International Journal of Applied Engineering Research ISSN 0973-4562 Volume 14, Number 7 (2019) pp. 1474-1483

Analysis on Industrial and Domestic Wastewater in South Africa as a Water-Scarce Country

JK Bwapwa,
Mangosuthu University of Technology, Engineering faculty, Department of Civil Engineering, P.O Box 12363, Jacobs 4026, Umlazi, Durban, South Africa.

Abstract

Water resources in a country such as South Africa constitute a very precious asset to be managed usefully. Water is one of the most important resources for human life used domestically and industrially, therefore, water scarcity can seriously affect the country's economy because manufacturing and industrial sectors are known to the biggest water consumers. Furthermore, water can be a key component in generating clean, renewable and environmentally friendly energy reducing sensibly the impact of environmental pollution. South Africa is not a water- rich country, despite its well performing and growing economy, water situation remains a concern. Being among the world driest countries, the country relies on rain water and rivers to harvest the necessary amount of water to face various challenges due to water scarcity. There is a necessity to manage adequately existing water resources and develop efficient technologies. In this regard, the current wastewater treatment infrastructure including the technology need to be upgraded to face high demand of water for use at industrial and domestic levels. An urgent need to develop innovative ways for efficient treatment of water resources in order to prevent a crisis in the next decade is required. Therefore, analyses from preliminary, physical, biological up to chemical treatment is important to model and design appropriate system and monitor them for an optimal efficiency. This analysis focuses on various aspects such as treatment methods for industrial and domestic wastewaters, the current water situation and state of water infrastructures in South Africa.

Keywords: water resources, water scarcity, preliminary treatment, physical treatment, biological treatment, chemical treatment

1. INTRODUCTION

Water situation in South Africa

South Africa just like many other industrialized countries is in challenging situation when it comes to its water resources (Wright and du Toit, 1996; Naik , 2017). As the country's population grows, more people migrate to urban areas putting additional pressure on the available water resources (Gleick, 2000) Also, the level of industrialization in the country has reached an advanced level due to an impressive growing and strong economy in which there is a very high demand of water for industrial and domestic activities. In addition, Climate change is another factor that contributes to South Africa water shortage situation and this is also valid for many other countries in the similar situation (Adewumi et al., 2010; Ricart Casadevall et al., 2019; Gosling and Arnell, 2016). Country's sources of water supply depend on rain, and during the droughts water resources are not getting replenished (Adewumi et al., 2010, Bwapwa, 2017). The existing resources are also getting contaminated by pollution (Adewumi et al., 2010; Bwapwa, 2017). Two main sources that contribute to water contamination include industrial wastewater and human wastewater from domestic sources. Because of water contamination municipalities have to recycle raw water from domestic and industrial activities (Adewumi et al., 2010). The situation of water scarcity in South Africa is very serious because the country is among the world 30 driest countries with less than 450 mm of rainwater per year. This is very low compared to the global average of 860 mm per year.

A specific approach needs to be implemented to prevent a crisis that can affect lives of millions of people and the country's economy

South Africa's water per capita is 1 000 m^3 /person/year, the comparison between South Africa and neighbouring countries shows that their available water per capita is much greater compared to the South African's one. Also, the country's annual runoff is approximately 43 500 million m^3 on average with the annual yield estimated at 13227 million m^3 (DWAF, 2004a). The demand for clean water is growing due to the industrialisation, modernization and fast population growth. Scarcity and quality of water can be a significant issue; however, storage of water is not a challenge, the country has many options including reservoirs or lakes, boreholes, and the current dams. However, more dams still need to be built, the existing 569 dams with a capacity beyond 1 million m^3 per unit, generating a total of 32400 million m^3 of water, are not sufficiently enough to sustain the water demand nationally. It is indispensable to add the fact that big dams collect nearly 70% of the regular runoff on yearly basis (DWAF, 2004a). Also, many dam designs countrywide do not allow the discharge of sufficient water to meet the needs of the reserve; therefore, there is a need for more dams and more treatment infrastructures must be built and maintained regularly (Bwapwa, 2015). The current water treatment infrastructures are aging building new ones is a necessity.

