point source pollution, but point source pollution is still a major issue.

Non-Point Sources

Nonpoint sources of water pollution originate at a variety of locations or over a large area, and these sources generally involve the flow of rainwater collecting and delivering pollutants to streams and waterways. Examples of nonpoint sources include fields covered in pesticides from agricultural use, areas used for defecation by either humans or livestock, and garbage dumping sites. Rainfall collects harmful chemicals from these sources and deposits them into lakes rivers, coastal waters, and ground waters (Environmental Protection Agency, 2012a). The United States Environmental Protection Agency also reports that nonpoint source pollution is the leading remaining cause of water quality problems in the United States (Environmental Protection Agency, 2012a).

Transmission of contaminants through stormwater runoff streams are a major source of pollution in underdeveloped countries. In fact, a study recently conducted in Guinea-Bissau, a country in western Africa, concluded that the greatest degree of drinking water well contamination occurs after periods of heavy rainfall (Bordalo & Savva-Bordalo, 2007). This study also found that, in addition to harmful chemicals, rainfall also transports bacteria and viruses into the groundwater (Bordalo & Savva-Bordalo, 2007). The chemicals and viruses originate from livestock grazing areas, fields covered with pesticides and fertilizer, and garbage dumps. When rain water flows through garbage dumps, for example, the resulting heavily-polluted water is known as *leachate*.

When leachate and other forms of contaminated stormwater later flow through areas with certain environmental conditions, such as a thin soil or a bed of porous rock, the likelihood of drinking water pollution is increased. For example, the City of Windhoek, Namibia, has an extremely thin layer of soil and bedrock separating the surface from a great underground aquifer used for clean water storage. This thin barrier allows for the easy transmission of harmful chemicals carried by rainwater which sink into the earth and infect the aquifer with contaminants (Winter et al., 2013).

2.3 Obstacles in the Regulation of Water Pollution in Developing Countries

One way to reduce pollution levels in areas with scarce water resources is to ensure that local industries comply with pollution regulations. However, while achieving industrial compliance is difficult in almost any region of the world, it is particularly troublesome in developing countries. Many developing countries lack the ability to effectively sample, monitor and analyze the pollution being discharged by different companies. Even more importantly, they struggle to adequately enforce pollution regulations. National environmental regulations may be in place, but effective enforcement at the local level is hard to come by due to limited resources and a lack of environmental activism (Tang, 1998). Environmental regulations are established on the basis of how much pollution can safely be introduced into a community without causing health concerns or harming key resources that sustain life. Because of this, it is essential that industries comply with the regulations in place.

There are a variety of challenges that developing countries face with regards to industrial compliance. One of the main challenges faced is simply an overall lack of resources and money for the agency enforcing the regulations. Without the proper manpower and tools to monitor and test the wastewater of different companies, effective enforcement is hard to come by. In regions attempting to utilize public disclosure as a method of control, a major factor that can hinder success is the level of environmental consciousness. The public won't scrutinize an industry for polluting if they don't have a certain degree of awareness of the importance of protecting the environment. Another major challenge is that communities won't reprimand a non-complying company if many people rely heavily on them economically. If many people depend on this company for employment or the services it provides, they are very unlikely to criticize the company for its poor waste management practices. These challenges as well as several others will be outlined in more detail below.

In the hopes of improving industrial compliance in developing countries, the World Bank has established a regulatory model, which highlights four main modes of control: market, social, voluntary, and state. Straying from the "command and control" approaches of many pollution control models, this model is centered more on the pressures that come from society and the market to help achieve a reduction in pollution (Van Rooij, 2010). This being the case, we discuss each of the models described by World Bank in more detail in the following sections and additionally provide examples of each, as they have proven to be relatively successful in the developing world. By understanding the models used to improve industrial compliance in other developing countries, Namibia can improve compliance with its own water pollution regulations.

2.3.1 Market Control: Economic Incentives

The first World Bank method of control uses the market through the establishment of economic incentives. Instead of establishing a set level of pollution that a particular company must remain below, economic incentives allow a company to choose how they go about reducing their pollution. By eliminating the requirement to remain below a certain pollution threshold, they are only charged a fee for the pollution loads they create. This type of system is referred to as a discharge fee program. This program was particularly successful in Rio Negro, Colombia in 1997.

Before the program's implementation, the environmental regulatory authorities in Colombia, *Corporaciónes Autónomas Regionales* (CARs), already had good relationships with the community and local businesses and had even been working with a handful of companies to establish methods to help reduce the pollution each generated (Van Rooij, 2010). Specifically, the program established that in addition to creating an inventory of companies that produced waste that generated biological oxygen demand (BOD) and total suspended solids (TSS), CARs gauged the baseline pollution discharge levels from each company as well. BOD and TSS are two common measurements of pollutants in water and from the information included in the inventory, CARs was able to determine a fee that would be charged per unit of BOD and TSS discharged by a given company. This discharge would be monitored every six months and each company would be informed of their pollution contributions and associated fee. As part of this, CARs also had to map out important bodies of water within their area of jurisdiction and come up with a five year goal of the amount by which they wanted to reduce pollution as a whole. From the implementation of this program in 1997 to 2003, BOD levels from point sources decreased by 27% and TSS decreased by 45% (Blackman, 2006). Though very similar to a command and control approach, the discharge fee system is different in that it does not have a set parameter that companies must meet with regards to pollution control, thus allowing them more flexibility.

While this was a promising change, it is important to highlight some issues within this program. Many public sector companies, for example municipal wastewater treatment plants, failed to pay discharge fees. This was further exacerbated by the fact that several of these treatment plants were preventing multiple water basins from reaching their projected five year goals. This resulted in increased fees for all companies who drained to the basin, which greatly upset the private sector companies who were complying. The lack of compliance on the part of these treatment facilities could have been due to poor wastewater treatment infrastructure. This particular road block has been found to be a crucial issue in establishing a discharge fee program in many countries (Blackman, 2006). However, through the implementation of an inventory of companies, the calculation of pollution loads and the creation of a monitoring program, Colombia made significant progress towards reducing their pollution and achieving increased industrial compliance.

2.3.2 Social Control: Public Disclosure

Another alternative to achieving industrial compliance is social or community pressure. This particular tactic uses pressure from society to create compliance, which can be achieved through public disclosure. Through this, the public is made fully aware of the polluting status of industries. The strategy behind it is, if the community is aware of an industry's poor pollution control habits, the industry will be more likely to take steps to prevent excessive pollution to avoid being seen in a negative light in the community.

An example of this type of control method is a rating system put in place in Indonesia in 1997 to monitor the pollution status of 187 industries. With this system, each industry was classified under one of five colors depending on their pollution control efforts. *Table 3* shows the different classifications:

Color Classification	Performance	Pollution
Black	No Pollution Control	High
Red	Attempted Control	Not Meeting Standards
Blue	Attempted Control.	Meeting Standards
Green	Good Maintenance.	Above Standards
Gold	Clean Technology	Minimal Waste & Pollution

Table 3 - Indonesia's Pollution Control Performance Classification System (Van Rooij, 2010)

As a result of this system, initially no firm was able to be classified as gold, five received green classification, most were either blue or red and six were classified as black industries. Those that qualified as green were positively recognized by the public and those in red and black were given six months to make progress before their pollution status was made public. After a year, the black group saw an 83% decrease and about 24% of the groups initially classified as red industries improved their practices and were classified as blue industries (Van Rooij, 2010). By the pollution status of the industries being made public, Indonesia was able to achieve increased compliance.

This being said, it is important to consider other factors such as the size of the industry and its potential political connections. Larger factories, which are more in the public eye, are more likely to be susceptible to public scrutiny. Large factories with connections to powerful political parties, however, may be less susceptible to this scrutiny. In addition, another major road block in this particular method is the economic dependence of a community on the industries in question (Van Rooij, 2010). Communities will often fail to pressure non-complying industries regardless of their awareness of the consequences if they rely on them economically.

2.3.3 State Control: Targeted Enforcement and Political Control

A third method in achieving industrial compliance to pollution regulations is state control. In developing countries, the governing body often cannot effectively monitor and regulate pollution because of a lack of resources and money (Van Rooij, 2010). Where this is the case, the government can employ a method known as targeted enforcement. The industries that produce the most pollution and the sources where most contamination occurs are monitored and regulated heavily, while less attention is paid to smaller businesses that do not pollute as much. The logic here is that inspecting a small business's effluent takes about as much time and effort as does inspecting a larger business's effluent, and with limited resources at their disposal, the government would prefer to spend its time dealing with the largest contributors to pollution (Stuligross, 1999). Rio de Janeiro's regulatory agency, the Fundacao Estadual de Meio Ambiente (FEEMA), had success with this method in the 1990's. They assigned each industry into a category based on how much waste they produce, which allowed FEEMA to regulate the heaviest polluters even with a scant amount of resources (World Bank, 2000).

Another method of state control that can be used to enforce compliance and reduce pollution is to increase the amount of money that local governments give to regulatory agencies. Due to limited resources in many of these developing countries, this is not always an easy task. However, securing a higher budget would allow for more pollution control inspectors to monitor industries, thus more effectively enforcing compliance. Two ways that this could happen are to allocate to the regulatory agencies any fees collected from polluting industries or to gain political and public support through educational outreach, enlisting help and participation from local communities, and working together with business leaders who actively reduce their own pollution (World Bank, 2000). Allotting money collected from polluting industries to regulatory agencies significantly increases the amount of money that they can use for regulation, thus allowing them to hire more inspectors or improve their system. However, this method could lead to regulatory agencies becoming dependent on fees collected from polluting companies, which could reduce their desire to promote cleaner productions, as was the case in China in the year 2000 (Ma and Ortolano, 2000). Increasing political support through outreach and increased transparency also has potential limiting factors. Often, communities may hold a heavily-polluting industry in high favor because of the amount of jobs the industry creates or the quality of products it produces (Rooij, 2010). Education and community outreach often do very little in the way of gaining support for pollution control when such highly-regarded companies are involved. Though political control is a viable method of increasing compliance for pollution regulation, there are numerous challenges that can obstruct this process from working.

In Namibia, a lack of resources and regulatory agencies proves challenging, especially when determining where to target enforcement of pollution regulations. Not only does a country need adequate resources to target enforcement, but they also need to have a good understanding of the water resources in a given area, especially those which are most prone to contamination.

2.4 Water in Windhoek

All the water in a given geographical area typically flows to a series of low points, such as rivers or lakes. This area is defined as a 'watershed' or 'catchment area' (NHDES, 2006).

Within this catchment are a variety of water resources such as surface water and ground water. When these particular water resources are scarce, reclaimed wastewater can be utilized to help accommodate the community's needs. Before wastewater can be reclaimed, however, it must be reticulated (distributed) to a facility to go through a series of treatment processes. From here, the treated domestic effluent can be further treated to be consumed as drinking water.

2.4.1 Catchment, Distribution, and Reticulation

The catchment area of Windhoek consists of several rivers which feed into a series of dams. There are three main dams that provide water to the city, these being the Goreangab, Von Bach and Swakoppoort, as seen in *Figure 4*.

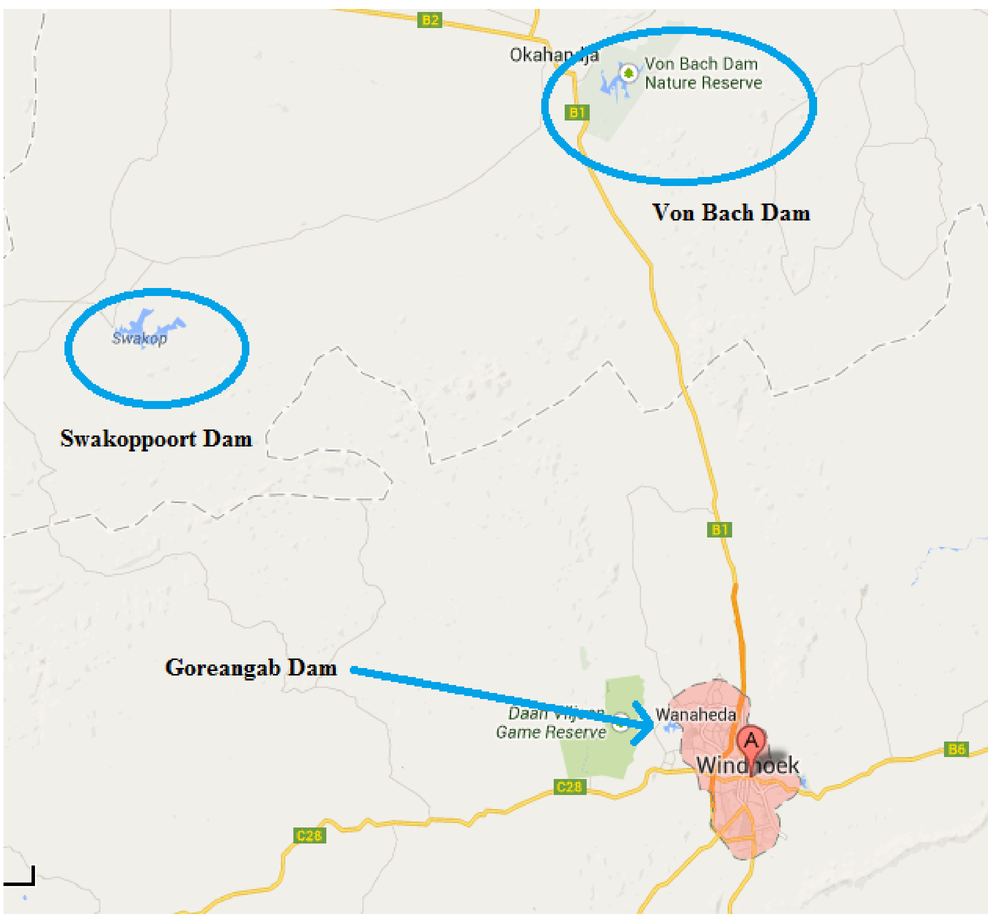

Figure 4 - Dams in Windhoek

The Goreangab Dam is located in the north western section of the city, being the closest source of water. The Von Bach Dam is located around 65 kilometers north of this in Okahanja. Lastly, the Swakoppoort Dam is located about 60 kilometers west of the Von Bach in Otjozondjupa. Being as these two dams are a significant distance outside the city, any water the city acquires from them is brought in via pipeline. From within the city, the Arebbusch and Gammams River merge to feed into the Goreangab Dam, as seen in *Figure 5*. These rivers as well as dams are often referred to as surface water sources.

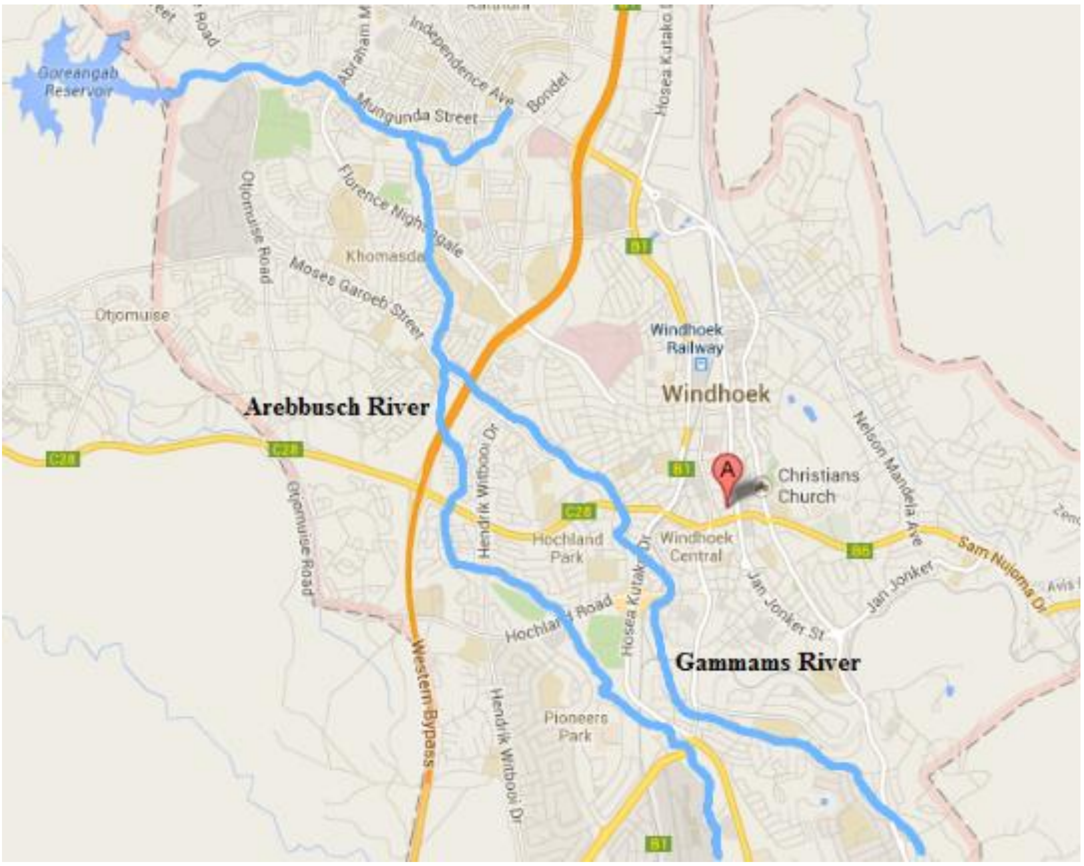

Figure 5 - Surface Water Sources in Windhoek

In addition to surface water, the City of Windhoek gets its water from two additional sources, groundwater and reclaimed water. Groundwater can be defined as water that is located in soil pore spaces or in fractured rock beneath the earth's surface. When groundwater flows easily through permeable rock it is defined as an aquifer and the water can be brought to the surface through pumping (Giordano, 2009). But because water scarcity is a growing issue, surface and groundwater cannot always meet a community's demand for water, especially in arid countries such as Namibia.

As a result, many communities have turned to direct potable reclamation, or water reclamation. Through this process, municipal wastewater or sewage is treated to the proper standards and is then used to replenish or 'recharge' a local aquifer or is mixed with surface water to be utilized as drinking water. Before municipal wastewater can be reclaimed as drinking water, however, it must first be sent to the wastewater treatment plant where it receives initial treatment. The wastewater treatment facility in Windhoek is the Gammams Water Care Works which specifically treats domestic wastewater. A brief overview of this process can be seen in *Appendix A*.

