A LCA (LIFE CYCLE ASSESSMENT) COMPARISON OF WASTEWATER RECLAMATION AND DESALINATION FOR THE ETHEKWINI MUNICIPALITY – A THEORETICAL STUDY

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ABSTRACT

Water is becoming a scarce resource in many of the South African municipalities and therefore, plans are put in place to deal with increased urban demand for this resource. In the eThekwini Municipality, among other alternatives, two methods are currently considered, namely the recycling of wastewater and the desalination of sea water. Advanced plans and designs are being developed and many factors considered in this decision-making process, including environmental performance of both methods. This study provides insight into the environmental burdens resulting from the two different methods and identifies main contributions to the overall burdens of each method, focusing on areas for improvement.

1. INTRODUCTION

The National Development Plan for 2030 states that there is a strong connection between food, fuel and water taking into context the advent of climate change (1). Of particular concern is the availability and quality of water in South Africa. Geographically, South Africa is located in a pre-dominantly semi-arid part of the world with the climate ranging from desert to semi-desert in the western areas to sub-humid along the eastern coastline (2). Compounded by this situation is the relatively low rainfall received of approximately 450 mm/a compared to a global average of 860 mm/a. This results in South Africa's water resources being termed as 'scarce and extremely limited' (2).

The quantity of water available for human use or to support ecosystems is dependant on availability and sustainability of the resource. According to the water cycle, rainfall, surface flows and groundwater recharge are all intricately linked. Overall, South Africa's use of water resources comprises of 77% surface water, 9% groundwater and 14% return flows (3). In order to effectively utilise the available resources, a thorough understanding of the location and quantity of fresh water that is available is necessary, as well as, the nature of demands for use. This knowledge will assist in decision with respect to the allocation of water to various users.

South Africa is reliant on its surface water resources for the majority of its urban, industrial and irrigation activities. Generally, the rivers and dams across the country are well developed with approximately 320 dams having a total capacity of 32 400 million m^3 which is equivalent to 66% of the total average runoff (2). This high percentage points to the fact that the construction of additional larger dams would be less efficient. These figures do not take into account the other private farm and municipal dams that are utilized for water storage. The usable yield from surface water is constrained by sources of pollution such as urban drainage and disposal of industrial and mining effluent (4). The 2012 report issued by the DEAT warns that dams have a significant detrimental impact on the state of aquatic ecosystems with multiple dams severely impacting on the state of inland waters.

Future pressure on the national water resources are expected to emerge as a result of population growth and economic development in the form of new mines and power stations, forestry and irrigation operations as well as pressures resulting from poor water management. In order to address such domestic, industrial and sustainable water provision requirements, a number of water reconciliation strategies have been drafted. The outputs of these policies aim to supplement existing programmes and effectively harness all available resources particularly in highly stressed water catchments. Such initiatives include the treatment and reuse of wastewater as well as desalination processes. These are the technologies that will be investigated in this study.

2. OVERVIEW OF AVAILABLE TECHNOLOGIES IN SOUTH AFRICA

Water scarcity is due to an imbalance between availability and demand as a result of exponential population growth particularly in the drier regions, industrialization and excessive use for sectors such as agriculture and energy. In order to meet the growing demand and to avert potential damage to ecosystems, water management regimes have to increasingly implement alternative technologies such as reuse of water and desalination.

Reuse of Water

Due to the increasing demand for potable quality water, water recycling has become almost universal. The global installed capacity of water recycling plants is approximately 50 000 ML/d with actual output estimated at about 60% of capacity (5). The results from a EU project in 2006 show that there are 3 300 water reuse plants worldwide with Japan having the largest number (1800) followed by USA (1600) and Australia (450).

In South Africa, it is estimated that there is 1 800 million m^3 of reused water which accounts for 14% of the total available water nationally. This water is processed via one of the more then 1 000 municipal wastewater treatment works that are responsible for the discharge of treated effluent back into the rivers (6). The one instance of direct potable reuse of treated effluent in South Africa is the upgraded plant built for Beaufort West Municipality in the Western Cape in 2010 when the town's main water supply, the Gamka Dam, dried up during a drought (7). The treated wastewater effluent is conveyed directly to a water treatment facility for further treatment to drinking water standard. George and Mossel Bay also built water reclamation plants during the drought with the George plant being an indirect potable reuse (IPR) plant, where the treated wastewater effluent is discharged to the Garden Route Dam for dilution and storage before it is piped to the water treatment plant for further treatment (7). In this case the reclaimed water replenishes the surface water supply. The Mossel Bay plant involves water reclamation for industrial purposes only with the final effluent from the regional wastewater works being treated further to provide the high-quality water needed for the PetroSA refining process.