This review analyses various aspects such as treatment technology for industrial and domestic wastewaters. The treatment infrastructures and the quality of effluents from selected sites are also part of this overview study.

Types of industrial and domestic wastewaters

The composition of wastewater is very important when it comes to designing the most efficient treatment process (Ras and Von Blottnitz, 2012). Industrial and domestic wastewaters in South Africa have very different content (Ras and Von Blottnitz, 2012; Harding, 2018) and the particular characteristics of wastewater depend on its source. Industrial waters have contents that depend on the type of industry and the characteristics of the catchment area (Ras and Von Blottnitz, 2012). Specifically, industrial wastewaters could include some very high concentrations of organic matters both bio-degradable and non-biodegradable. The industrial wastewaters often lack nutrients in them and have high percentage of heavy metals, especially industrial waters coming from the mining industry (Ras and Von Blottnitz, 2012; Masindi and Abiye,, 2018). In addition, industrial wastewaters flow patterns are very different from the domestic wastewater, mainly because it depends on shifts due production and quality requirements.

Composition of various industrial and domestic wastewaters and its physical, biological and chemical characteristics

As it was mentioned before, the composition of industrial wastewater differ depending on its type, i.e. industrial versus domestic. Industrial wastewaters are devoid of nutrients, but could have high levels of suspended solids and heavy metals. The municipal and domestic waters have very different content as characterization is based on three main factors: nitrogenous, phosphorous and organic components (Struyf et al., 2011; Ravndal et al., 2018). In regard to chemical oxygen demand (COD) wastewaters are characterized based on three components: active biomass, biodegradable and non-biodegradable components (Mhlanga and Brouckaert, 2013; Asperger et al., 2018). Table 1 shows the COD data of wastewaters collected in three different areas. In this table it is observed that the highest values of COD were slowly biodegradable COD. This is an indication of high biological activity taking place in the effluent.

Table 1: COD fractions of effluent collected from the Marianridge, Darvill and Hammarsdale WWTP (adapted from Mhlanga and Brouckaert, 2013)

Description	%Total COD in influent wastewater		
	Marianridge WWTP	**Darvill WWTP**	**Hammarsdale WWTP**
Soluble inert organics, S_I	7.5	7.3	5.2
Readily biodegradable substrate, X_s	18.1	19.1	14.6
Slowly biodegradable substrate , X_S	44.2	36.8	59.4
Inert particulate organics,X_I	15.6	36.7	5.3
Heterotrophic biomass, X_H	14.6	Not determined	15.6

Domestic wastewater is usually sewage that has very different composition as well. It is mainly water that comes from several sources (street runoff and groundwater), bacteria (mainly coliforms) and phosphorus (Table 2) (Eddy, 2011). In addition, it has nitrogen; some suspended solids, organic substances and trace elements, although typically domestic wastewaters do not have heavy metals in such high concentrations that are found in industrial wastewaters (Eddy, 2011).

Table 2: Typical sewage composition (adapted from Eddy,2011)

Constituent	Sources	Typical concentration
Water	Including groundwater that may leak into sewer infrastructure as well as runoff from streets	99%
Microorganisms	Faecal coliforms such as Echerichia coli	10000000 E-coli per 100 ml
Phosphorus	Present in human wastes and detergents	10-15 mg/l