2.4.2 Direct Potable Reclamation

Direct potable reclamation is a potentially sustainable option to supply a community's demand for water because it is not dependent on climate or rainfall, and it is able to produce water that meets the standard for drinking water (Rodriguez et al., 2009). In Windhoek, the original facility that treated wastewater for reuse was the Old Goreangab Water Reclamation Plant (OGWRP). Initially, it was only designed to treat water from the Goreangab Dam, but was upgraded about a decade after its initial construction to treat wastewater as well. After Namibia gained independence in 1990, a new plant was built next to the old one to meet the increased water demand in the city as a result of population growth. This facility is referred to as the New Goreangab Water Reclamation Plant (NGWRP), which is run by the Windhoek Goreangab Operating Company, or WINGOC, which is a privately owned company. Once the OGWRP and the NGWRP receive the raw water from the maturation ponds at the Gammams, a series of treatment barriers are used to bring the wastewater up to potable standards. The treatment consists of an eleven step process, extensively outlined in *Appendix B*. At the conclusion of this treatment, the water is blended with another source water (usually water from the Goreangab Dam), so at most only 35% of the final product for drinking is reclaimed (du Pisani, 2006).

But due to the plant repeatedly achieving acceptable standards for potable water, this proportion was increased. Around 2007, about 50% of the water entering the water reclamation plant was treated wastewater and the other 50% was water from the Goreangab Dam (Lahnsteiner & Lempert, 2007). This, however, is no longer the case. Surface water runoff from the city, particularly from the informal settlements that are in close proximity, feeds into the Goreangab Dam. Due to the levels of pollution in the runoff, the NGWRP is no longer able to treat water from the dam to potable standards. The water in this particular reservoir is now only treated at the OGWRP and used for irrigation. Currently, Windhoek's drinking water is composed of treated surface water from the Von Bach Dam in addition to the reclaimed wastewater from the city.

However, the Gammams Water Care Works is currently receiving increased levels of pollution. The presence of these contaminants complicates some of the treatment and disinfection processes at NGWRP, specifically the stage of ozonation. Through this particular disinfection process, ozone (O_3) is injected into the water where it oxidizes non-biodegradable dissolved organic compounds to create biodegradable dissolved organic compounds. These biodegradable compounds are later taken up by microorganisms in the next stage of treatment, biological activated carbon filtration (BAC). Additionally, the ozone inactivates viruses and parasites such as Giardia and Cryptosporidium, further disinfecting the water (WINGOC, 2006).

While ozone is a very affective disinfection process due to its high oxidizing ability, like many other disinfecting processes, it comes with disinfection by-products (DBPs). Specific DBP's of particular interest are bromates, which are created through the oxidation of bromides present in the water. The presence of bromates in drinking water is of particular concern because of their possibility of being carcinogenic. This being the case, the World Health Organization (WHO) suggests a provisional guideline value of 10 µg/L (World Health Organization, 2005). In other words, if the level of bromates in the drinking water is much over 10 µg/L, the associated health risks will increase as well.

Due to the lack of clean water and the harmful effects of water pollution, Namibians are hard-pressed for a sustainable source of drinking water. Because the City of Windhoek has a distinctive lack of readily-available water resources, there is a desperate need for new methods for the prevention and monitoring of pollution. Additionally, there is a need for better understanding regarding the motivations for and ability of industries to comply or not comply with water pollution regulations. These methods and motivations will be examined with the goal of both identifying sources of pollution as well as understanding what actions the city could take to increase industrial compliance with pollution regulations.

3 Methodology

The goal of our project was to investigate the factors influencing industrial compliance with regards to water pollution regulations in Windhoek, Namibia. Furthermore, we sought to locate potential point sources of critical contaminants responsible for operational difficulties at the city's wastewater treatment plant. In order to accomplish our goal, we achieved the following objectives:

1. Explored past and current data regarding pollution levels at the wastewater treatment plant.
2. Identified reasons why companies fail to comply with water pollution regulations and mechanisms by which the city can encourage more voluntary compliance.
3. Identified potential sources of industrial pollution to the Gammams Water Care Works

In this chapter, we describe the methods we took to complete this project and to achieve our three objectives.

3.1 Explored Past and Current Pollution Data from the Gammams Water Care Works

In order to get a firm grasp on which pollutants caused the wastewater treatment plant to become ineffective in treating the city's wastewater, we spoke with employees at the Gammams Water Care Works, the Gammams Research Laboratory, the Goreangab Reclamation Plant, and other members of the Bulk Water and Wastewater Division (BWWD) at the Department of Infrastructure. We asked them what are the consequences of higher levels of pollution, which pollutants are the most difficult to treat, and which contaminants, in their opinion, should be our focus. They told us to concentrate on the wastewater treatment plant and its reticulation, which is the network of pipes directing wastewater from throughout the city to the plant. Then, we began analyzing the potential point sources of the critical contaminants identified by these experts, which were bromides, ammonia, total Kjeldahl nitrogen (TKN), and chemical oxygen demand

(COD). We specifically looked into which companies in the city are likely to discharge them. To help us understand the wastewater system, the city supplied us with pipeline diagrams of the City of Windhoek, as seen in *Appendix J*, which depicted the location of the three pipelines that lead into the wastewater treatment plant. The maps also showed how wastewater from different regions of the city flowed to the plant.

After learning from the experts that bromides, ammonia, TKN, and COD were most harmful agents to the water treatment process, we analyzed data from past tests from a variety of water sources. The wastewater treatment plant conducts regular tests on water entering the plant to ensure that the contamination in the wastewater is not too high for their processes to treat. We acquired results from these tests dating back to 2007, and we sorted and analyzed these results graphically in Microsoft Excel, and based on the results in our analysis, we located trends of when pollution levels were highest. We cross referenced the concentrations of certain chemicals against each other and against rainfall data in order to identify correlations. A brief graphical representation of our analysis specifically on bromides is featured in *Appendix M.*

3.2 Identified factors affecting noncompliance and mechanisms for improvement

In order to gain an understanding of the attitudes and behaviors of different industries with regards to water pollution, we first had to narrow down a list of almost 17,000 registered businesses that we received from the Business Registry to those most likely to be the source of the contaminants of concern. Research on which industries commonly utilize the contaminants of concern helped us to effectively do this. We created 23 broader company categories and determined seven types of industries to be the most relevant to our investigation, including service stations, slaughter houses, meat vendors, medical facilities, dry cleaning and laundry businesses, tanneries and manufacturing industries For a complete list of company categories, reference *Appendix E*.

Once the categories were finalized, several representative companies from the top seven relevant categories were selected for structured interviewing in order to understand how these different industries handle their wastewater and any issues they may be facing in trying to adhere to pollution regulations. We worked with our sponsor, Trudy Theron-Beukes, to come up with a formal survey that would be distributed to each business prior to these interviews. The survey was a modified version of a past survey that the city used to investigate wastewater disposal practices of certain larger industries that drained to the Ujams Wastewater Treatment Facility. We distributed this survey to 25 companies, and the questions included in this survey can be found in *Appendix H.* Distributing the surveys before the interviews was intended to allow us more time to ask questions related to business owners' knowledge of pollution regulations and what their opinions on the pollution regulations were, so as not to waste time having them fill out the generic survey questions during the interview. After not receiving any surveys back, we decided to rework some of the questions to be more straightforward. We sent the improved survey to 50 companies. The questions included in the second version of our survey can be seen in *Appendix I.*

Even after revising our survey questions, we only received two responses, and even then, many questions were left blank or not answered in full detail. Despite this unfortunate setback, we were still able to acquire much of the information we needed through a series of structured interviews. For a list of the specific questions that we asked, reference *Appendix F.* We decided to interview companies belonging to the various categories discussed earlier, with a focus on industries that have high potential to be over-polluting their wastewater. We began by interviewing smaller industries that drain to the Gammams Water Care Works, but found that many of them did not know the information that we were hoping to get from the interviews. Since they did not know this information, they also believed that they had no struggles with compliance and thus had no suggestions for the city. After discovering this, we decided to interview the larger industries in Windhoek that drain to the Ujams Wastewater Treatment Plant, and we had much more success gathering the information we needed. Firstly, from these interviews, we acquired information on the history, any major expansions or upgrades, and general practices of the business. We additionally gathered information on what chemicals they used and what, if any, by-products were produced as a result of their regular business practices and were thus released in their effluent. From here we determined what steps, if any, they were taking to manage their waste on-site, such as with the use of an oil or fat trap, or for larger industries, an on-site wastewater treatment facility. An important follow-up question was then how frequently were the oil and fat traps and wastewater treatment facilities cleaned. These questions regarding their wastewater management provided us with information regarding the challenges they face when trying to manage their effluent.

After gaining an understanding of their general business practices as well as how they managed their waste, we inquired about these businesses' overall awareness of the city's pollution regulations. We determined if they were aware of the pollution regulations that the city has in place regarding pollution and if they were, if they felt that they were well-advertised. If they felt that these regulations were not well advertised, we encouraged them to make suggestions on how they could be better communicated to them and other businesses in the city.

3.3 Identified Potential Point Sources of Pollution

After understanding the contributions of local industries to wastewater contamination, we then began to identify regions in the city with high levels of pollution. In order to accomplish this objective, we first identified locations, or "critical points," where excessive pollution discharge occurred. We first took wastewater samples from points close to the water treatment plant and then continued sampling along the sewer system at greater distances from the plant to identify a pollution gradient. The city pollution inspector, Salatiel Kalimbo, assisted us in this process as he had 15 years of experience collecting samples for the BWWD.

With detailed pipeline maps of the city, we pinpointed exactly which pipeline access locations we wanted to test. The maps that we obtained, as seen in *Appendix J*, showed city building lots, wastewater pipelines, and manholes. The manholes located throughout the city and detailed on the schematics are of importance because they are the access points to the pipeline system. We needed to locate specific manholes in order to sample the sewer system at the necessary locations. Driving out into the city, finding these manholes, and accessing the sewer system, however, was far more difficult than anticipated. Numerous manholes were either locked by steel bars or located in hard to reach places that were far out of sight. Due to these difficulties, we began taking printouts of maps from the BWWD's Enlighten software with us when sampling. Enlighten is a program used by the BWWD that overlays pipeline locations onto a satellite image of the city, and it allowed us to locate different manholes based on various landmarks and buildings throughout the city.

When we located the required sewer access points, Mr. Kalimbo opened the manholes and together we took samples of the wastewater at that location. A picture of Mr. Kalimbo with his testing apparatus is shown in *Figure 6*. Water from a bucket attached to the end of the apparatus was brought up and transferred into sealable bottles that we labeled with time, date, and location and brought to the Scientific Services research laboratory at the Gammams. The research lab tested the water that we brought them for parameters that our sponsor had identified as contaminants of concern, such as COD, ammonia, TKN, and bromides, as well as other harmful pollutants to drinking water, such as pH level, nitrates, and nitrites. One week after receiving the samples, they sent us the results of their testing for analysis. How the results affected our further testing and more details about our testing methods are discussed further in the Findings section.

Figure 6 - Mr. Kalimbo and his Testing Apparatus

4 Findings

Through working closely with the City of Windhoek's Bulk Water and Wastewater Division (BWWD), we investigated the major sources of contamination flowing to the Gammams Water Care Works that impede effective wastewater treatment. From these investigations, we were able to discover that the city utilizes a complex waste water system and that the BWWD is currently unable to identify the point sources of several critical contaminants to the system, which we explain below. In this chapter we also describe our findings about compliance on the part of industrial firms with water pollution regulations.

Contextualizing our Findings

To contextualize our findings, we first discuss the details of the city's water distribution and reticulation systems.

The City of Windhoek acquires its water from a variety of sources. In addition to using surface water from three local dams and groundwater from its underground aquifer, Windhoek uses direct potable reclamation to provide its residents with clean drinking water. Through this process, wastewater is treated and reused as drinking water after first going through decontamination at the Gammams Water Care Works and then the Windhoek Goreangab Operating Company (WINGOC). Reclaimed water is combined with water from the aquifer and with surface water from the Swakoppoort, Von Bach, and Omatako dams, which are each operated by NamWater. The treated and mixed drinking water is pumped into numerous water towers across the city, and from there the water is distributed to homes and businesses throughout Windhoek. A brief diagram of this distribution is featured in *Figure 7*.

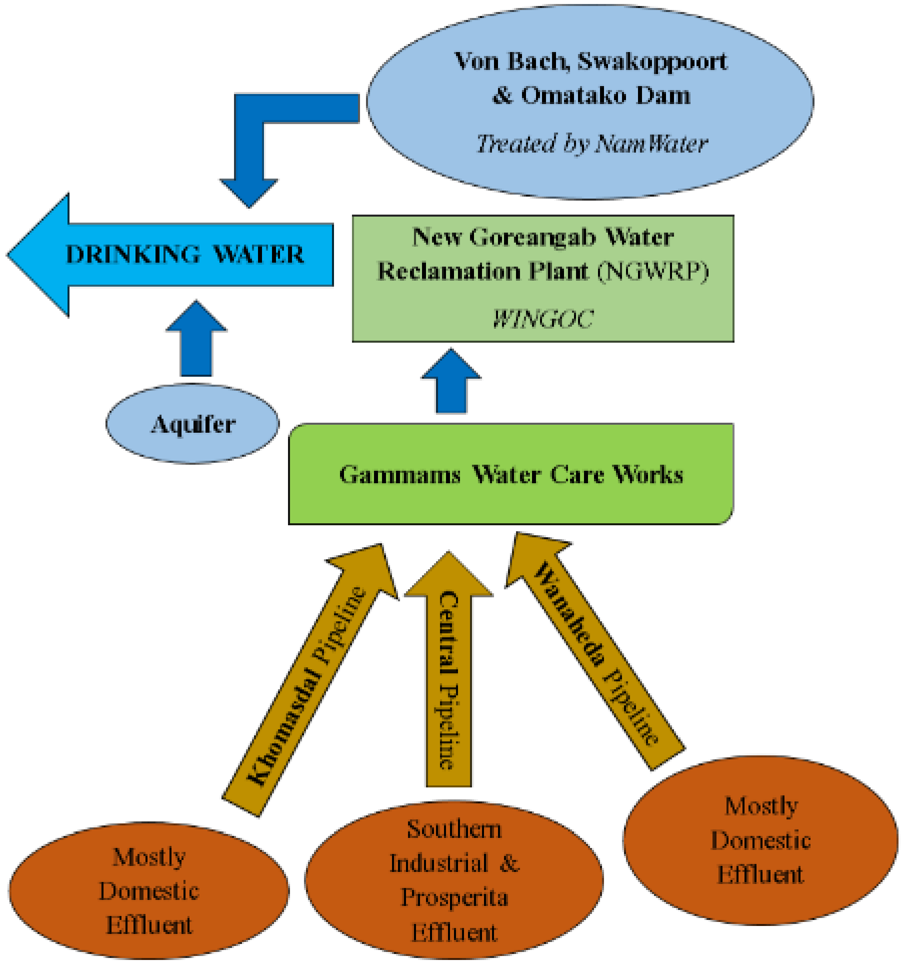

Figure 7 - Windhoek's Water Distribution System

After the water is used by the population, any resulting wastewater enters the reticulation system. The wastewater system consists of an intricate network of pipelines that spreads across the entire city and carries wastewater to one central location: the Gammams Water Care Works. This pipeline system consists of three main pipelines: Central, Wanaheda, and Khomasdal. The Khomasdal pipeline consists of mostly domestic wastewater, and the Wanaheda line consists of the same, though Katutura and the informal settlements contribute some wastewater to this line. Similarly, the Central pipeline carries wastewater from domestic sources as well, but it also carries wastewater from the Southern Industrial and Prosperita sectors of Windhoek. It should be noted that the Central pipeline is the largest of the three, as it is connected to more domestic locations than the other two lines and also includes Prosperita and Southern Industrial. These areas have higher concentrations of industries that all contribute various pollutants to the reticulation system. A general diagram of the reticulation system can be seen in *Figure 11* of Finding 4.

The City of Windhoek has standards for maximum concentrations of effluent allowed to be discharged into the reticulation system, and industries are not permitted to discharge water that has higher concentrations than these maximum standards. The standards that city has in place for wastewater flowing to the Gammams are outlined in *Appendix C.* These standards exist because the wastewater needs to be treated and cleansed at the Gammams Water Care Works and then sent to WINGOC for direct potable reclamation. If water entering WINGOC is too heavily contaminated, the company will stop receiving water and will shut down entirely so as to not damage their process. In order to monitor contamination levels and prevent damage to WINGOC's facilities, wastewater is sampled and tested by the Scientific Services research laboratory at the Gammams. This facility tests all the water that enters and exits the Gammams Water Care Works, as well as water from numerous other sources.

In addition to the reticulation that covers the majority of Windhoek, a separate reticulation system exists for companies in the Northern Industrial sector of the city. This section of the city has a number of larger industries that operate in Windhoek. These companies are generally industries that have high levels of contamination in their wastewater, such as Meatco, Namib Poultry, and Namibia Breweries. The Northern Industrial sector has its own reticulation system where any wastewater that is generated drains directly to the Ujams Wastewater Treatment Plant. This plant specializes in cleaning industrial waste, and the effluent from this facility is not used for direct potable reclamation. However, cleaned water from the Ujams is discharged to the Klein Windhoek River, which eventually flows to the Swakoppoort Dam. A diagram of the Northern Industrial sector's location with regard to other important areas of the city can be seen in *Figure 8*.

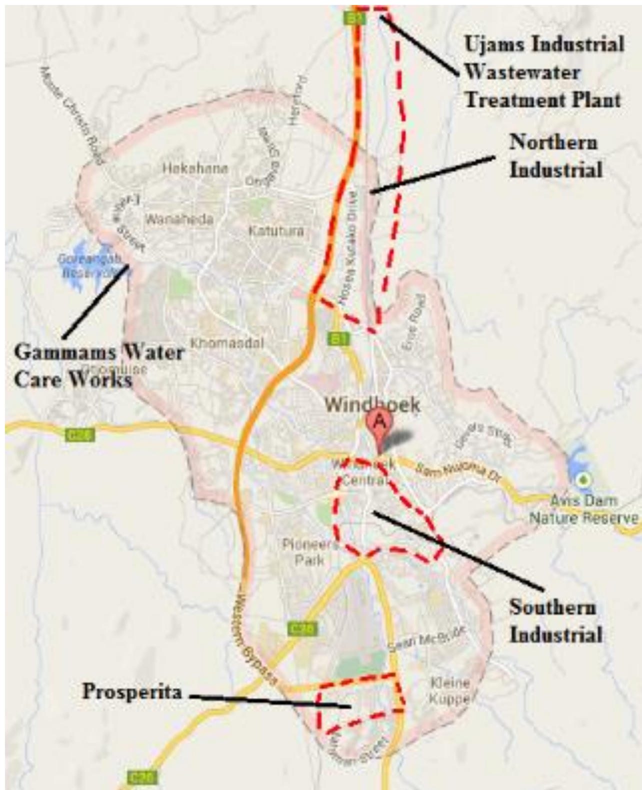

Figure 8 - Important Industrial Areas in Windhoek

Though most of the industries with the largest amount of contamination in their wastewater operate in the Northern Industrial sector, there are still numerous industries that exist within the catchment of the Gammams. For example, informal meat markets operate in areas that drain to the Wanaheda pipeline. These industries produce effluent that is much higher in contaminants than effluent simply from domestic wastewater. Additionally, the Southern Industrial and Prosperita areas of the city, areas that contain numerous light industries that discharge pollution, all drain to the Gammams. However, these two areas, Southern Industrial and Prosperita, are certainly not the only areas of the city that have industries in them. There are thousands of businesses scattered throughout the city, each one contributing pollutants to the reticulation of the Gammams.