An example of a successful reuse plant in the eThekwini Municipality is of the Southern Wastewater Treatment Works (SWTW) situated in Merebank. The wastewater that is treated by the reclamation process is predominantly domestic in nature and enters SWTW from the Chatsworth (Umlaas) catchment. Primary and preliminary treatment processes comprised of screening, degritting and primary settling with the discharge being sent to sea via a marine outfall pipeline while secondary works enables a higher quality of treated effluent to be discharged to sea. Tertiary treatment occurs within the Durban Water Recycling Works, which was commissioned in May 2001 and located in the grounds of the SWTW (8). The plant is designed to treat 47.5 Ml/d of domestic and industrial wastewater to a near potable standard for sale to industrial customers such as Mondi and Sapref for direct reuse in their processes (9). Such an initiative was expected to meet 7% of the city's potable water demand and reduce the city's treated wastewater output by 10%.

Reuse of treated mine water for local municipality use is another type of reuse technology that has enjoyed tremenduous growth over the last ten years. The Emalahleni Water Reclamation Plant which is owned and operated by Anglo American Thermal Coal was designed and built to recover potable water from acid mine drainage emanating from several mines in the Witbank region. The plant was successfully commissioned in September 2007 with a capacity of 25 Ml/d (10). Another example is that of the Optimum Water Reclamation Plant which supplies potable water to the Steve Tshwete Municipality (11).

Desalination of Water

With the cost of treating water representing a fraction of the total cost of supplying water to the consumer and the decreasing costs of membrane technology, desalination is fast becoming a viable option to increase supply of fresh water for domestic purposes. Desalination is practiced in 150 countries worldwide with more then 17 000 plants (12). The latest figures from the 19th IDA Worldwide Desalting Plant Inventory indicate that the installed capacity for desalination of seawater approached 24.5 million m^3/d in 2005 with the majority of desalination plants situated in the Arabian Gulf (United Arab Emirates, Saudi Arabia and Kuwait) where low cost energy is available by utilising low-pressure steam discharged from turbines (13).

The national government recognizes the fact that desalination will play a significant role in guaranteeing South Africa's future water supply. As opposed to reuse, the facilitation of desalination can render return flows that are seen as fit for use by a wide range of water users. The main applications of desalination in the South African context are the development of brackish surface water and groundwater as well as seawater into a reliable water source (14).

The technology required in desalination is typically energy intensive, as it does not only facilitate the removal of salts but also a number of other pollutants in the form of metals, nutrients and organics. In South Africa, the majority of electrical power is generated by coal-fired power stations. Unless the availability of sufficient waste heat or low cost fuels is guaranteed, reverse osmosis (RO) will always be the preferred process as opposed to thermal distillation systems in the South African context (15). A project conducted by the Water Resources Commission (WRC) also highlights the fact that significant savings in power consumption can be achieved in RO plants by including energy recovery devices in the plant design (16). The sustainability of desalination projects can also be advanced if such processes are developed in parallel with nuclear energy and renewable energy projects. This would also ensure an improved energy mix for the country's needs.

Desalination is already occurring in South Africa with several plants in operation mainly in the Western Cape. The plant situated in Mossel Bay is South Africa's largest seawater desalination plant to date with a total capacity of 15 Ml/d (17). PetroSA utilizes 5 Ml/d to supplement their supply of industrial process water while the bulk of the water is chemically treated before being fed into the municipal water line as potable water. Another desalination plant of note in South Africa is situated in Knysna and was designed to produce 2Ml/d. Water is abstracted from the lagoon with the generated potable water being pumped into Knysna's reticulation system (18). Other plants include the Plettenberg Bay (design capacity – 1.5 ML/d) and Sedgefield Plant (design capacity – 2 ML/d), which were designed for brackish water and seawater desalination (19). Planning for future desalination facilities is underway as there is scope to grow and commercialise local desalination technology as well as increasing the local content of such projects.

3. CASE STUDIES

The water situation in the KwaZulu-Natal coastal metropolitan areas is dire as water use already exceeds the assured supply of water. This poses a challenge for future water security over the short to medium term period. The state of affairs is compounded by a rapid increase in water demand due to the mass migration of people from rural areas, economic growth and other developments (20). To mitigate this, two water treatment plants have been proposed: the first being a desalination plant funded by Umgeni Water and the second being a wastewater reclamation plant by the eThekwini Municipality.