Impacts of wastewater on human health and aquatic life

It is not surprising that wastewaters could pose significant risks to both human health and the environment, especially aquatic environment. Furthermore, wastewaters (both industrial and domestic) could cause significant ecological damages (Mhlanga and Brouckaert, 2013; Kupoluyi et al.,2018; Halder and Islam,2015). For example, suspended solids that are found in domestic and industrial wastewaters could cover water bodies like rivers and lakes (Mhlanga and Brouckaert, 2013; Dolph et al., 2017). Such cover will impede proper respiration by benthic fauna and flora. There are many other additional negative effects on the aquatic life. For example, proteins and other substances with nitrogen tends to breakdown and release ammonia (Mhlanga and Brouckaert, 2013). Ammonia has been constantly shown to be extremely toxic substance for aquatic animals, and it can create extremely negative impact even at low levels. Additionally, domestic waste waters have been shown to significantly impact dissolved oxygen in aquatic environments (Mhlanga and Brouckaert, 2013; Sancho et al., 2017). In some cases the organic pollution levels are very high that aquatic sources become completely devoid of oxygen. As a result, the aquatic life dies off because the entire body of water is now putrefied and contains hydrogen sulphide (Mhlanga and Brouckaert, 2013). Another impact is the promotion of harmful algae growth in aquatic sources that come in contact with wastewaters. The aquatic sources that come in contact with nitrogen and phosphorus rich wastewaters develop uncontrollable algae blooms that could be toxic to nearly all aquatic life. Add this to reduced oxygen levels and results become disastrous (Mhlanga and Brouckaert, 2013). Heavy metals form industrial wastewaters create another danger for both aquatic life and human life (as it will be discussed below). Heavy metals tend to bio-accumulate and make their way up to food chain affecting all aquatic life in a negative way as they are hazardous to health (Mhlanga and Brouckaert, 2013; Qureshi et al., 2016). Wastewaters are also detrimental to human health and as mentioned before, in South Africa wastewaters have been increasingly contaminating water sources, making it more expensive to recycle (Odjadjare and Okoh, 2010). When water sources are contaminated with wastewater it poses significant risk as people get sick from both bacteria and viruses resent in water sources (Igbinosa et al., 2011). The gastrointestinal problems are the most common one, especially when waters are contaminated with coliforms (Igbinosa et al., 2011). Similarly, the long-term use of water that contains heavy metals from industrial wastewaters leads to additional health problems.

Relationship between global warming and wastewater

Climate change poses a significant risk to the issue with wastewaters and it is especially true for South Africa (Friedrich and Kretzinger, 2012; Schoen et al., 2017). Two main manifestations of global warming are particularly relevant for the issue of wastewaters: sea level rise and flooding inland. In this regard South Africa is particularly vulnerable as it has extensive coastline and many cities and urban centers are located near the coastline (Friedrich and Kretzinger,2012). With regard to climate change research showed that water rise and inland flooding will cause the blockage of many wastewater systems and create the overflow problems as well. One study specifically investigated one municipality that is located on South Africa East Coast: the eThekwini Municipal Area (Friedrich and Kretzinger,2012). It was selected for the study as it processes a lot of waste waters and also because of its coastal location. The study used the projections that the sea level will raise by nearly 3 m over next 100 years (Friedrich and Kretzinger,2012). The results showed that some structures and wastewater facilities are more vulnerable than others such as for example the Point Road pumping station. The main factors that contribute to the vulnerability are proximity to the coast, size, number and size of underground structures and connectivity (Friedrich and Kretzinger,2012). On a positive side the study found that during the initial stages of sea level rise the municipality will be able to cope successfully and will have some time to prepare and implement necessarily measures. Another important factor that was discussed in this study was that it appears that the effect will be no uniform and some waste treatment plants and facilities will be affected more than others (Friedrich and Kretzinger,2012).

2. ANALYSIS OF THE SITUATION

Critical analysis of treatment technologies and processes

Wastewater treatment industry in South Africa has its own very pronounced peculiarities. One such peculiarity is that the majority of water treatment and wastewater facilities in South Africa are quite small (Figure 1) (Snyman et al.,2006).