We have also learned that a number of changes will be occurring regarding the wastewater treatment systems in Windhoek and how industrial pollution is handled. As of now, industries draining to either the Gammams or the Ujams treatment plants are charged for their effluent based solely on volume of effluent produced. A meter records how much water the company receives from the city, and based on their manufacturing processes, the companies report what percentage of that water is discharged into the reticulation as wastewater. However, as of July 2014, industries will all be charged for their excess effluent based on both volume of wastewater and concentration of pollutants. The City of Windhoek will utilize a formula based on the parameters listed above to calculate how much each industry must pay for wastewater disposal. This formula is detailed extensively in *Appendix D.* In addition, a new reclamation plant is under construction in the Northern Industrial sector. With this, instead of Ujams disposing its effluent into the Klein Windhoek River, it will send its treated wastewater to this new plant. Water will be further treated here and then used for irrigation at various locations, such as farms and golf courses, near the Northern Industrial sector of Windhoek.

4.1 The City of Windhoek's Water Reticulation System

Finding 1: Due to a lack of data regarding contamination from different locations throughout Windhoek, the Bulk Water and Wastewater Division is unable to determine the point sources of bromides, TKN, ammonia, and COD that enter the Gammams Water Care Works.

In general, there is not much knowledge about the sources of pollution to the Gammams Water Care Works. No tracing of pollutants has occurred, and little data regarding what types of pollutants that specific industries release has been gathered. In general, however, certain companies are tested regarding their wastewater quality. Salatiel Kalimbo, the sole pollution inspector for the City of Windhoek, monitors roughly 50 of the largest water polluting industries in the city. Samples of wastewater are taken from each industry monthly and analyzed at the research laboratory at the Gammams. The research lab also analyzes samples of water that enter from each of the three pipelines that run through the city, as well as samples of water that exit the Gammams and flow to the Goreangab Reclamation Plant.

Testing wastewater samples in the lab can be an effective method of monitoring pollution levels. The research laboratory conducts numerous tests daily on water coming into the Gammams, water leaving the Gammams, any samples that the municipality brings into the lab, and any samples that outside companies wish to bring in for sampling. The lab tests for numerous parameters and contaminants in the water, and each time we collected water samples from various manholes across the city, we brought the samples to the research lab for testing.

We have found that, while a sizable amount of data has been collected in recent years, no analysis of this data had been conducted, which resulted in a lack of significant enforcement or action. The primary testing done at the research laboratory is on samples that come from the inlets and outlets of the Gammams Water Care Works, and the results from the tests are mostly used to ensure the process at the plant is working effectively, but not utilized to determine any specific trends in incoming wastewater quality. Also, it is clear that little analysis or tracing of specific pollutants has been taken into consideration in the past when the research laboratory has reported wastewater testing results. The data is presented in excel sheets in a manner that is difficult to visualize, to link to specific locations, and to analyze across different time periods.

Finding 2: The ability to identify polluting industries and enforce existing regulations is hampered by a lack of manpower at the Bulk Water and Wastewater Division.

Pollution control is not an easy task to handle, and proper enforcement of regulations requires both extra manpower and numerous resources. Windhoek does not currently have the resources or man-power to work towards effectively controlling pollution. Pollution control requires diligent inspection, testing, and enforcement and currently, as mentioned above, Salatiel Kalimbo of the Bulk Water and Wastewater Division (BWWD) at the Department of Infrastructure, is the only pollution control inspector in Windhoek. He is essentially doing the job of four people, as there are currently three unfilled positions in the department. These consist of a second pollution control inspector, a pollution control officer to work under the inspectors, and a pollution control engineer. As of May 2014, the pollution control engineer position has been open for 1.5 years, and the other positions have been vacant for over 3 years. The BWWD is looking to fill these positions as soon as possible, especially the pollution control engineer position, but the search has yet to yield a qualified individual.

The monthly samples that he takes are brought to the research laboratory are tested for various pollutants including bromides, nitrates, nitrites, and ammonia, amongst others. The purpose of these tests is to determine whether industries are within the city's wastewater quality standards, which are outlined in *Appendix C*. Mr. Kalimbo utilizes an automatic sampler, seen in Figure 9, to gather the samples in order to surprise industries so they cannot simply prepare for the sampling by ensuring that only clean water goes into the drains. The automatic sampler that he uses is a 24 hour sampler, and it is used because the BWWD wants an understanding of what types of pollutants are discharged throughout an entire day. The results of the tests are intended to be used for regulation enforcement. If an industry's pollution levels are too high, then it becomes the pollution inspector's job to issue a warning or a fine depending on the nature of the pollution. If an industry is a repeat offender, then they are likely to receive a fine, but if the owner of the industry simply did not have proper education regarding proper waste disposal, then they are likely to receive a warning. The samples are an effective way of monitoring industrial pollution levels and with more manpower the city would have the opportunity to test much more than just the 50 industries that Mr. Kalimbo can handle by himself.

Figure 9 - 24 Hour Sampler

Finding 3: With proper manpower, testing water starting from the Gammams and moving upstream along various pipelines in the city has been identified as a feasible method for locating sources of industrial pollution in Windhoek.

Why We Tested

Sewage and industrial discharge contains various pollutants that pose risks to human health. For this reason wastewater must be heavily treated at a wastewater facility before it can be returned to the public drinking water supply. The pollutants that exist in wastewater, specifically the ones that the Gammams monitors, include nitrates, nitrites, ammonia (NH3), phosphates, organic compounds, and bromides. Additionally, total Kjeldahl nitrogen (TKN), is a measurement of the nitrate, nitrite, and ammonia levels in water, and is commonly used to determine if a water source is potable. Additionally, organic compounds, which always include carbon, have the potential to become carbon dioxide through an oxidation process. The oxidation process removes oxygen from water sources, and the amount of removed oxygen is measured by chemical oxygen demand (COD) levels. The COD level is another necessary measurement for the Gammams Water Care Works to make because high levels can make the water unfit for treatment and reclamation.

A collection of experts from both the city's wastewater treatment plant, the Gammams Water Care Works, and the Bulk Water and Wastewater Division of the Department of Infrastructure identified the contaminants and parameters of concern as chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), ammonia, and bromides. It was expressed that these particular contaminants are the major causes of operational problems at the Gammams Water Care Works. Unlike the other contaminants listed, bromides themselves do not pose a direct threat to human health, but they do undergo a reaction in the ozonation stage of Windhoek's current reclamation process that causes cancer-causing bromates to form. Bromides originate from a wide variety of sources, and they are commonly used, along with a variety of other chemicals, as fire retardants. Additionally, numerous industries, including the photography, refrigeration, and cleaning industries, use some form of bromide in their production or cleaning processes. These bromides are discharged into wastewater reticulation systems, sewer systems, along with the rest of the wastewater produced by various industries and businesses.

At the Gammams, bacterial communities are part of the physical and biological processes utilized to treat the wastewater. Beau Smith, the Process Engineer at the facility, informed us that high levels of pollution often cause disruptions in the bacterial communities which are responsible for breaking down the contaminants in the wastewater. The treatment process involves utilizing oxygen for a nitrification process which converts ammonia to nitrates and nitrites, both of which are less hazardous and easier to treat than ammonia. A more detailed explanation of the wastewater treatment process can be seen in *Appendix A*.

In the effluent, chemical oxygen demand (COD) is used as a measurement of how much oxygen is required to break down organic material. If the levels of COD are high at the Gammams, the facility can have difficulties treating the effluent because they only have a limited amount of oxygen available for the nitrification process. If that happens, it will cause major disruptions at the Gammams, which can prevent the bacterial communities from effectively breaking down the organic material in the wastewater and can reduce the treatment plant's ability to treat the effluent properly. When they cannot treat the water, they must divert it to another facility, which results in a lower amount of water that is available for the city's drinking water supply.

Initially, the experts we spoke with assumed that the majority of these pollutants were coming from a region known as Prosperita, a location that is identified in Figure 8, and contains a large volume of light industries, such as small auto garages. This assumption was solely based on the fact that these industries are connected to the Central Pipeline that leads to the Gammams Water Care Works, when in reality their effluent should be draining elsewhere. This particular region of the city should never have been connected to the city's reticulation system, as industrial waste of that magnitude and quality should be connected to Ujams, the city's industrial wastewater treatment plant. Water that is treated at the Ujams is not used for direct potable reclamation because of the large amount of contamination in the industrial effluent. The other two pipelines, Wanaheda and Khomasdal, were not believed by these experts to be significant contributors to pollution issues at the Gammams as they mostly distribute domestic effluent.

What We Did

Due to resources constraints, the city could not conduct field investigations to confirm or reject the suspicions mentioned above. This requires inspectors or municipality workers to go out and collect samples from different points in the sewer system, which would then be analyzed to identify contaminant concentrations by the research laboratory at the Gammams. The sampling is a very significant time commitment, as the reticulation system in Windhoek is very extensive and has thousands of points to sample from. In addition to the large number of sampling points, there are thousands of businesses in Windhoek that could be the sources of pollution. This raises the problem of knowing where to test in order to identify the most polluting companies. Not only is the city faced with the difficulty of determining test locations, but the research laboratory only has the capacity to perform tests on Tuesdays and Wednesdays. This makes the entire testing and analysis process take significantly more time. These delays can often hinder successful results, as a sample could show low readings one day and high readings another day depending on what was drained that day at that specific time. In order to get more accurate results and to ensure statistical significance, multiple samples need to be taken at different times during the month.

In conducting this project, we were able to provide the city with the manpower needed to start a testing protocol at various points in the sewer system. Early on, we were provided with several schematics of the sewer reticulation system in the city. The schematics that we acquired are detailed in *Appendix J*. These schematics provided us with a complete layout of the city's sewer system, along with street names and manhole locations. The testing methods we utilized can be seen in Figure 10, where the green dots represent sampling points with low pollution readings and the red dots represent sampling points with high pollution readings.

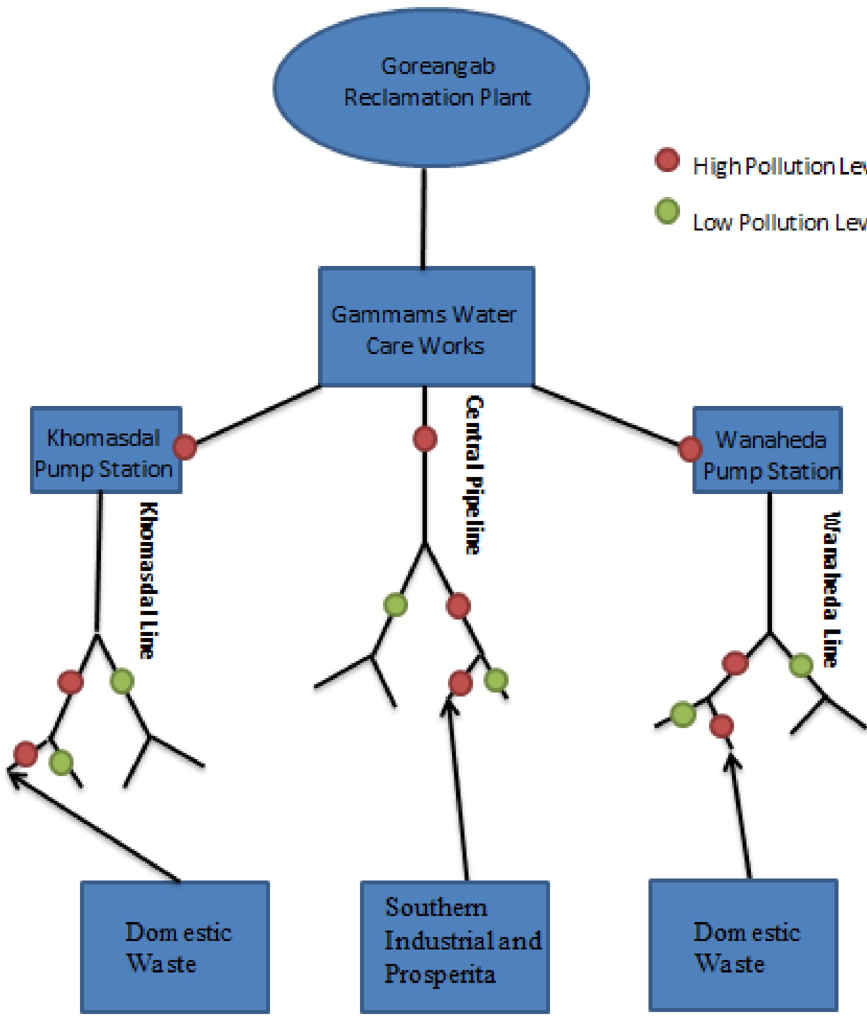

Figure 10 - Pollution Testing Method

The initial locations we tested were selected randomly, but were focused in areas very close to the Gammams. However, as we acquired data from sampling, we utilized the results to guide us as to where to test in subsequent weeks. By following the sampling locations that showed high pollution levels (red dots) back from the Gammams, we hoped to determine general locations of the sources of pollution. The intent of using this method was to help the city understand where they should focus their future testing after our initial testing protocol. Our exact sampling points, along with testing results from each point, are detailed in *Appendices K and L*.

What We Learned

This method of following high levels of pollution back from the Gammams proved to give accurate readings. Since our readings are concentrations of contaminants per mL of water, we had a suspicion that the larger volume of water the Central line receives could dilute the water and thus produce lower concentration readings. We were able to take samples from points along the Central line that contained a lesser flow of wastewater, and the results from these samplings confirmed our suspicion. The levels at the points we took samples from were higher than the final mixing point where the Central line becomes one line. In fact, the samples from the points on the Central line taken on April 9th showed higher levels of pollution than any other samples taken that same day, especially regarding bromides. This has led us to believe that the city should pursue the Central line further and begin sampling near Prosperita and Southern Industrial, which are believed to be potential sources of pollution. A map of important locations can be seen in *Figure 11*.

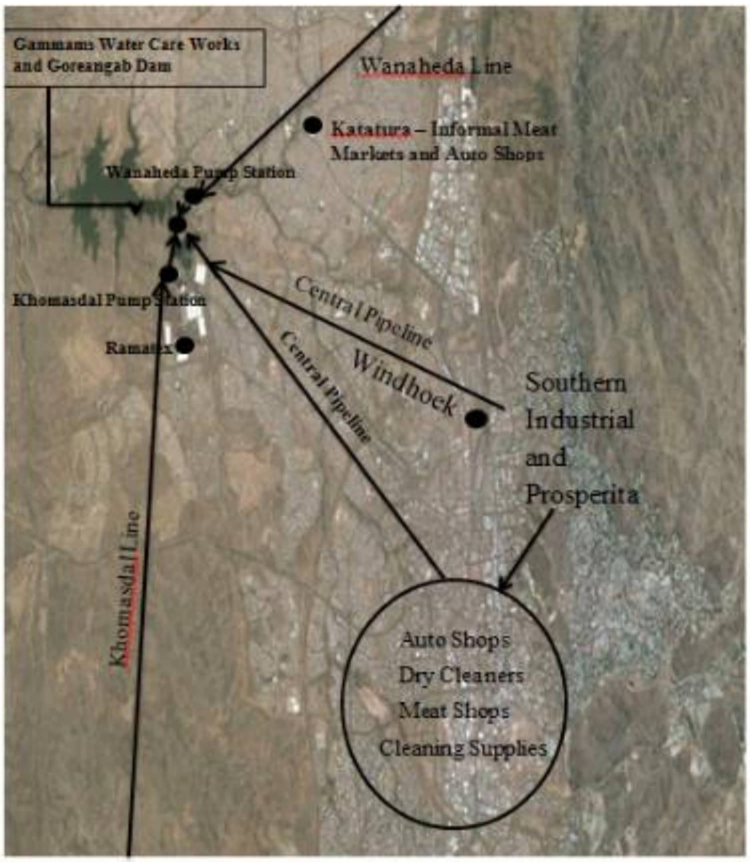

Figure 11 - Central Pipeline and Other Important Areas

Following the Central line, we were able to locate a particular section of Southern Industrial that had extremely high concentrations of contaminants. The reading taken at the manhole located on Marconi Street showed that the wastewater in this small area was far exceeding city standards. The bromide concentration at this location was .72 mg/L, but the city standard for bromides is .5 mg/L. Also, the COD reading here was 1880 mg/L, which is more than double the city standard of 900 mg/L. Based on the results, we identified this small area of the city as a critical point, and that industries in this area were adding too many contaminants into the wastewater reticulation system. A photograph depicting oil flowing down the side of the wall of one of the potentially polluting industries is featured in *Figure 12*.

Figure 12 - Polluting Industry in Southern Industrial

Finding 4: Due to an absence of proper monitoring and maintenance, the sewage infrastructure in Windhoek is not functioning adequately, thus making domestic effluent from the city the largest source of pollution to the Goreangab Reservoir.

Due to a lack of infrastructure maintenance, numerous manholes have either been uplifted or outright decimated. These manholes are the access points for municipality workers to enter the sewers, and are thus physically connected to the wastewater reticulation system. Manholes in Windhoek are commonly located in riverbeds, and the curvature of the pipeline system in some instances follows the contours of the river. The water that should flow through the pipe systems at locations with malfunctioning manholes instead pours upward out of the manholes and into the river bed. One river in particular that has suffered from these malfunctions is the Arebbusch River. This river leads directly into the Goreangab Dam, so when there is high enough flow in the river, such as during the rainy season, contaminants that lie in the river bed are washed directly to the Goreangab. The BWWD's water resources manager and pollution inspector have both stated that because of these uplifted and destroyed manholes, the domestic effluent from City of Windhoek is currently the largest source of pollution to the Goreangab Dam. A picture of a destroyed sewer access point is depicted in *Figure 13*.

Figure 13 - Destroyed Manhole in Arebbusch River

In one location found during sampling, the water in the Arebbusch River was very clear and clean, but only a few meters further downstream, the water was green and clearly being polluted from a source within the riverbed. Because of the way the wastewater reticulation system follows the river, the source of the pollution is almost certainly the sewer. This transition is shown in *Figure 14* and *Figure 15*. When informed of the leakages, the city promptly sent out a maintenance crew to fix the problem, thus halting the pollution. It is essential, however, that in the future, leaks are made known before too much sewage has been sent to the dam.