Umgeni Desalination Plant

The investigation by Umgeni Water was initiated by undertaking a desalination pre-feasibility study to determine the viability of constructing a large scale desalination plant. The ultimate capacity of this plant was set at 450 Ml/d and would be servicing the eThekwini area (21). However, upon further examination, it emerged that there were few points that existed within the water supply infrastructure of the municipality that had the capacity to receive such a large quantity of potable water from a single point desalination plant. In addition, space constraints dictated that a phased implementation of the pipelines would not be possible. With this in mind, a revised strategy was adopted where the detailed feasibility study would consider the option of a 150 Ml/d plant situated on both the North and South Coast (21). This volumetric flow rate was based on the capacity of existing and proposed bulk water supply infrastructure which would be used to convey the final potable water from the desalination plant to the various distribution plants. Through a site selection study which was undertaken by Umgeni Water's Planning Department, two potential sites were identified. The location of these sites would enable the new plants to supplement the Mgeni and Hazelmere systems in the medium term with supply to areas in the various municipalities.

In general, the desalination plants at the selected locations would include the following key components (22):

- Offshore open intake and discharge pipeline with diffusers
- Pipeline and structures conveying intake water to the desalination plant
- Pre-treatment facilities
- Reverse Osmosis systems equipped with energy recovery devices
- Post-treatment systems for re-mineralization and disinfection
- Water storage tanks and pump stations
- Electrical substations connected to power grid.

A significant process in desalination treatment is the pre-treatment of the incoming seawater. In order to select the best pre-treatment method for the water supply in the South Coast, four pilot plant pre-treatment systems are currently being tested in Scottburgh (23). The systems will run simultaneously for a period of one year and will be evaluated based on the final water quality. The main organism that needs to be removed is a specie of plankton called Pico-plankton. This entity can cause major problems in downstream processes by clogging filters and contributing to the turbidity of treated water. They can also cause the production of an undesirable taste and smell of the water and can lead to the formation of assimilable organic matter (23).

eThekwini Wastewater Treatment Plant

The eThekwini Municipality, together with Hitachi, are planning to construct and commission a demonstration and commercial plant that uses treated wastewater as its primary input. To remove contaminants and treat the water to potable water quality, a three-stage system that treats effluent through RO and ultra filtration will be used together with disinfection by ultraviolet light and chlorine (24). The treated water would then be stored and tested before release into the water distribution network.

Before the commencement of the design work, the site location and plant capacity had to be confirmed. In the pre-feasibility study, Central Waste Water Treatment Works (Central WWTW) has been chosen as the project site due to the availability of space through excavation of a hill (25). However, this would substantially affect the cost of the project. According to an article published by the Inter Press Service News Agency, the municipality's senior planning manager states that the purified water will be mixed with conventional drinking water at a ratio of 30% reused water to 70% conventional water. Reusing wastewater in this manner will effectively add 116 Ml/d of tap water to the municipality's supply (24). This will feed the northern regions including areas such as Umhlanga, Durban North, Reservoir Hills and KwaMashu.

4. PLANNED LIFE CYCLE ASSESSMENT OF CASE STUDIES

In order to gauge the environmental impact of the two water treatment processes, the use of an environmental management tool is required. Conducting a Life Cycle Assessment (LCA) of the entire process would provide a comprehensive evaluation of the environmental impact for each stage of the product's life cycle.

A LCA is an analytical tool that is used to determine the potential environmental impact of a product or process by characterising and quantifying the inputs and outputs of a specific system (26). In particular, the procedure provides an evaluation of the product's life cycle from '*cradle to grave*' i.e. from raw material acquisition through production, use, end-of-life treatment, recycling and concluding with final disposal. Thus, an LCA can be utilised to quantify the amount of energy used, the consumption of raw materials, emissions to the atmosphere as well as the amount of waste generated during a product's life cycle (27).

As stated in the ISO 14000 series of documentation, the LCA process is a systematic approach, which consists of four major components namely goal definition and scoping, inventory analysis, impact assessment and interpretation. The first stage involves defining the goal and scope of the study. The goal includes information regarding the intended purpose and application while definition of the scope relates to the provision of sufficient detail to satisfy the stated objectives. This should cover aspects such as the functional unit, the system boundaries that define the product system as well as assumptions and limitations that could potentially affect the assessment. For this study, it is proposed that the functional unit is the production of one kilolitre of water to the stipulated quality for potable water. The second step of the study, being the Inventory Analysis, involves the collection of environmentally relevant data as well as formulation of calculation procedures to quantify inputs and outputs such as raw material usage, energy usage and environmental emissions (26). The end result would take the form of an inventory list for each technology. The process of conducting an inventory analysis is iterative in nature and thus requires the use of a software package capable of modelling data. SimaPro will be utilised for the purposes of this study due to its accessibility at University of KwaZulu-Natal (UKZN). It contains various inventory datasets for the most common processes and materials to aid in the creation of an accurate LCA model (28).