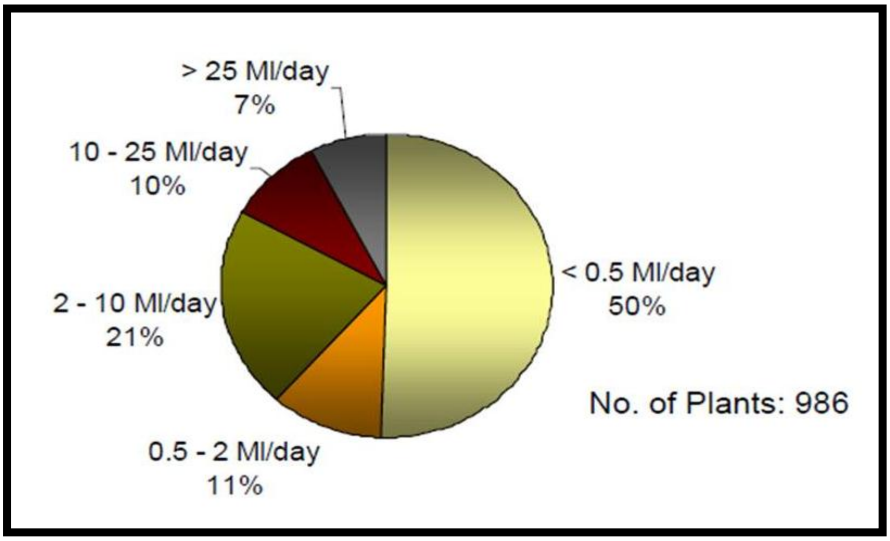

Figure 1: Chart representing the distribution of wastewater treatment plants in South Africa (Snyman et al.,2006).

They also have very modest processing capabilities and financial abilities, especially when it comes to some rural areas (Snyman et al.,2006). It is a big problem though as the mining industry is also often located in rural areas and they generate a lot of industrial wastewaters that small scale wastewater facilities have a lot of troubles dealing with (Ras and Von Blottnitz, 2012). Contrarily, urban areas tend to have bigger wastewater treatment facilities that not only much larger but also have better and more effective equipment and technology (Ras and Von Blottnitz, 2012). Hence the main challenges that the wastewater treatment industry faces in South Africa is these rural/urban discrepancies and also numerous issues with technology and maintenance (Snyman et al.,2006). One South Africa national surveys investigated 51 wastewater treatment facilities and concluded that over 50% lacked professional and highly skilled personnel, over 35% of plants needed significant investment in infrastructure and technology among other findings (Bwapwa , 2017 ; Snyman et al.,2006). In regard to flow characteristics the survey discovered the presence of significant overflow (18%), overload with nutrients/organic matters (22%) and many plants already run at the peak capacity (Figure 2) (Snyman et al.,2006).