Figure 14 - Before: Clean Water

Figure 15 - After: Green Water

The opposite relationship, river water flowing into the sewers, exists as well because rainwater fills the riverbed and then flows into the uncovered manholes. As it flows through city streets and industrial sites, the rainwater collects and carries contaminants, such as heavy metals and oils, to the riverbed and to stormwater drains. Some pre-existing data that we analyzed indicated that there is a direct correlation between rainfall and pollution levels flowing to the Gammams, especially where bromides are concerned. This data, which contained testing results from the Gammams Research Laboratory from years dating back to 2007, was acquired from the municipality's archives. We analyzed the data and presented it graphically, and the correlation between bromide levels and rainfall can be seen in *Figure 16* below. During or immediately following months that experience heavy rainfall, the bromide levels spike. This relationship is most likely connected to nonpoint sources of pollution and stormwater runoff entering the reticulation through Windhoek's storm drains. However, this relationship is also connected to the open manholes because the river flows directly over the manholes during times of heavy rainfall. If they are open, then the water would naturally flow into the wastewater reticulation and then to the Gammams, as long as water is not already overloading the sewer system, causing the water from the sewer to enter the river bed, as discussed earlier.

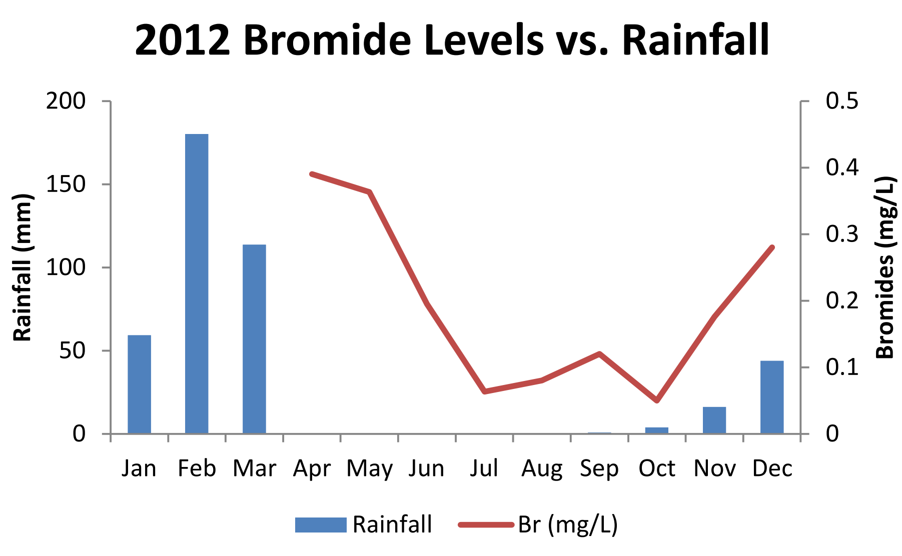

Figure 16 - Bromides vs. Rainfall

During our investigations, we found that almost every single manhole in the vicinity of the Arebbusch River has been found forced open due to excessive water flows created by blockages in the sewer system. Often, what will happen is that a blockage forms inside the pipeline because of excessive solid matter contained in the wastewater, amongst other reasons. This blockage stops the flow of water from moving further down the pipeline toward the Gammams Water Care Works. Since water is entering the vicinity of the blockage from further upstream in the pipeline, an overload will form near that area. Because the manholes are connected to the pipeline system, water often flows up and out of them because that is the easiest way for the pressure buildup due to excess water to be released. Even manholes with special locks that bolt the lid shut have been found to be broken. An example of this can be seen in Figure 17, and a visual of the uplifting process can be seen in *Figure 18.* The uplifted manholes are holding back pollution control efforts for the BWWD.

Figure 17 - Uplifted Manhole

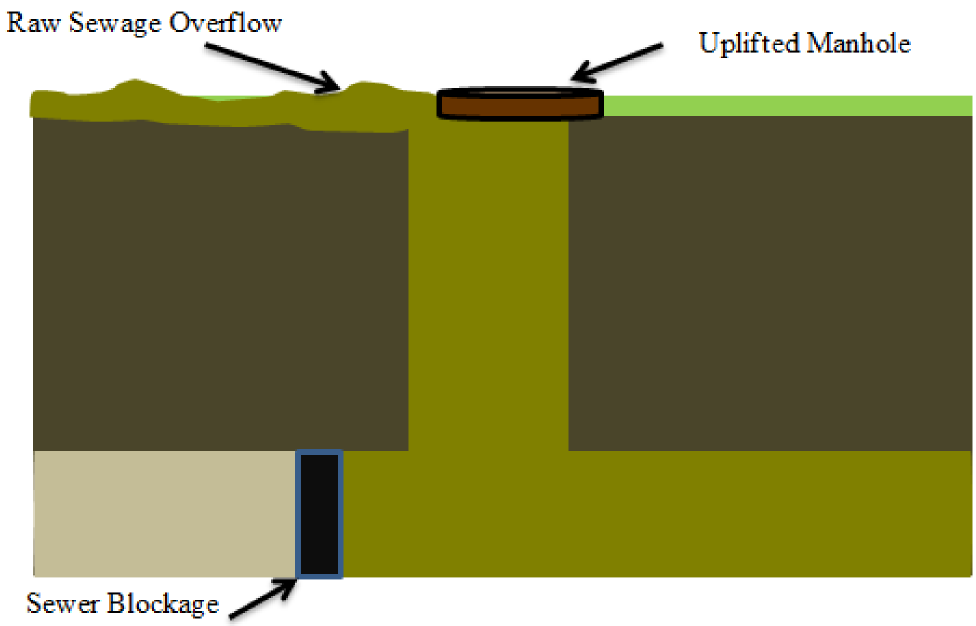

Figure 18 – Sewer Blockage Diagram

4.2 Industrial Compliance

Finding 5: Companies seeking to implement appropriate wastewater management infrastructure often struggle to cover the costs of installment and maintenance, thus creating a roadblock for compliance.

The high costs of pollution control systems, specifically on-site wastewater treatment facilities, make it particularly challenging for industries to comply. As mentioned previously, many companies illegally dump to escape this extra cost, and even for those who choose to take on the financial burden and install an on-site facility, challenges with compliance still remain. Our interview with Trudy Van der Merwe, quality control manager at Namib Poultry, highlighted these challenges. Namib Poultry is the only poultry slaughterhouse in Namibia and therefore has no competition. Although they have their own wastewater treatment facility on-site and are not illegally dumping, currently they are unable to treat the wastewater to reach acceptable pollutant levels due to a variety of reasons. The on-site facility utilizes a variety of biological treatment processes including anaerobic and aerobic dams as well as reed ponds. This particular design was based on a similar system utilized in Cape Town, South Africa, but due to the variation in environment, the biological treatment processes in place are not working as effectively. As an example, *Figure 19* depicts the reed pond stage of Namib Poultry's wastewater treatment process. Note that the reeds are all dead and that the water is covered with a layer of sludge, whereas the reeds should be alive and green, and there should be water visibly flowing through the pond. Along these same lines, she also mentioned how the company had been advised that it would be beneficial to add an additional chemical treatment process to the facility to help move towards complying with pollution regulations. While Namib Poultry would ideally like to make these changes, they claim not to have funding to completely rework their wastewater treatment facility. They are still recouping their initial investment of $N480 million that was required to build their entire facility and are unable to put significant amounts into wastewater treatment and still maintain their current production practices.

Figure 19 - Ineffective Water Treatment Stage - Namib Poultry

Meatco, a major supplier of meat in Namibia and the surrounding countries, is another industry that incurs significant pollution control expenses. We interviewed Tony Holbling, the group engineer at Meatco, and he described the measures they have been taking to reduce their pollutant loads. Meatco operates a tannery on the outskirts of the city, and this tannery has an on-site treatment facility of evaporation ponds. The ponds are meant to dispose of the wastewater in a safe manner, but Mr. Holbling informed us that evidence has shown that wastewater is leaking into the ground and contaminating the boreholes in the area. The evaporation ponds are lined with a special liner that is intended to keep all water from seeping through and to prevent the contamination of the borehole water, but testing has shown that pollutants are seeping through the liner. Mr. Holbling stated that Meatco is in the process of upgrading the lining of the ponds and he showed us a sample of the liner. He also stated that the liner is very expensive and that Meatco does not budget enough funds to cover the cost of purchasing all of the new lining at one time; they instead make changes in smaller increments from year to year. Meatco represents a second major industry in Windhoek that claims to face economic challenges in terms of pollution control. This shows that industries that are forced to front the costs of compliance on their own either cannot or choose not to budget the necessary funding for wastewater treatment.

For other companies that may be part of a larger chain, such as Wika Service Station, though implementation costs are still high, the financial burden is much smaller. Wika Service Station is part of a chain of service stations under the ownership of Total. Upon interviewing Kobus, the Senior Manager at Wika, we learned that recently, many service stations in the city started being required to install concrete slabs at all fuel pumps, replacing the current system of interlocking bricks. With interlocking bricks, any spilled fuel has a direct pathway to the ground through the gaps between bricks and can easily infiltrate into the soil. Kobus informed us that this upgrade for their particular site cost around $N10-15 million. Fortunately for them, however, Total covered the majority of the costs for this facility upgrade, and as a result, Wika is not having any issues with compliance.

The ability to meet the city's regulations is not solely due to their ability to afford the cost of upgrading their pollution control infrastructure. Kobus also described to us the station's constant upkeep of smaller wastewater management systems allows them to meet regulations as well. Wika has both an oil trap and a fat trap on site. The fat trap is cleaned by them twice a week, and they additionally have their oil trap cleaned once a month. This maintenance allows for these smaller systems to work effectively, thus reducing the amount pollutants being discharged into the water.

To bypass some of these costs, some industries resort to illegal discharging. Occasionally, lack of awareness may also influence these types of practices, but that is a factor we discuss in Finding 9. While searching for manholes to sample on April 8th, we discovered a pipe that led directly from the workshop at the former textile factory, Ramatex, into the Arebbusch River, which eventually feeds into the Goreangab Reservoir. According to the pollution inspector, the pipe was connected to the drains of the Ramatex workshop, and it served as a way for them to cheaply dispose of chemicals used in the dyeing process. See *Figure 20**Error! Reference source not found.*** below.

Figure 20 – Illegal Waste Disposal

The city pollution inspector informed us that this kind of setup was not allowed, and that anything entering the river from that pipeline would be classified as illegal discharging. He also informed us that one of the main reasons companies discharge in this manner is a lack of sufficient funding to properly dispose of wastewater. He stated that for these companies, money is everything and that one of the easiest ways for them to save money is by failing to comply with pollution regulations by illegally dumping their waste. However, if the city discovers any form of illegal discharging, stringent fines, at least in theory, are imposed on the business. The intent of the fines is to make it cheaper to comply with regulations than to pollute.

In the case of Ramatex, political pressure made it difficult to impose these fines for illegal discharges because of the thousands of jobs that Ramatex provided to citizens. To attract the company, the national government subsidized its water and electricity costs and did not force the company to build the water treatment plant it had agreed to during initial negotiations. The pollution inspector stated that he was looking into the illegal discharging at Ramatex and the possibility of imposing fines until he was instructed to stay out of the matter. This highlights how political pressure can cause cities to not enforce water pollution regulations.

We learned more about the existence of illegal dumping through an interview with Mr. Brandt at Nowak Automotive. Mr. Brandt used to work for the City of Windhoek, giving him a decent understanding of the inner workings of government control and regulation. He told us that many people rent out property in the city to begin businesses, but often fail to follow good waste management practices. Soon after settling into a property, businesses, such as car shops, will start to dump their waste illegally and eventually move out after three months of not paying rent. After moving out of their current property, these businesses often repeat the process of improper waste management elsewhere. This behavior could again be related to economic issues on the part of the renters of the property as well as the property owners themselves. Because the renters of the property are seeking a profit, much like the property owners, they are not likely to turn away a business that lacks certification from the city.

Finding 6: Inadequate communication between the governing bodies of Windhoek clouds industries' understanding of regulations in place, hindering their compliance efforts.

As there are many different divisions of the government in the City of Windhoek, effective communication is certainly an issue. This was voiced as a major concern by the quality control manager, Ms. Trudy Van der Merwe, of Namib Poultry. Specifically, she described how the building department had allowed them to build on their current plot of land, but after the facility was already constructed, the water department questioned why they were allowed to build there. This questioning stemmed from the fact that much of the northern region of the city, where Namib Poultry is situated, is considered to be a "hot spot", meaning that any pollutants they discharge in their effluent will flow directly into the catchment of the city if not disposed of or treated properly. Our sponsor explained to us that much of this miscommunication had to do with the fact that the location that Namib Poultry built their farm was not until recently included in the jurisdiction of the city. Therefore, it was not questioned by the water department until it fell under their jurisdiction, which was after the farm had already been fully constructed. As a result, Namib Poultry found themselves stuck in the middle of this miscommunication. At this point, the quality control manager mentioned how they were made to feel like they did something wrong when in reality all the necessary approval steps were followed. This being said, Ms. Van der Merwe understands where the concern is coming from based on the location of the poultry farm, but that an increase in communication between the municipal departments would be an improvement she would like to see.

Finding 7: Increased awareness of water pollution allows the city to help those in need of proper wastewater treatment by suggesting solutions for the given industry without the immediate threat of penalization.

Through multiple interviews, we gained the impression that the city could improve efforts in educating the industrial community regarding pollution regulations. Up until now there have not been significant efforts to educate the industrial community, but the BWWD has informed us that it would like to change this and ensure that the regulations are well known. Our interview with Namib Poultry brought about the idea of the city working together with industries in this interactive manner to help them control their pollution. Currently, the city is aware that Namib Poultry is over the discharge regulations. However, the city will allow them to continue operations as long as they continue to show evidence of working to reduce their pollutant levels. The awareness of the pollution allows the city to help those in need by suggesting solutions for the given industry without the immediate threat of penalization. Without the city having accurate data regarding wastewater quality, and if companies do not reach out to the city for help, then the BWWD cannot assess the company's performance nor help them reduce their pollution levels.

Additionally, we received numerous suggestions from industry leaders regarding their opinions of how the city can better communicate information about water pollution and how to spread the knowledge of proper disposal methods. For example, during an interview with Mr. Erich Muinjo of the Neo Paints factory located in the Southern Industrial sector of Windhoek, he recommended that the City of Windhoek send out an email or letter update every month to the major polluters in the city. He mentioned that the update should inform major businesses and companies of the results from pollution testing. In his opinion, if major companies could be "put on the mailing list" in regards to pollution testing results, it would definitely help with industries understanding pollution in the city. We have found that if the city were to inform these industries of their contamination results, the companies would potentially have the information necessary to change their processes and reduce their pollution contributions. For example, if water tested from Neo Paints was found to have high levels of COD, and if the research laboratory informed the company of this information, then Neo Paints would potentially be able to adjust their manufacturing processes in order to lower the COD levels in their wastewater.

The city would also like to find a way to ensure that all business owners are properly educated in proper waste disposal techniques, but the lack of manpower hinders their ability to do so. The pollution inspector has a full schedule, as he is the only pollution inspector in Windhoek, and he does not have time to go industry to industry educating owners about pollution control. Education is one aspect of pollution control that can truly be controlled by the city if they have the necessary employees. Locating repeat offenders who have no regard for the regulations in place may never be an easy task, but the city realizes that limiting the number of people who have little knowledge of the regulations would be a catalyst for cleaner wastewater effluents in the future.

Finding 8: Due to a lack of awareness of both pollution standards and proper wastewater treatment practices, many industries in Windhoek are not complying with regulations.

From our interviews with local light industries, we discovered that a general lack of awareness exists regarding pollution limits and proper waste management techniques in many companies. For example, we spoke with Mr. Pierre Dall, the owner of Diff Doctor, which is a car maintenance shop specializing in work on differentials. As an auto shop, Diff Doctor is required to use and maintain an oil trap to filter out any oil from their wastewater before it enters the reticulation. The city requirements regarding oil trap maintenance are that it has to be a three chamber process, the oil trap has to be covered, and it has to be cleaned out and drained once per month. However, Mr. Dall proudly informed us that he had just cleaned the oil trap for the first time in 13 years, and that because it was so unkempt, he had decided to start cleaning every 10 years. He had spray painted "2014" onto his wall to remind him of the last time he cleaned the trap. When we informed him of the monthly requirement, he was completely taken aback, and he readily informed us that he had no idea this was the case. It was very clear to us that the city needs to increase efforts of informing potentially polluting industries, such as small auto shops like Diff Doctor, of pollution regulations.

Additionally, industries have been found to be uninformed about the best management practices regarding water pollution control. Andreas Minz, the owner of A. G. Minz automotive repair shop, informed us in an interview that he only has a single chamber oil trap, and that he does not clean it more than every half a year. Also, he was unsure if his oil trap was even connected to the city's reticulation, and that he hoped it was not because of how much oil is usually in the trap. We checked with the city's pollution control inspector, and we discovered that Minz is indeed connected to the sewer system, even with his poorly maintained oil trap. Essentially, his oil trap is almost constantly full of oil, and therefore not properly working. Additionally, the oil trap was open to the environment, meaning that excessive rainwater entered the trap and caused even more oil and other pollutants to spill on the ground and enter the reticulation. Mr. Minz was unaware that he needed a three chamber oil trap, and he was unaware that a roof or other type of cover had to be over the trap in order for it to work properly. If he had been properly informed of the correct way to install and handle the trap, he would be introducing significantly less pollution into the sewer system.

In summary, we have found that the city needs to better maintain its infrastructure and does not currently have adequate manpower to monitor industries and enforce compliance with pollution regulations. Additionally, we have found that, in general, larger industries need more prompting to construct and maintain wastewater treatment facilities, for many do not adequately invest in environmental pollution control. Also, we have found that smaller industries in Windhoek need more targeted education and outreach about wastewater disposal and the maintenance of adequate treatment facilities. Recommendations for addressing these issues will be discussed in the next chapter.

5 Recommendations & Conclusions

After analyzing existing water pollution data, testing samples throughout the city, and interviewing a number of industries with regards to water pollution, we have come up with the following list of recommendations and conclusions for the Bulk Water and Wastewater Division.

5.1 We recommend that the BWWD expand its inspection staff to enhance pollution monitoring and enforcement of regulations in the city.

Mr. Kalimbo is currently the only pollution inspector in Windhoek and monitors about 50 companies in the city. Having only one inspector limits the city's ability to identify infractions and to enforce regulatory standards. When Mr. Kalimbo focuses on one portion of his duties, the other portion suffers. For example, when he is in a meeting, there is no one out sampling or monitoring industries. The hiring of more officers or inspectors would not only allow the city to increase the number of industries that are monitored, it would allow for further enforcement of the city's regulations as well. While one of the inspectors is testing, the others can go to industries and make sure their wastewater treatment processes are up to standards. They do not need to conduct more tests necessarily because of the limited availability of the research laboratory to perform tests. However, it would be useful to have the other two employees focus their efforts on other aspects of the pollution inspector's position, such as education of industries and raising awareness of pollution regulations. Moreover, it could allow for further analysis of the samples taken in order to bring the city closer to identifying the point sources of industrial contaminants.