For the impact assessment stage, the data generated from the second phase will be evaluated and related to various relevant environmental impact categories (e.g. global warming, acidification, toxicity, etc.). For each of these impacts, a score will be calculated and the sum of the scores will provide information regarding the environmental profile of that particular technology. As the final phase of the LCA process, the aim of life cycle interpretation is to identify the most significant aspects from the preceding stages, evaluate the selected data and report the conclusions and recommendations in an effective and transparent manner (27).

The use of LCA as an assessment tool to gauge the environmental impacts of water technology has been increasingly used since the late 1990s. A series of studies have shown that energy consumption for the different water processing technologies is critical and is the source of many environmental burdens (29, 30 and 31). In South Africa, it has been proposed that electricity consumption be used as a crude environmental indicator for the performance of urban water systems with an electricity index (e.g. kWh/kℓ) applied to the treatment processes and pumping of water and wastewater (32). Vince et al. (2008) undertook a comparative LCA study of different water treatment processes for the production of potable water (29). Table 1 summarises the results in terms of energy requirements.

Table 1: Range of Electricity Consumption Value for Different Technologies (29)

Potable water production plant life cycle steps	Electricity consumption in kWh/m^3 of potable water	
	Min	Max
Intake pumping	0.05	1
Water treatment process		
Conventional fresh water treatment process	0.05	0.15
UF/MF membrane fresh water treatment process	0.1	0.2
Advanced fresh water membrane treatment process	0.4	0.7
Brackish water desalination (NF, BWRO)	0.6	1.7
Seawater membrane desalination with ERI (SWRO)	3.5	4.5
Seawater membrane desalination without ERI (SWRO)	5.5	7
Thermal desalination (distillation)[a]	6.5	20
Reuse	0.25	1.2
Chemicals production	0.1	0.4
Potable water distribution	0.2	0.8

[a]Electricity + electrical equivalent of heat.

As seen from this table, the energy required by different technologies vary with thermal desalination consuming the most amount of energy (6.5-20 kWh/m^3 of potable water). Seawater membrane desalination utilizing reverse osmosis without energy recovery devices is slightly less energy intensive (5.5 – 7 kWh/m^3 of potable water). In between the treatment of fresh water and desalination of seawater lies the electricity consumption of brackish water desalination. This variance is expected if these or similar technologies are applied in the proposed developments discussed in the case studies.

International LCA studies have shown that the range for the energy needed in wastewater treatment processes is on average about 0.29 kWh/m^3 electricity to produce drinking water from municipal wastewater (33). The LCA studies in the local context (34) show that the recycling of water as undertaken at the Durban Water Recycling Plant needs on average about 0.44 kWh/m^3 electricity to produce industrial water from municipal wastewater. This technology seems to require less energy as compared to the desalination technologies. However, one should also consider the quality of both the incoming water source as well as the treated water (in terms of salinity, suspended matter etc.) as waste water requires more purification compared to fresh water.

Due to the dependence on fossil fuels (as a result of the abundance of coal) for energy generation in South Africa, it is expected that environmental impacts, and in particular Greenhouse Gas (GHG) emissions and associated Global Warming Potential (GWP) will be much higher for all technologies considered in the local context. However, the results of numerous international studies show that GHG emissions could be reduced through the use of renewable energy as a power source (35, 36). Thus, there is substantial potential to mitigate the effects of GHGs by dealing with both energy and water in an integrated way to reach a more sustainable fresh water production.

5. CONCLUSIONS

The current water supply from both groundwater and surface water is insufficient to meet the domestic and industrial requirements in South Africa. Internationally, there has been progress in the utilisation of alternative technology to bridge the gap between supply and demand. In South Africa, there are a number of smaller plants using, amongst other technology, desalination and wastewater reclamation. It has been proposed that the construction of two new plants in the eThekwini area would assist with the dire water situation. In order to fully quantify the environmental impact of both technologies, a LCA should be conducted. Previous LCA studies indicate the electricity required for potable water production is the main source of environmental impacts. A comparison of the various water treatment technologies reveal that desalination is the most energy intensive process. However, the expected impact of global warming for the study is expected to be higher for the proposed plants due to the energy mix in South Africa. It is recommended that alternative energy sources such as wind and solar energy be utilised to decrease the environmental burden of the future water treatment plants.

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