Hiring additional inspectors would be a good start, for it would be beneficial for the city to look into sampling additional industries across the city. However, while we realize that there are methods to expand the quantity of samples taken across the city, we feel that it is much more important to address the educational aspect of pollution control with small industries in the city. Also, because the Gammams research lab cannot handle additional samples anyway, any extra samples brought to them will simply slow down the process, and results would take far too long to be returned. Therefore, we recommend that the BWWD hires people who can work with these industries and effectively communicate city standards to them, thus reducing the amount of pollutants they discharge and encouraging voluntary compliance with regulations.

5.2 We recommend that the BWWD continue sampling away from the Gammams along the city's reticulation to identify point sources of industrial pollution.

We created a testing method to help the city understand where it should focus their future testing after our initial testing protocol. We recommend that the BWWD should continue collecting samples from different points in the sewer system in order to locate the major sources of pollution in the city. These different points can be located in a similar manner to the way in which we selected our sampling points for our initial protocol. By beginning at the wastewater treatment plant and following higher pollution loads upstream into the reticulation, we feel that they will be able to identify other areas of high contamination in the city. We also recommend that the city continue adding sampling points as well as relevant companies to the maps we used to get a better visual sense of where in the city problem industries exist. Additionally, we suggest that they continue looking into the polluters in Prosperita and Southern Industrial, regions which we found to be discharging rather high levels of the contaminants of concern. By testing over a longer period of time, more regions in the city would be able to be sampled, thus potentially providing evidence to more point source locations.

While our testing protocol proved to be relatively successful, there are some improvements we suggest the city make to it when implementing it in the future. If possible it would be beneficial for more frequent testing to be performed over the course a week, instead of just on Tuesdays and Wednesdays like we did. In addition, if it is possible to set up a 24-hour auto-sampler at locations of particular concern to get further readings, this could also be useful in more effectively locating point sources of industrial pollution as concentrations and quantities of pollutants in industrial effluent vary throughout the day. Lastly, we believe it would be useful for the city to sample locations more than once to yield more reliable data.

5.3 We recommend that the municipality should perform routine walks along the riverbeds to look for lifted manhole covers and sewer blockages.

Many of the sewers in the City of Windhoek run directly beneath the riverbeds which feed into the Goreangab Dam. To prevent raw sewage from flowing in the riverbeds and consequently into the Goreangab dam, it is crucial that the city send municipal workers out along river beds to ensure that the sewer system is working properly. Evidence of the system malfunctioning could be manholes that are opened and/or spilling water and manholes that are destroyed or washed further downstream than their original location. In general, these manholes are far away from the road and are commonly isolated away from public view. This causes overflowing manholes to go unnoticed for long periods of time, especially if not inspected regularly. By regularly checking the sewer lines for any unexpected blockages, the city can greatly improve the quality of water flowing to both the Goreangab and the Gammams.

5.4 We recommend that the City of Windhoek explore opportunities for encouraging companies to voluntarily comply with regulatory standards, including education and expanded outreach.

One of the most difficult tasks we faced was locating industries who were currently failing to comply with pollution regulations. This task would have been much easier if those industries were willing to come forward on their own, without fear of fines or penalties, in order to work with the city of Windhoek to reduce their wastewater effluent. Some industries avoided questions when we asked them about their pollution control measures, in part because of concerns of liability and potential regulatory action. The city could use a more proactive method of informing companies of pollution regulations and encouraging compliance without directly punishing them. For example, Namib Poultry was one of the few industries to be very open with us about their effluent, and they knew all the pollution standards they needed to meet. Through working with the city and other outside experts on water treatment, they have made plans improve their wastewater treatment system. If other industries come forward and ask the city for help with their effluent, then it would allow the city to be more knowledgeable about industries that are having trouble with pollution, and it would allow the industries to receive help from the city with managing their water pollution and complying with regulations.

In order to reach companies that do not comply, we recommend that the BWWD work with the Namibian Chamber of Commerce and Industry (NCCI). This organization represents roughly 2500 businesses in Namibia, 231 of which are located in Windhoek. The BWWD should send information to the NCCI that would be distributed to these industries, encouraging them to seek help with their wastewater. Some of the companies working with the NCCI are larger industries with multiple branches and locations throughout Windhoek, such as Total, Puma, NamWater, and NamPower. Companies with as much power such as these could hopefully help spread the information first to their own individual branches throughout the city and then to similar industries in the area. We also recommend that the city not penalize industries that do come forward in any way. Instead, the city should provide information to these businesses and work with them to improve their treatment systems and contamination discharge.

5.5 We recommend that the City of Windhoek issues posters or diagrams to industries that illustrate best practices for managing their pollution control measures.

We spoke with several automotive industries in the city and found that most of them were unaware of how often their oil trap should be cleaned. Some of these industries were located in Southern Industrial at a location that our testing had indicated contained high pollutant levels. Requiring these industries to hang up posters or diagrams in their shops of proper oil trap maintenance would ensure that awareness would no longer be an issue. Unlike through newspaper or emails that people may forgot to read or simply throw away, mandatory posters that hang on the wall of the shop will remind those auto industries every day of the regulations regarding oil traps. In this manner, we can assure that these industries have the proper information regarding how to treat their wastewater.

5.6 We recommend that the BWWD provides industries with results from their effluent samples as well as the breakdown of how effluent charges are calculated.

We believe that industries need to have a better understanding of exactly what they are contributing to the reticulation system. Additionally, if they understood how high levels of certain contaminants affected how much they are charged in discharge fees, they most likely would be more inclined to comply with regulations in order to lower their costs. The research laboratory already sends pollution testing results to the pollution inspector so it would make sense for them to send those same testing results to the various industries that are being tested. This could be done either by direct contact with the industries by letter or through a database that would make the sampling results public knowledge so that companies would be held accountable by their peers. The fear of being publicly exposed as a polluter could be an added incentive for industries to improve the quality of their wastewater effluent.

5.7 When voluntary compliance is not working with a company or a sector, we recommend the city more strongly enforce infractions against industries that knowingly pollute.

Companies that are not complying with pollution standards should be given an initial warning and be asked to meet the standards within a set length of time. The city should provide the offending company with help and any suggestions on how they can reduce pollution. This help could range from verbal recommendations to pamphlets outlining proper maintenance procedures for oil traps and other on-site treatment facilities. If the industry continues to violate the pollution regulations and does not adequately improve the quality of their effluent, then a fine should be issued, and in extreme cases, closure should be threatened. This is something that the city currently practices, but currently the city only monitors the larger industries in Windhoek. The smaller industries that drain to the Gammams Water Care Works tend to slip under the radar and are not monitored as closely as the larger ones, or they are not monitored at all. This is important because the Gammams Water Care Works is the wastewater treatment plant that sends its treated water to be cleaned again at the reclamation plant and used for the city's drinking water. In aggregate, this can lead to significant amounts of pollution entering the wastewater system. Because the smaller industries are typically not inspected, they have little incentive to limit their pollution levels.   With limited manpower available, the city could intermittently speak to and monitor some smaller industries. This would keep the number of industries being tested per month the same, but it would result in a wider variety of industries being tested and thus a broader range for enforcement. By briefly taking the focus off of larger industries that drain to the Ujams Water Treatment Plant, the BWWD would allow itself more opportunities to educate and test smaller industries that drain to the Gammams Water Care Works.

5.8 We recommend that the BWWD engage in monthly meetings with the Business Registry of Windhoek.

We recommend that the Business Registry and the BWWD meet at least once per month to collaborate on various undertakings and provide each other with assistance. Monthly meetings would be beneficial for each group because each can share with the other upcoming projects they are working on and any difficulties that they may be experiencing. At these meetings, it would be beneficial for the Business Registry to provide the BWWD with a list of any newly registered businesses in the city as well as a list of any businesses that have been closed down. In this manner, the BWWD can easily identify industries in the city that may need educational materials regarding wastewater treatment. For example, if a new automotive repair industry registers with the city, then the BWWD can both forward them oil trap construction and maintenance diagrams and offer them assistance with the implementation and upkeep of these facilities.

If, however, the meetings are not possible, then we recommend that at least an email exchange take place once per month to keep the BWWD updated on which industries are active within the city. Meetings would be more beneficial because they provide the two groups with more opportunity for discussion and collaboration than regular emails would. Additionally, requiring monthly meetings would ensure that regular contact is maintained. Emails, though efficient, can be easily forgotten, which could break down connections between the two groups. Additionally, if regular meetings and emails are not possible, the BWWD should request access to the Business Registry's databases. In this way, the BWWD can keep itself updated about the businesses in the city, though no other valuable collaboration between the two groups would take place. Enhanced communication between these two groups is essential for the spread of knowledge of proper wastewater management techniques to industries throughout the City of Windhoek.

5.9 We recommend that the BWWD further encourage people to report damaged infrastructure and leakages in the pipe system.

Due to broken manholes in the Arebbusch River bed, the municipal wastewater is currently the main source of pollution to the Goreangab Dam. The BWWD has workers on staff that are ready to fix problems with the infrastructure as they arise, but because of the lack of reports of broken infrastructure, it is hard to find leakages in the first place. Due to this situation, we recommend the city first put up posters or fliers to make people understand why manhole leakages cause issues and why this problem what they can do to help. The posters can be as simple as a photograph of a leaking manhole that includes a number that they can call if they see such a situation. Encouraging people to report damaged infrastructure would be useful both on its own and in tandem with having municipality workers walk the rivers looking for damaged infrastructure. With the addition of the public eye monitoring and reporting problems with the manholes in the city, the BWWD will be able to conduct a more thorough investigation of the quality of the pipeline system. Also, if the city cannot allocate its workers to walk the rivers, public monitoring represents a less expensive alternative that would hopefully accomplish the same goal. Any breaks in the sewerage system need to be reported as soon as possible to minimize pollution to the Gammams and to the Goreangab. An example of such a situation is shown in *Figure 13* and *Figure 17* of the Findings chapter.

We understand that finding adequate manpower is a difficult task for the city to accomplish. It is extremely challenging to locate people that have the necessary expertise required to do all of these jobs, and even with an increase in manpower, only so much can be done with regard to educating industries. With the large amount of businesses in Windhoek and the small percentage of businesses that are actually registered with the city, we realize that it will be difficult to educate and monitor every business. However, we feel that by focusing on spreading awareness to smaller industries in Windhoek, the city can most effectively reduce the amount of pollution received by the Gammams Water Care Works. These industries need to be made aware that contaminants that they release into the pipeline system can severely reduce the ability of the treatment plants to provide adequate drinking water to the city. We hope that these recommendations will prove useful for the BWWD and will lead to both increased industrial compliance and decreased industrial pollution.

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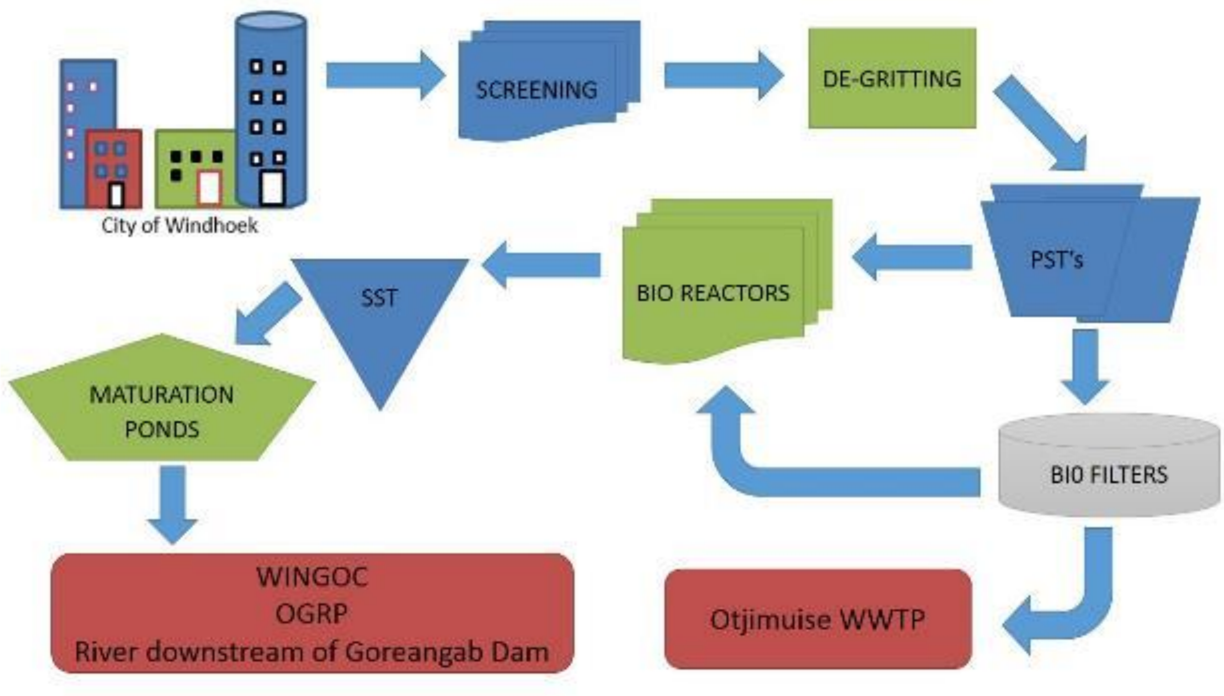
Appendix A: Wastewater Treatment Process at Gammams Water Care Works



Step 1: Nutrient removal plant treats the inflow through an activated sludge process and with trickling filters in parallel (Lahnsteiner & Lempert, 2005).

Step 2: Fine screening, coarse screening, grit and grease removal and primary sedimentation treatment (PST) help separate large particle as well as grit and sand from the wastewater.

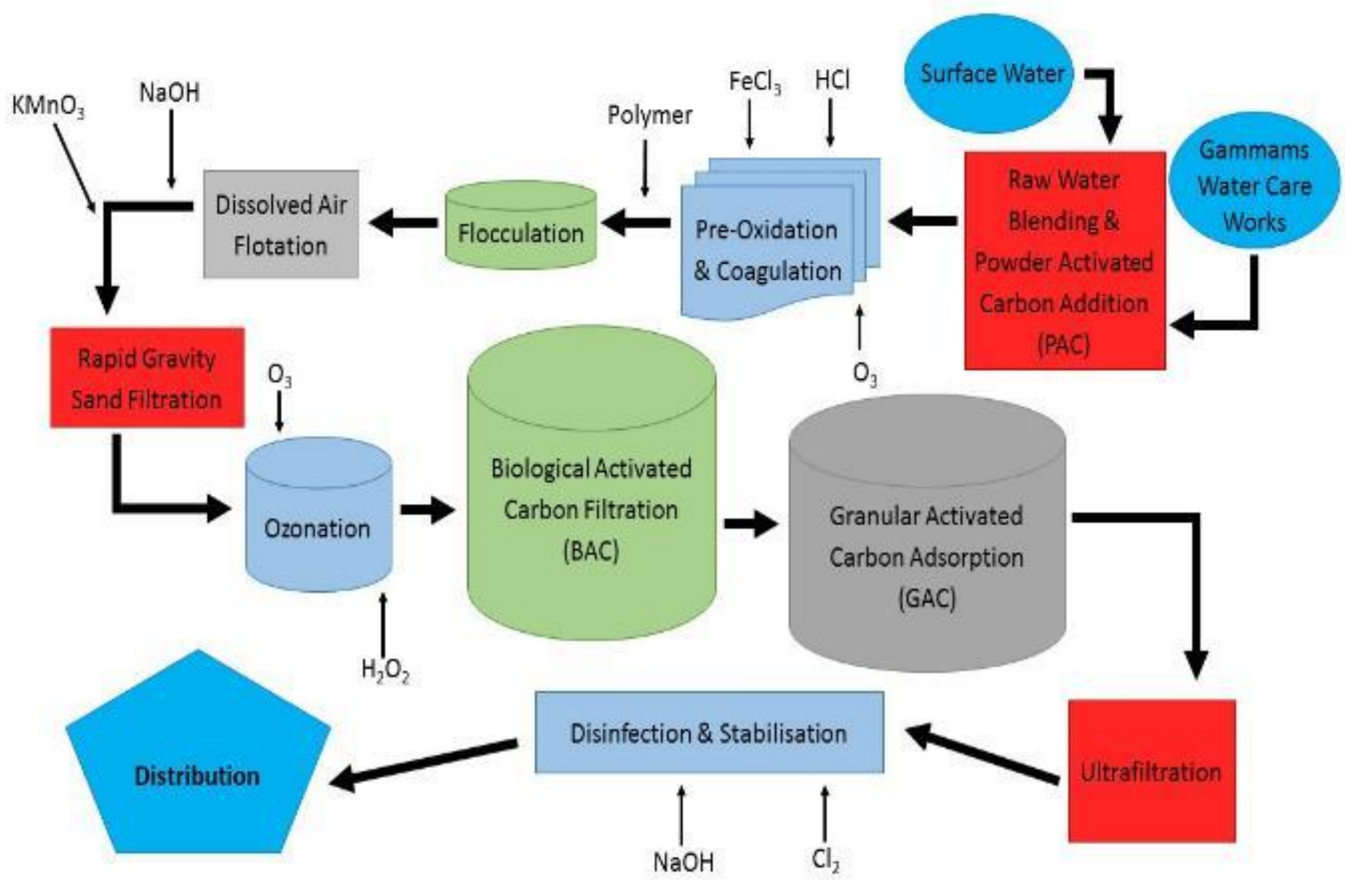
Step 3a: Half of the primary effluent goes into the bio filter which uses conventional rocks to remove the dissolved organic solids. It is then sent to Otjimuise Wastewater Treatment Plant.

Step 3b: The other half flows directly into the bio reactors to remove any nitrogen and/or biological phosphorous.

Step 4: After the bioreactors it is settled through the secondary settling tanks (SST) and polished in maturation ponds with retention time of approximately three days to decrease the chemical oxygen demand (COD).

Step 5: Water from the ponds serves as raw water for the NGWRP and OGWRP. Any water not sent to these two plants is fed into the river downstream of Goreangab Dam.

Appendix B: Direct Potable Reclamation Process at the NGWRP



Step 1: Raw Water Blending & PAC – Treated water from both the Gammams Water Care Works as well as water from NamWater is combined in this first step. The powder activated carbon is added to the water in order to remove dissolved organic compounds.

Step 2: Pre-Oxidation and Coagulation – The water from step 1 is split into two lines which both lead into the stilling chamber of the pre-oxidation section. This stage assists with micro-flocculation, with oxidation of various substances, and with color removal. This step also features a flash-mixing section that adds hydrochloric acid to correct pH and ferric chloride as a primary coagulant. The coagulation process features destabilization of suspended solids in water. The particles have the same charge and therefore naturally repel each other, but destabilization prevents this and promotes the formation of large collections of particles.

Step 3: Flocculation – The water is gently agitated, thus promoting the micro particles formed in flash mixing to agglomerate into macro particles. Water is stirred very slowly in this step, causing the reaction described in the previous sentence.

Step 4: Dissolved Air Flotation – This stage removes suspended solids in the form of light particles. Most of the particles are floated to the surface and removed. This stage also features a sludge removal system to remove the particles on the surface of the water. The flotation of particles is accomplished by injecting microscopic air bubbles into the water. The air bubbles stick to the suspended solids and cause them to float to the top.

Step 5: Rapid Gravity Sand Filtration – Caustic soda and potassium permanganate are added to the water to help with the oxidation and precipitation of dissolved iron and manganese. Removing these substances generally removes undesired color from the water as well, where such color is undesirable for people wanting to drink the water. The main function here is to remove the remaining suspended solids and microorganisms that are still in the water.

Step 6: Ozonation – Ozone gas (O_3) is injected into the water to oxidize non-biodegradable dissolved organic compounds, thus making them biodegradable dissolved organic compounds. This stage is also used for the inactivation of viruses and parasites. This is the stage that can potentially create bromates from dissolved bromides.

Step 7: Biological Activated Carbon Filtration (BAC) – The activated carbon filters reduce the concentration of organic constituents that remain in the water after ozonation. The filters utilize microorganisms to reduce organic loading on the plant. Most of the organic constituents are in an easily biodegradable form after the ozonation step.

Step 8: Granular Activated Carbon Filtration (GAC) – The first stage of this step, the up-flow filter, is used as the roughing filter that removes the bulk of the remaining organic matter. The second stage, the down-flow filter, is the final polishing stage where the remaining dissolved organic compounds in the water are absorbed by the GAC to produce water with limited concentrations of dissolved organic compounds.

Step 9: Membrane Filtration – This stage polishes the product water and is the final barrier against biological contaminants. Ultrafiltration membranes remove all remaining suspended particles, bacteria, viruses, and pathogens.

Step 10: Balancing Reservoir – Permeate from the membrane stage is discharged into the balancing reservoir. Water is further disinfected with chlorine gas. This stage serves as a flow stabilisagion for the clear water reservoir and the emergency water supply for Windhoek.

Step 11: Disinfection and Stabilization – The chlorine contact and stabilization tank receives water from the balancing reservoir. The final product water is prepared for blending with other potable water sources by adding chlorine for disinfection and caustic soda for pH stabilization. The final potable water coming out of this stage conforms to the highest quality standards and guidelines. However, only water that is also mixed with other potable sources is distributed.

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Appendix C: Maximum Discharge Concentrations for Wastewater

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Limits on the concentration of some physical and chemical pollutants – Industries draining to Ujams Treatment Plant.

Parameter	Range & Limits		Base Value	Unit
	Min.	Max.		
PHYSICAL				
pH	6	10.5	3	pH unit
Electrical Conductivity (EC) at 20 °C		500	30	mS/m
Suspended Solids (SS)		1000	500	mgSS/l
INORGANIC (NON-METALLIC)				
Cyanide (CN)		20	20	mgCN/l
Sulphides as (S)		50	50	mgSH-S/l
Sulphate as (SO_4)		150	80	mgSO_4/l
Total alkalinity as ($CaCO_3$)		2000	1500	mg/l as$CaCO_3$
METALS (Group 1)				
Cadmium as (Cd)		20	20	mgCd/l
Chromium as (CrO_3)		20	20	mgCrO_3/l
Cobalt as (Co)		20	20	mgCo/l
Copper as (Cu)		20	20	mgCu/l
Iron as (Fe)		50	50	mgFe/l
Manganese as (Mn)		20	20	mgMn/l
Nickel as (Ni)		20	20	mgNi/l
Zinc (Zn)		20	20	mgZn/l
Total metals (Excluding Iron and Sodium)		50	50	Tot.Metals1/l
METALS (Group 2)				
Arsenic as (As)		5	5	mgAs/l
Lead as (Pb)		5	5	mgPb/l
Mercury as (Hg)		5	5	mgHg/l
Selenium as (Se)		5	5	mgSe/l
Total metals (Group 2)		20	20	Tot.Metals2/l
IMPORTANT BIOLOGIC TREATMENT POLLUTANTS				
Chemical Oxygen Demand (COD)		5000	5000	mgCOD/l
Total Kjeldahl Nitrogen as (N)		120	120	mgN/l
Total Phosphate as P		35	35	mgP/l
Anionic surface active agents		500	500	mgASAA/l
Fats, Oil & Grease		2000	2000	mg/l
Formaldehyde as (HCHO)		50	50	mgHCHO/l
Phenol		5	5	mgPhenol/l

Limits on the concentration of some physical and chemical pollutants – Industries draining to Gammams Water Care Works.

Parameter	Range & Limits		Base Values	Unit
	Min.	Max.		
PHYSICAL				
pH	6.5	9.5	3	pH unit
Electrical Conductivity (EC) at 20 °C		80	30	mS/m
Suspended Solids (SS)		200	500	mgSS/l

INORGANIC (NON-METALLIC)				
Bromine		0.5		mgBr/l
Cyanide (CN)		0.2	20	mgCN/l
Flouride		2		mgF/l
Sulphides as (S)		25	50	mgSH-S/l
Sulphate as (SO_4)		100 above influent	80	mgSO_4/l
Free Chlorine as (Cl_2)		1		mgOCl^-/l
Total alkalinity as ($CaCO_3$)		500	1500	mg/l as$CaCO_3$
METALS (Group 1)				
Cadmium as (Cd)		0.5	20	mgCd/l
Chromium as (CrO_3)		0.5	20	mgCrO_3/l
Cobalt as (Co)		0.5	20	mgCo/l
Copper as (Cu)		1	20	mgCu/l
Boron		0.5	50	mgB/l
Iron as (Fe)		10	20	mgFe/l
Manganese as (Mn)		5	20	mgMn/l
Nickel as (Ni)		4	20	mgNi/l
Zinc (Zn)		5	50	mgZn/l
Total metals (Excluding Iron and Sodium)		20	50	Tot.Metals1/l
METALS (Group 2)				
Arsenic as (As)		0.25	5	mgAs/l
Lead as (Pb)		2	5	mgPb/l
Mercury as (Hg)		0.005	5	mgHg/l
Selenium as (Se)		0.5	5	mgSe/l
Silver		0.1		mgAg/l
Total metals (Group 2)		10	20	Tot.Metals2/l
IMPORTANT BIOLOGIC TREATMENT POLLUTANTS				
Chemical Oxygen Demand (COD)		900	500	mgCOD/l
Total Kjeldahl Nitrogen as (N)		100	120	mgN/l
Total Phosphate as P		10	35	mgP/l
Anionic surface active agents		300	500	mgASAA/l
Fats, Oil & Grease		500	2000	mg/l
Formaldehyde as (HCHO)		10	50	mgHCHO/l
Phenol		5	5	mgPhenol/l

D Radio-active pollutants

The Council reserves the right to limit or prohibit the total mass of any radioactive substance discharged within 24 hours into the sewers from any premises.

Appendix D: Formula for Upcoming Pollution Charges

ANNEXURE D
INDUSTRIAL EFFLUENT CONVEYANCE AND TREATMENT CHARGES
(Regulations 42, 43, 44, 45, 47, 48)
Calculation of Charges

A General

(a) These provisions apply with regard to and for purposes of calculating the conveyance and treatment charge provided for in regulations 42, 43, 44, 45, 47 and 48.

(b) The occupier of any premises from which industrial effluent is discharged into the public sewer, must, without prejudice to any other charges leviable under the Sewerage Tariff, pay to the Council an industrial effluent charge, including any minimum charge, in accordance with the formulae, principles and rates specified in **B** to **C** below.

(c) The industrial effluent volumes to be used in the charge calculation procedures set out below are to be determined in accordance with regulation 44.

(d) The industrial effluent quality parameters and values to be used in the charge calculation procedures set out below are to be determined in accordance with regulation 44 and as further stipulated in **C** and **D** below.

B

1) Charge for the conveyance of industrial effluents

The cost for conveying industrial effluents is based on the volume of industrial effluent, the area of the industrial premises, the cost of capital redemption, and the specific overhead costs pertaining to the conveyance system. The charge in N$ can be calculated with the following formula:

Conveyance Tarrif: L1

$$L_1 = \frac{Ai}{12At} Rn + \frac{Qi}{Qt} (Rm + Rrs)$$

A_i = Area of specific industrial premises
R_n = Annual loan redemption on sewer network
A_t = Total area served by sewerage network
Q_i = Industrial effluent generated on specific premises (m^3/month)
Q_t = Total effluent treated at WWTP (m^3/annum)
Rm= Annual loan redemption on outfall sewer
Rrs = Annual overhead cost (manpower, pumping, maintenance, etc.)

The values for the following items must be updated by the City of Windhoek on an annual basis: At; Qt; Rn; Rm; Rrs.

2) Charge for the treatment of industrial effluents, L

The treatment charge for industrial effluents is based on the capital cost redemption and the specific overhead costs. The treatment charge must be calculated by the following formula:

$$L_2 = (Rp + Rrt)\frac{Qi}{Qt}\left[a\left(\frac{CODi}{CODt}\right) + b\left(\frac{Ni}{Nt}\right) + c\left(\frac{Pi}{Pt}\right) + d\left(\frac{Ssi}{SSt}\right)\right]$$

Where,

L_2	=	Levy for the Treatment Costs	(N$)
Qi	=	Calculated or measured industrial effluent flow originating from the relevant premises	(m^3/ month)
Qt	=	Annual total sewage inflow to the appropriate wastewater treatment plant	(m^3/annum)
Rp	=	Annual loan redemption on sewage treatment works	(N$/a)
Rrt	=	Annual overhead and running cost on the sewage treatment plants, including personnel cost, pumping, maintenance and laboratory costs etc.	(N$/a)
CODi		Average chemical oxygen demand (COD) concentration of the **settled** sample originating from the relevant premises, as determined for the relevant month	(mg/l)
Ni		Average ammonium concentration of the sample originating from the relevant premises, as determined for the relevant month	(mg/l)
Pi		Average ortho-phosphate concentration of the sample originating from the relevant premises, as determined for the relevant month	(mg/l)
Ssi		Average suspended solids concentration originating from the relevant premises, as determined for the relative month	(mg/l)
CODt		Annual average chemical oxygen demand (COD) concentration of the settled sewage in the total inflow to the appropriate wastewater treatment plant	(mg/l)
Nt		Annual average ammonium concentration of the settled sewage in the total inflow to the appropriate wastewater treatment plant	(mg/l)
Pt		Annual average ortho-phosphate concentration of the settled sewage in the total inflow to the appropriate wastewater treatment plant	(mg/l)
SSt		Annual average suspended solids concentration of the wastewater in the total inflow to the wastewater treatment works	(mg/l)
a		Portion of the costs directly related to the removal of chemical oxygen demand	
b		Portion of the costs directly related to the removal of ammonium	
c		Portion of the costs directly related to the removal of o-Phosphate	
d		Portion of the costs directly related to the removal and treatment of suspended solids	

The values for the following items must be updated by the City of Windhoek on an annual basis:

Rp; Rrt; CODt; Nt; Pt; SSt; and

a = 0.6
b = 0.15
c = 0.1
d = 0.15

Unless determined otherwise by the engineer.

The total charge for conveyance and treatment of normal industrial effluent is the sum of L_1 and L_2.

C Penalty for exceeding Limits on the concentration of some physical and chemical pollutants – Industries draining to Ujams Water Care Works.

An additional tariff is payable with respect to industrial effluents exceeding the minimum and/or maximum concentration of the measured items listed below. The specific charge for each item is different and depends on its relative effect on the wastewater treatment process as well as the subsequent reclaim potential of the treated wastewater. The formula used for calculating a specific penalty charge as per the formula set out hereunder.

$$L_3 = \frac{Q_i \cdot (UnitCost) \cdot (P_i - Limit_i)}{BaseUnit_i}$$

Base Unit - determines how much the concentration of a particular pollutant is exceeding the predetermined concentration limit or range. The base unit is used to adjust the charge for a specific pollutant.

Unit Cost – disincentive cost unit is a unit cost that applies to each base unit that a specific pollutant is exceeding a specific concentration limit or range. This disincentive cost unit is used to adjust the charge for all selected pollutants.

P_i – is the average parameter concentration of the sample originating from the relevant premises, as determined for the relevant month measured.

$Limit_i$ – is the Limit/Standard for the different parameters as determined for the different Municipal Treatment Works as per Limit/Standards tables hereunder.

Incentive discount rate determination for the treatability of certain qualifying industrial effluents.

Treatability of industrial effluents based on TKN:COD ratio

Meaning	**TKN/COD range: Min**	**Max**	**%Discount**
Excellent	0.000	0.029	α
Good	0.040	0.059	β
Average	0.060	0.089	0
Poor	0.090	0.120	0
Very Poor	> 0.12		

The values of α and β are reviewed and updated by the City of Windhoek at own discretion.

Appendix E: Categories for Registered Businesses

#1-7 = Most Relevant
#8-16 = Moderate
#17-23 = Least Relevant

1. *Service Stations*
2. *Slaughter*
3. *Meat – butchers, selling of meat*
4. *Medical – hospitals & clinics*
5. *Dry Cleaning & Laundry*
6. *Tanning & Leather Goods*
7. *Manufacturing*

8. Cleaning & Chemical Use – cleaning products, chemical companies, pesticide use etc.
9. Refrigeration & Air Conditioning – manufacturing and repair
10. Salons – cosmetic use
11. Workshop & Repair
12. Restaurants, Prepared Food & Take Away
13. Food Industry – manufacturing/production of food
14. Waste Management
15. Printing, Paints & Photography
16. Energy Products – petroleum, gas etc.

17. Bars, Clubs & Cafes
18. Dairy
19. Textiles – clothing manufacturing
20. Food/Beverage Vendor – grocery stores & general pre-packaged food vendors
21. Lodging
22. Pharmaceutical – pharmacies
23. Offices – law firms, schools etc.

Appendix F: Business Owner Interview Questions:

1. What is your role within the business?
2. Can you tell us about the history of your company? (When was it established, changes in the competitive environment, changes in workforce composition/numbers, changes in workforce capacity development, changes in production practices, changes in regulatory compliance, etc.)
3. Over the past five years have you expanded your business? Has it changed at all?
4. We'd like to get a better understanding of your current production practices. Can you give us an overview of what your company does? Or a tour of the facilities?
5. What chemicals are used in these processes?
6. How do you dispose of chemicals?
7. Do you have an oil/fat trap? Could we take a look at it?
8. Do you treat wastewater on-site? Can we see your treatment area?
9. What chemicals are you treating your wastewater against?
10. Are the regulations in place for wastewater well-advertised? Has the city done a good job of making people aware of the regulations? For example, have you seen this sheet? (Provide sheet of maximum concentrations).
11. Have you had a hard time meeting the regulations?
12. What are you currently doing to reduce pollution?
13. What are the challenges you face in reducing pollution?
14. What information or training from the City would help you reduce contaminated effluent?
15. Are your employees educated on harmful contaminants and proper disposal techniques?
16. If yes, how are they educated?
17. How much do you know about the water reclamation process in Windhoek?
18. How would your industry cope with a shortage of water in the future due to pollution?

Appendix G: Example Interview Write up - Namib Poultry

We interviewed Namib Poultry on 16 April 2014, at 15:00. We spoke with a lady named Trudy van der Merwe, and she was the Quality Control Manager at the facility. She met us at the main reception and then took us deeper into her building through a few doors and past a chicken manufacturing room. Her office was very cold, and she herself mentioned that it was a bit like being inside of a refrigerator. She, however, was one of the friendliest people that we have talked to thus far. She was constantly making friendly jokes, and she was more than willing to share any and all information that she had. She even had one of her assistants bring in a blueprint of the plant simply to facilitate our understanding of the plant's process. Overall, it was an extremely useful interview for our project.

History

She informed us that as of 27 April, the plant would have been there for 2 years. It is the only poultry abattoir in Namibia, and it is privately owned. They were part of a bigger company called NMI, which focuses on chicken feet. The fact that they have only been around for two years is slightly concerning, when you take into account their pollution control facilities. We visited their treatment facilities in late March, and they were certainly not up to par. Kalimbo at the time was concerned about the future of the company's process. He mentioned something along the lines of "**if it is this bad already, how bad will it be in another 10 years**?" – indirect quote.

General Practices

She was able to produce a large number of statistics for us in the meeting. For example, she stated that 1.7 million live chickens are present in the plant at any given time. They receive new chicks every 8 to 10 weeks. Chickens spend time in the egg laying area for 42 weeks to produce new chicks. The good eggs that meet weight and other standards are sent to the hatchery where 300,000 chicks were born per week. If production goes down, then they sell the hens as live chickens. Then, after being born, the new chicks go to the "broiler" section where they stay until they are 32 days old. After this, they are slaughtered. 50,000 chickens are killed there daily. They stun the chickens with water and a small amount of electricity, and then they slit their throats. The chickens bleed in the blood box, and then they are heated up in hot water and plucked of their feathers by machines. The head is pulled off, as are the feet, which are all cleaned elsewhere. All the refuse from this is pumped to a rendering plant. Their chickens go to Nandos, Hungry Lion, KFC, etc.

Cleaning of the facility is done by a private company. Also, workers from one section of the plant are not allowed to enter other parts of the plant due to the spread of disease. "Finicky chickens – they like to die of anything" (if you yell to loud at them, they will die of a heart attack…).

Effluent Treatment Practices and Regulations

All water used in cleaning the chickens is treated with chlorine oxide. We checked online after the interview and confirmed that chlorine dioxide is a common cleaning agent for the disinfection of municipal drinking water. This chemical is used in chlorination stages in water cleansing. She also mentioned that 11-13 liters (her units must have been pretty bad) of water was used per chicken for cleaning. This results in 70 m3 per day (70,000 liters per day), which she said was a lot. As previously mentioned, the units she used must have been off. According to her math here, they only clean off about 5,800 chickens per day, but she had previously mentioned that they kill and process roughly 50,000 chickens per day. She also mentioned that they use nozzles around the pipes to reduce the amount of water coming out.

She mentioned that they have their own effluent treatment process on site. First, water goes through a screen to remove the solids. Then, the water enters the first anaerobic dam. Then, it enters a bigger anaerobic dam which they treat with chemicals. Then the water goes to a flowing dam, and then on to another dam. Then, the water goes through 4 reed ponds, and then into the river. **She openly admitted, however, that the process is not up to standard, and she said that they were having a hard time with it** - more on this later in the write up. We have photographic evidence that confirms the inability of the system to properly treat water. It can be noted that that the reed ponds are dead and that the process does not work as designed.

Figure 21 - Dead Reeds in Namib Poultry Treatment Process, Their Facility in Background

Figure 22 - Overflowing Waste (left) Contaminating Soil

Challenges Meeting Regulations

"Namibia has strict rules on effluent COD levels – much higher than South Africa". Before entering the treatment process, their COD levels are generally at 3200. After treatment, the levels are usually around 880. The regulations require 75. Their best was 640. 25 is required for TSS, and 10 is for Ammonia, and 5.925 is pH requirement. She did not supply units, but we have a list of requirements of our own, so this is not a problem. It is interesting to note that **they were very aware of the specific regulations in place and how much they did not comply**. She said that now that they had already been settled and had started production, THEN the regulations were made clear to her.

She went on by saying that their system used to work in Cape Town, but due to the different climate in Namibia, it does not work as well here. In general, Cape Town had more lenient limitations on wastewater quality. I am not sure why that would be the case here. Yes, the city uses direct reclamation, so the wastewater going to the Gammams should be kept to a certain standard. However, this company drains to Ujams, where the water is treated and sent elsewhere and not used for drinking. Windhoek has a different set of regulations for those companies draining to Ujams, though she feels they are still a bit strict.

She mentioned that Gunther Lempert, the owner or president of Aqua Engineering, was helping them with their pollution cleanup process. He recommended more screening of water and more chemical treatment before discharge. This is definitely a positive sign, because it shows that they are actively trying to improve their process using professionals in the field of water treatment.

She said that money was not available for big expansions. They are still paying off the R480 million initial investment, which they need to pay off before they throw their money around at other projects. This is a huge information point for us. This large company that produces basically the only chicken in Namibia has money issues that prevent it from complying with regulations. We have also noticed, when researching compliance for our background chapter, that pollution control is another huge business expense for companies. It does not seem, however, that this company is being greedy and expanding profit rather than cleaning itself up. On the contrary, it seems like a new company that moved here from another land that had trouble with government regulatory agencies when it started up. We discuss the issue of communication later in the write up.

"As soon as you start hiding stuff, that's when the problems come" – this direct quote indicated to us that she was very honest and open. She has a point as well. As of now, Namib Poultry is working with the city and with water professionals to clean up their effluent, and there seem to be no secrets above it. They are way above regulations, and they admit it openly in order to try and solve the problem.

"Can't run away from things that you need to implement"

When asked if they were having trouble meeting regulations, she replied that the 25 requirement was giving them a lot of trouble, and with Gunther's help, they will be at standards sooner rather than later.

Coming from South Africa, they knew nothing of the land. She also didn't know who to contact within the municipality about water issues. She mentioned that communication is a key factor. Now, she is fine because she likes talking with Trudy and others at the BWWD.

Competition was not a factor for them. They are the only poultry people around.

Plans for the Future

Once standards are met, they want to use the treated wastewater for their animals. They want to use the water for chickens to drink, and they will also sell the water to Meatco as well as use it on their grass. She also wanted to put little ponds in for animals.

Suggestions for the City

We asked her if the city's regulations were well advertised, and she responded with information about the Swakkopoort meetings. This is a conference where stakeholders are allowed to voice their concerns about the quality of the water and the system as a whole.

Her biggest concern was that the ministries do not communicate. The building department approves people, but then you have the water department coming in and saying why would you build here. **They apply to let you build, but the ministries do not tell one another**. They wait until after you have built the facility to say that something is wrong, and you get caught in the middle. - - - This is also a huge finding for us – one which reaffirms our perception of the situation. We already plan to recommend more open communication between branches of the government here in the city. This is another huge reason why! Now we have this company, who is trying to comply with regulations and run an effective business, who is caught between two different agencies that do not work with one another. The building dept. approved their requests for the land, and they filled out all the necessary paperwork, so they build the facility. When the water dept. finally found out, they were up in arms, but it was too late because the facility had already been built and paid for.

She mentioned that it is very frustrating to be between departments. She felt that they did not do anything wrong, and that they are caught in the middle. Kalimbo said that that's what happened to Ramatex. She understands where the concern is coming from, though. She said that they and the tannery were both "hot spots". If the quality of Swakkopoort declines too much, then the whole city could be in danger.

She kept saying that the departments within the city needed to communicate better. Kalimbo mentioned that while someone is approving something, it creates a problem for someone else. He pretty much agreed with what she was saying, which we think gives credit to her statements.

Other Notable Information

They tell the city everything it needs to know. They tell the city all their pollution levels, and they tell the city that they are over regulation requirements. They also present plans for improvement. They have open communication with the municipality. She realized that their registration is linked to the water quality. **If they don't make plans for improvement, then they can be closed down**. Thus, they put effort into this area. This is another big incentive that we discovered from this interview. Fear of being shut down is definitely relevant for compliance.

She mentioned that water is more expensive in Namibia compared to Cape Town. In South Africa, water was R8/m3, but in Namibia, water is R25/m3.

She said something along the lines of "**we are not meeting effluent standards, but it is important to remember how many jobs that they provide" – not a direct quote**. There are 680 total workers at the plant, but 450 were on that site. This is another big finding that we have from the interview. There has to be a balance between their benefits and their downfalls. In their mentality (with regards to this statement), sure we pollute, but we also employ 680 people in a place where jobs are extremely scarce. – This is not the sense that we got from them, but she just mentioned this as a small reason, and she only talked briefly on it. However, a balance does need to be reached in the eyes of regulatory forces. Is it more beneficial to keep this company around and deal with their mess because of the people they employ? Or would it benefit the city more to shut them down so that water can be treated more effectively?

They send tests of their own wastewater to a place in the northern industrial sector, and Kalimbo also samples their effluent all the time. (Analytical Labs).

Appendix H: First Questionnaire for Industries

Business Background and Activities

1. Firm Name.
2. Nature of the industry or business concerned.
3. Name and style of registration.
4. Year of registration of business.
5. Location of industry
6. Physical address and telephone number.
7. The total area of the business.
8. Name of representative and telephone number.
9. Name of the owner(s):

Information about Activities

1. The type of product(s) manufactured/produced:
2. The sort of raw material used:
3. The process of manufacturing (briefly)/ activities:
4. Is there cooling or boiling applied (refer to it)?
5. What types of chemicals are used during processing?
6. How much of these chemicals do you use per month? (m^3/month)
7. Are there special instructions for their use and handling (chemicals)?
8. Do you have any material safety data sheets (MSDS) for the chemicals?
9. How are these chemicals stored?
10. What are the by-products produced during processing?
11. How do you dispose of your byproducts?
12. Is the water treated first before it is released? If yes, with what?
13. Please describe the process you use for cleaning activities.
14. How do you deal with water used for cleaning?
15. How do you handle stormwater on site? Are there drains?

Water Consumption

16. Where does the water that you use come from?
17. What is your average monthly quantity of water purchased from City of Windhoek (Kiloliters)?
18. What is your average monthly quantity of water obtained from other sources like boreholes and recycling (Kiloliters)?
19. What is your total monthly average of water consumed (Kiloliters)?
20. What is your monthly average of water used as boiler make-up (Kiloliters)?
21. What is your monthly average of water used as cooler make-up (Kiloliters)?

22. What is your monthly average of water used for cleansing (Kiloliters)?
23. How much do you pay per m^3 (cubic meter) of water?

Waste Products and Environmental Management Strategies

31. What are the waste products produced and how are they disposed of?
32. Is there any type of waste recovery for solid waste and water products (mentioned above)?
33. Where does your effluent drain to?
34. Is there a separate pipeline for domestic effluent?
35. If yes, where does it lead to?
36. Are there any laboratory tests being done to test your waste products (if yes, what are these)?
37. Is there any type of treatment for waste water on the premises? If yes,
    a) What type of treatment?
    b) Where is the treated water disposed of?
    c) Is the quality of the treated water monitored and measured? If yes what chemicals/other substances are found in the treated water? Does the quality of the treated water meet the stipulated standards?
38. If no,
    a) What chemicals/other substances are found in the untreated wastewater?

    ____

    b) Where is the untreated waste water disposed of?

    ____

39. What waste materials are discharged during processing (solid/liquid) and where are they discharged?
40. Can you sample your own effluent on-site?
41. How often do you sample your effluent?
42. Is anything done with the results of sampling?
43. What is your average monthly effluent? (m^3/month
44. Is there any alternative process in place or being implemented that discharges lower amounts of pollutants?
45. What standards (health and safety) does the company adhere to?
46. Are there any environmental practices being practiced on site? If yes, what are they?
47. Do you have any environmental management system in place? Please explain
48. Are you experiencing any water quality or water related environmental concerns?

Wastewater Pollution Control

49. Do you know about the City of Windhoek's water reuse and direct potable reclamation?
50. Are employees trained in the proper disposal of waste?
51. If yes, by what methods are they trained (pamphlets, workshops, etc.)?

Business Specific

Restaurants: Do you have a fat trap?

Garages: Do you have an oil trap?

Garages: How do you clean spills?

Garages: Do you ever have a professional cleaner clean your business?

Appendix I: Revised Questionnaire for Industries

The following questions were sent to roughly 75 light industries in Windhoek. Adequate space was provided on the questionnaire for written responses, but with the intent of simply providing the questions we asked, we have eliminated the excess space for this appendix.

Windhoek Water and Wastewater Survey

If you do not know the answer to any questions, or if you do not feel comfortable answering them, then feel free to leave them blank. You do not need to answer any questions that you do not want to. These surveys are very valuable to us, even if there are unanswered questions.

Background about the Business and Activities

1. Business Name.
2. What type of business are you running? (ex. Meat, Automotive, Service Station, Brewery)
3. Name and style of registration.
4. Year of registration of business.
5. Location of industry.
6. Address and telephone number of business.
7. The total area of the business (m^2).
8. Name of representative and telephone number.
9. Name of the owner(s):

Information about Activities

24. Briefly explain your manufacturing process or service provided:
25. What raw materials do you keep in storage?
26. What raw materials are used in production?
27. Is there cooling or boiling applied (refer to it)?
28. Please describe the process you use for cleaning activities (ex. Garages, how do you clean up spills?)
29. How do you deal with water used for cleaning?
30. How do you handle stormwater on site? Are there drains? Where do they drain to?

Chemical Usage

1. What types of chemicals are used during processing?
2. How much of these chemicals do you use per month? (m^3/month)
3. Are there special instructions for their use and handling (chemicals)?
4. Do you have any material safety data sheets (MSDS) for the chemicals?
5. How are these chemicals stored?

Waste Products and Environmental Management Strategies

1. What are the waste products produced in your processes at your business? (What chemicals?)
2. How are the waste products disposed of?
3. Is there any type of waste recovery for solid waste and water products (mentioned above)?
4. Where does your effluent drain to? (Gammams? Ujams?)
5. Is there any type of treatment for waste water on the premises? If yes,
    d) What type of treatment? (Oil trap, Fat trap…etc)
    e) Where is the treated water disposed of?
6. Is there any alternative process in place or being implemented that discharges lower amounts of pollutants?
7. If your wastewater is not treated on-site, where is it disposed of?
8. Do you sample your own effluent on-site or is it sampled by the city/separate organization?
9. How often is it sampled?
10. Have you had any troubles meeting the city's standards regarding water pollution?
11. Is anything done with the results of sampling?
12. What is your average monthly effluent? (m^3/month)
13. Do you have an environmental management system in place? Please explain.

Wastewater Pollution Control

1. Are employees trained in the proper disposal of waste?
2. If yes, by what methods are they trained (pamphlets, workshops, etc.)?
3. Are the regulations in place for wastewater well-advertised?
4. Has the city done a good job of making people aware of the regulations?
5. Do you know about the City of Windhoek's water reuse and direct potable reclamation?

Suggestions for the City

1. Is there anything you think the city could do better in terms of pollution control and regulation?
2. Is there anything the city could do to better advertise the restrictions that are in place for wastewater effluent?
3. Do you have any suggestions for how the City could make it easier for businesses to comply with pollution regulations?

Appendix J: Reticulation Schematics

In this appendix, we show our detailed pipeline schematics that were provided to us by the BWWD. Note that the red star on each map was added to indicate the location of the Gammams Water Care Works, where all of the pipelines converge. The purple lines on the map indicate the pipelines, and the red pins represent either sampling points or the locations of industries that we sent questionnaires to. The purple dots, which are hardly visible here, represent the locations of access points (manholes) for the pipelines.

Figure 23 - Khomasdal Line

Figure 24 - Wanaheda Line

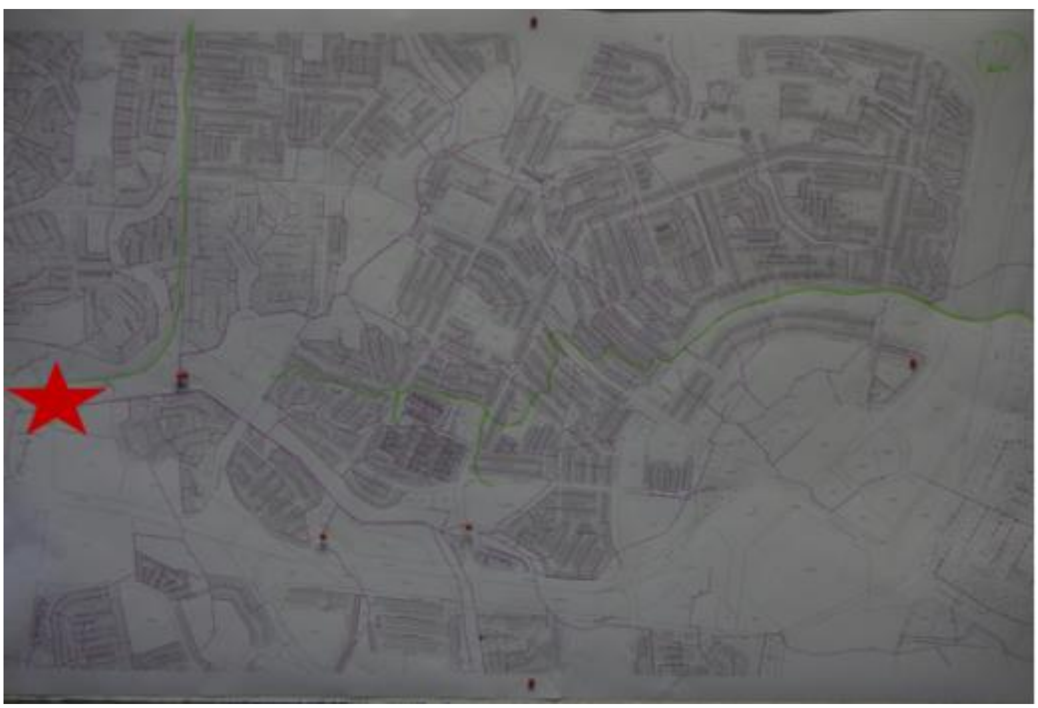


Figure 25 - Central Line

Figure 26 - Central Line - Southern Industrial and Prosperita

Appendix K: Sampling Results

LABEL	DEFINITION	POLLUTANTS			
		Br (mg/L)	NH_3 (mg/L as N)	TKN (mg/L as N)	COD (mg/L)
K-MG 1	Khomasdal – Moses Garoeb Str 1	0.28	51	72	-
K-MG 2	Khomasdal – Moses Garoeb Str 2	0.12	2.3	0.5	-
K-R 1	Khomasdal – Ramatex 1	0.11	20	32	-
K-R 2	Khomasdal – Ramatex 2	0.18	15	19	-
KPS	Khomasdal Pump Station	-	-	-	-
K-RE	Khomasdal- Ramatex Entrance	.2	43	70	-
K-W	Khomasdal- Wendy Str	.25	27	64	-
G-R+C	Gammams- Raw Mix + Central Line	-	-	-	-
WPS	Wanaheda Pump Station	-	-	-	-
W-O 1	Wanaheda– Otjomuise Road 1				-
W-O 2	Wanaheda – Otjoumuise Road 2				-
C-A 1	Central- Arebusch River 1	0.4	80	115	-
C-A 2	Central- Arebusch River 2	0.4	88	115	-
C-S	Central- Safari St	0.17	31	49	-
C-Sh/F	Central-Shanghai/Friedrich	0.3	35	51	-
C-GC	Central- Game Centre	0.15	-	-	740
C-M 1	Central- Marconi Str 1	0.72	-	-	1880
C-M 2	Central- Marconi Str 2	0.49	-	-	440
C-M/E	Central- Marconi/Edison	.27	27	72	950
C-E 1	Central- Edison Str 1	.4	52	98	1300
C-E 2	Central- Edison Str 2	.13	48	72	620
C-J 1	Central- Joule Str 1	.13	34	76	1620
C-J 2	Central- Joule Str 2	.15	12	32	1110
C-Su/A 1	Central- Suiderhof/Arebusch	0.17	-	-	780
C-Su/A 2	Central- Suiderhof/Arebusch	0.15	-	-	690
C-GS	Central- Golf Str	0.17	-	-	830
C-WB 1	Central- Western Bypass 1	.1	33	52	380
C-WB 2	Central- Western Bypass 2	.12	57	82	640
C-P 1	Central- Palladium St 1	.14	32	130	490
C-P 2	Central- Palladium St 2	.21	24	155	1830

Appendix L: Sampling Locations

The results from the specific locations labelled in the following pictures are displayed in *Appendix J*.

Figure 27 - Wanaheda (top), Khomasdal (bottom), and Central (right)

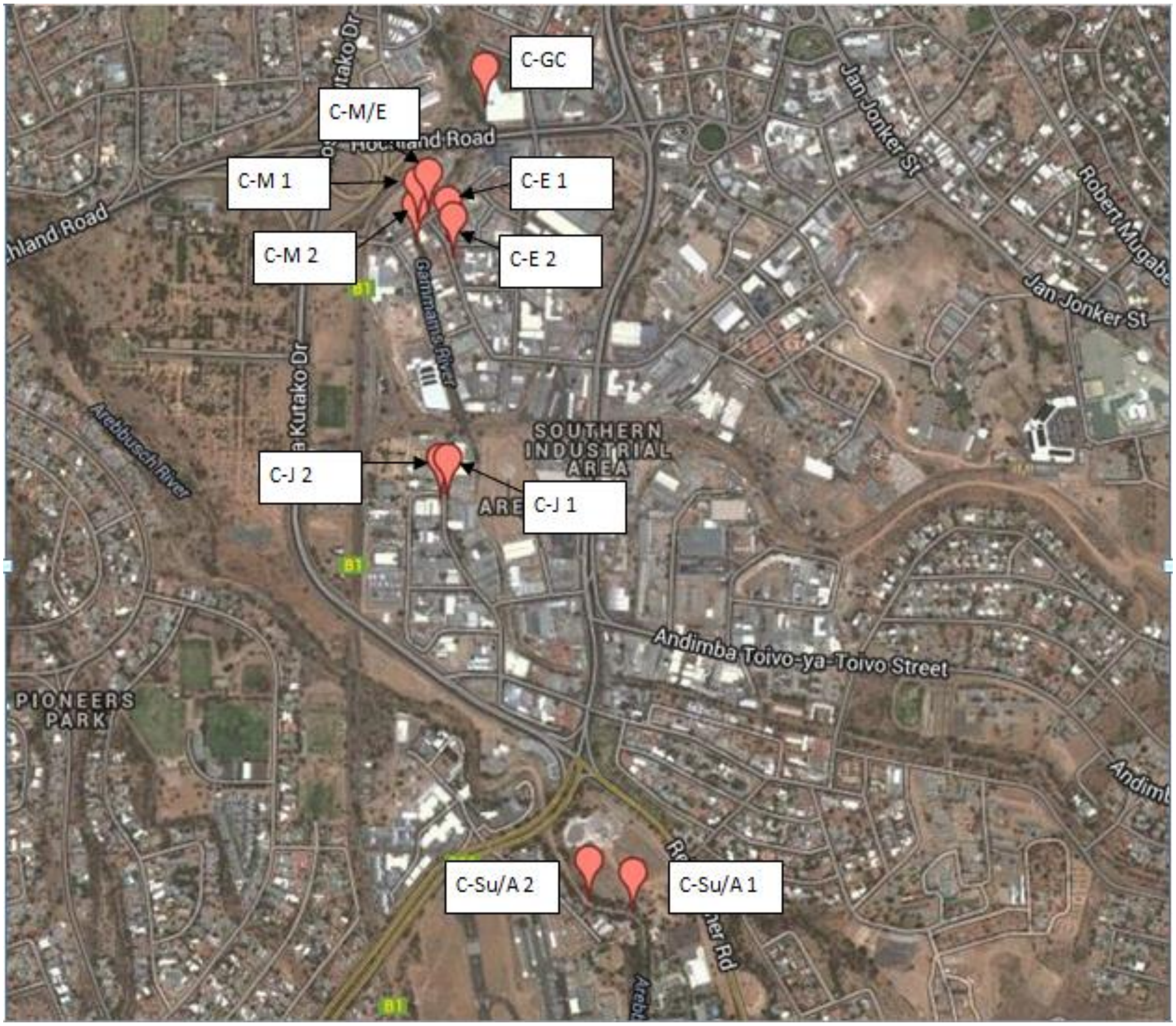
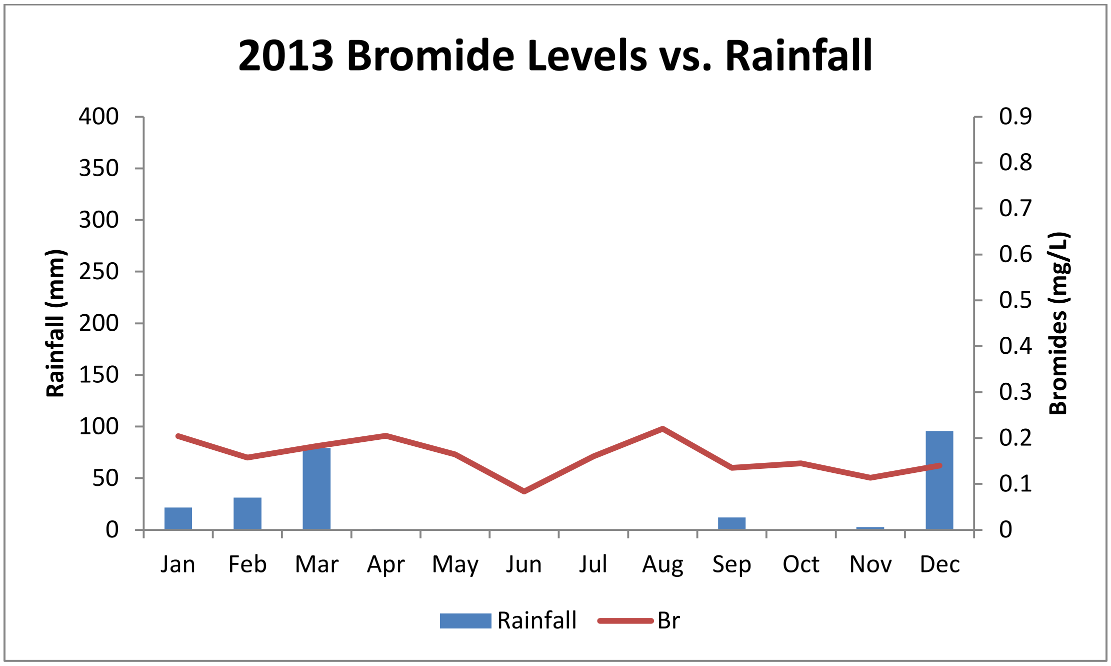
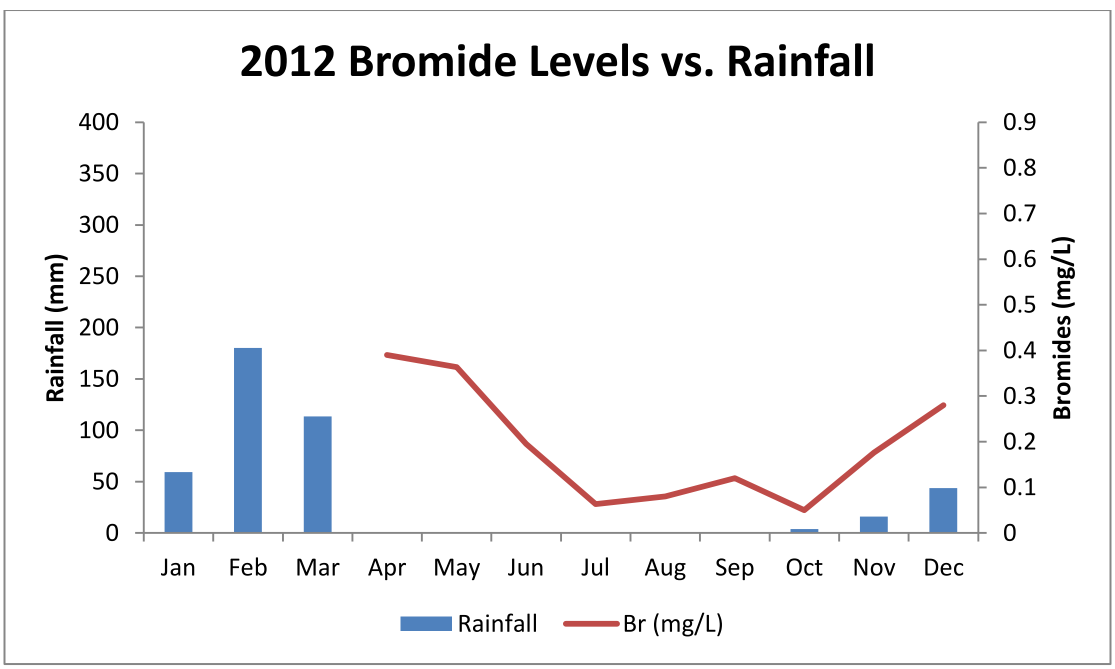


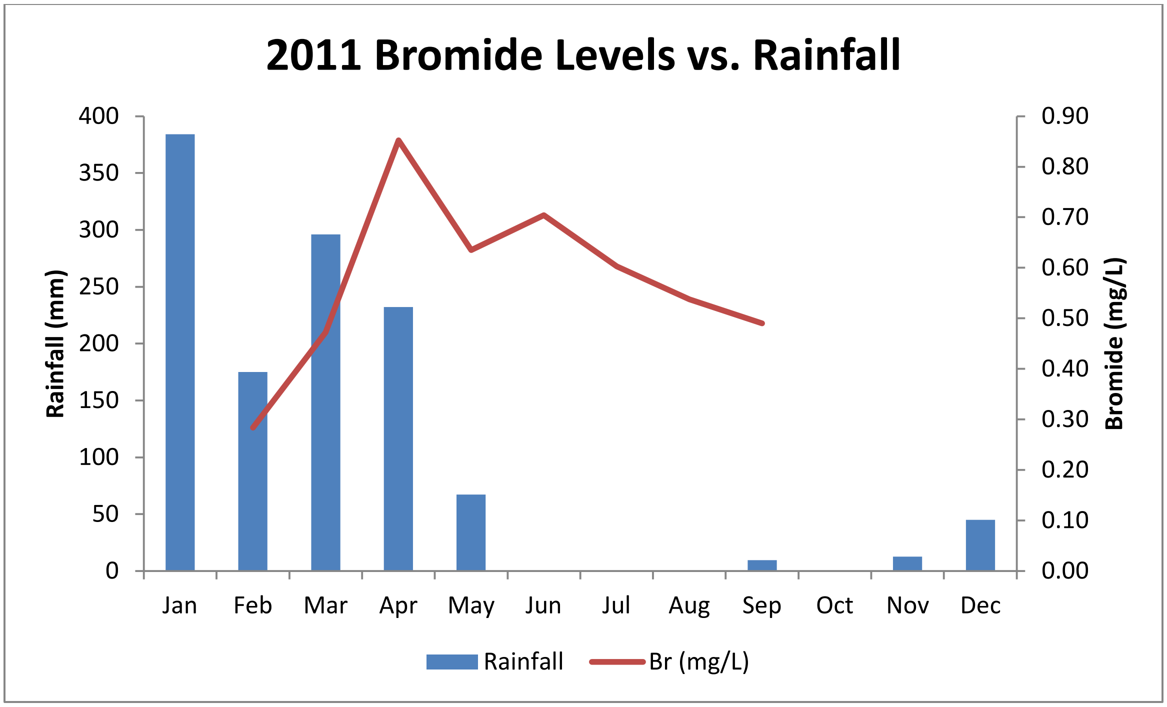
Figure 28 - Southern Industrial (Central Line)

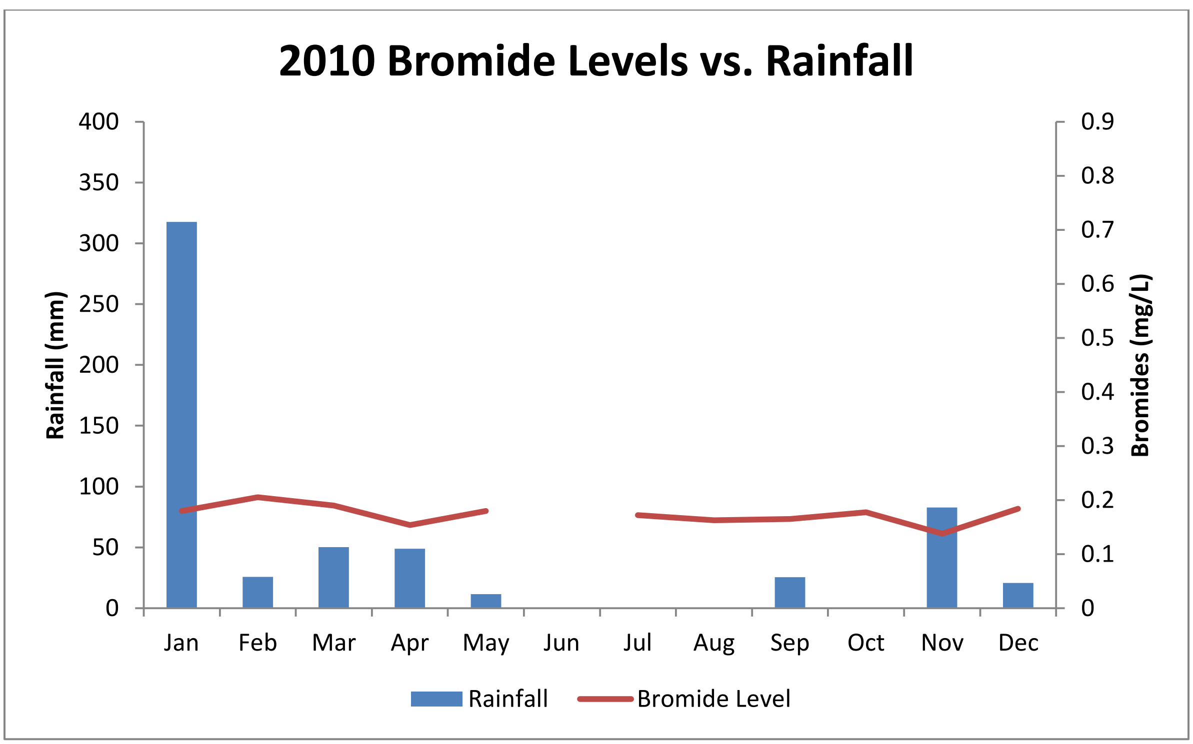
Figure 29 - Prosperita (Central Line)

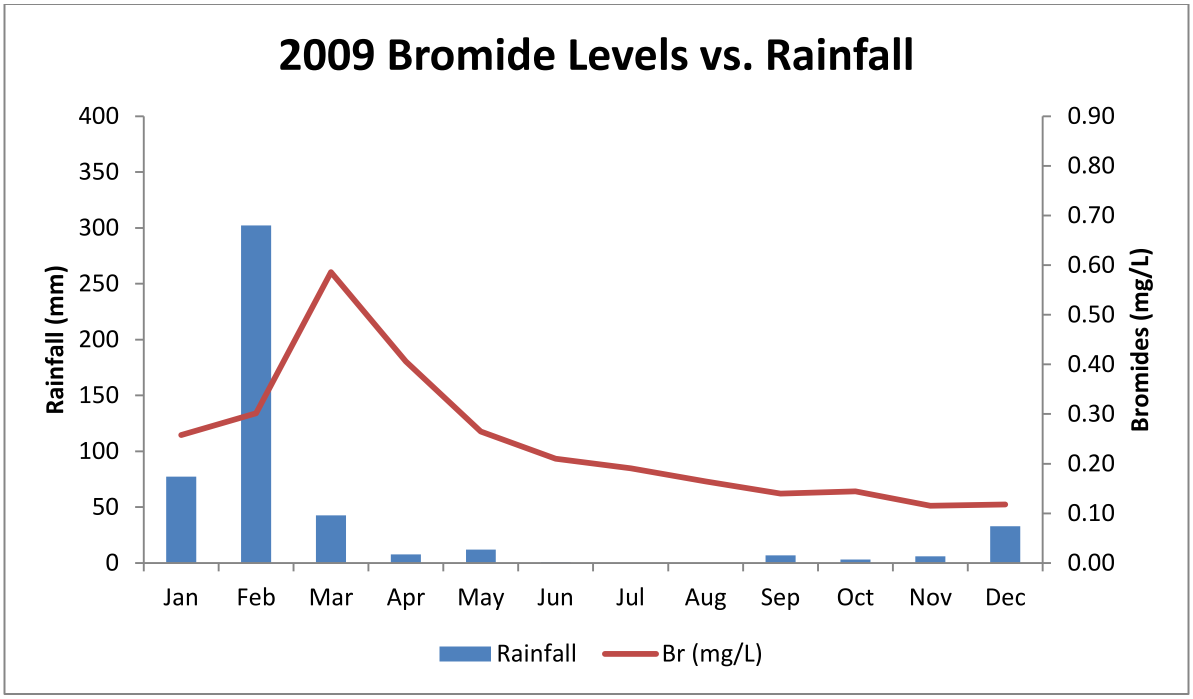
Appendix M: Bromide Analysis – Pre-existing Data

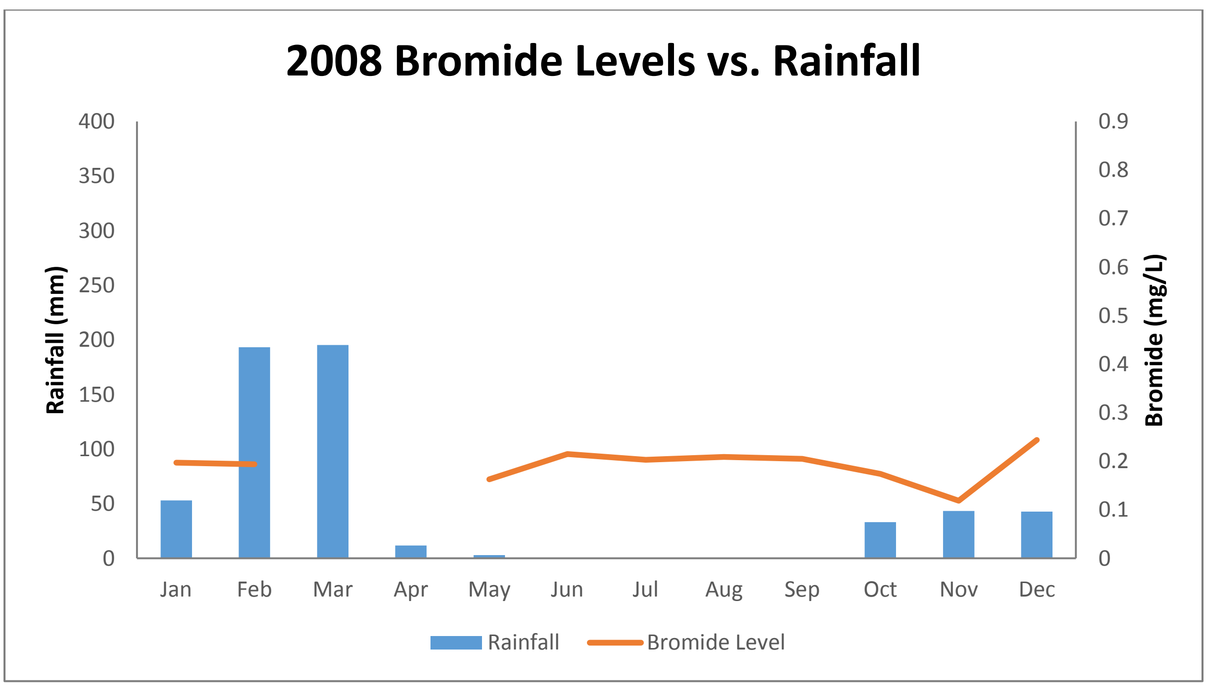





2011 Bromide Levels vs. Rainfall
Rainfall (mm)
Bromide (mg/L)
400
350
300
250
200
150
100
50
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Rainfall
Br (mg/L)


2010 Bromide Levels vs. Rainfall
Rainfall (mm)
Bromides (mg/L)
400
350
300
250
200
150
100
50
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Rainfall
Bromide Level


2009 Bromide Levels vs. Rainfall
Rainfall (mm)
Bromides (mg/L)
400
350
300
250
200
150
100
50
0
0.90
0.80
0.70
0.60
0.50
0.40
0.30
0.20
0.10
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Rainfall
Br (mg/L)


2008 Bromide Levels vs. Rainfall
Rainfall (mm)
Bromide (mg/L)
400
350
300
250
200
150
100
50
0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Rainfall
Bromide Level