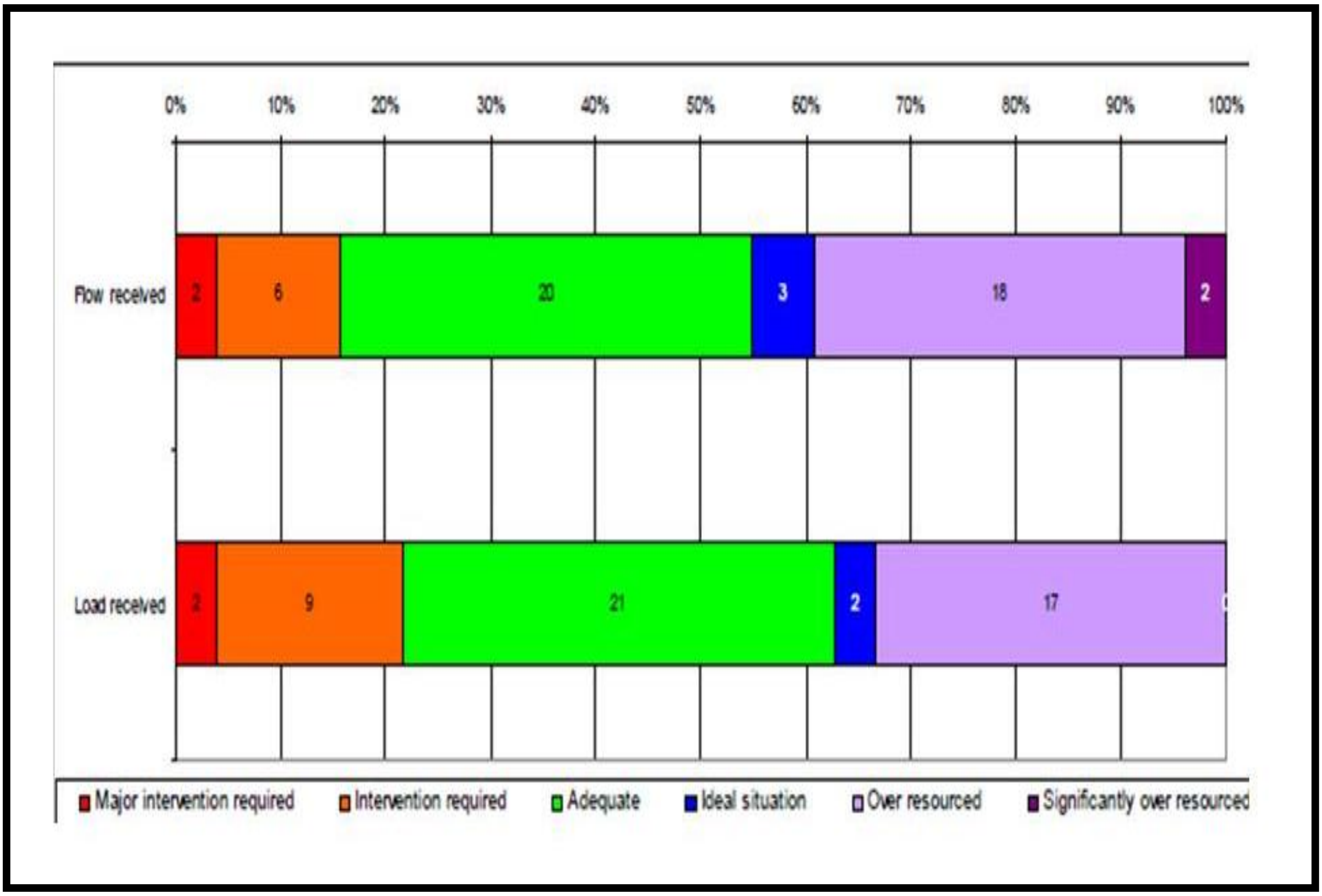

Figure 2: Level of intervention required for wastewater treatment plants in South Africa (Snyman et al.,2006)

Advantages and disadvantages

The current wastewater treatment technologies that are being used in South Africa have some definite advantages namely the fact that these are well-tested and well-researched technologies that have been used extensively all over the world (Mara and Horan, 2003). For example, screening and grit removal are both simple yet effective technologies that have been used extensively for dealing with grit all over the world. Disinfecting with chlorine has been also extensively used all over the world as it has been proven to be one cheap and effective way to disinfect water (Mara and Horan, 2003). Maturation ponds have been proven to be extremely important for disinfection and polishing (Haarhoff and Van der Merwe,1996). The clear disadvantages of the currently used technologies is that they are either outdated or even not used appropriately as the personnel is not skilled and cannot operate and maintain the equipment properly. Recent survey showed even worse situation arguing that over 300 plants in fact lack suitable technology to properly treat wastewaters. The problem with newer technologies is that not only it costs more (and many rural facilities and small operators cannot afford it), but it also requires more energy and more importantly highly skilled and educated personnel which is a big issue in South Africa (Snyman et al.,2006). This survey also showed that more often than not the poor performance and equipment failure results not from inadequate technology, but from improper operation and maintenance (Snyman et al.,2006). Hence it seems that at least to some extent the problem is not the technology and equipment but issues with operation and maintenance.

Comparison of some treatment methods

Comparing methods based on their merits and demerits will help decision makers and engineers to choose an efficient and appropriate wastewater treatment process. This comparison is aiming to show how good a particular treatment method is for a specific condition regarding the type of wastewater. The major criterion for comparison and choice making is based on the efficiency in terms of contaminants removal, treatment effectiveness, capital and operating costs. Table 3 presents a summary of some treatment processes including their merits and demerits.

Table 3: Treatment methods, advantages and limitation (adapted from Ifeanyichukwu, 2008)

	Treatment method	advantage	limitation
1	**Biological methods** • Activated sludge	BOD removal: 90% COD removal : 83-97 %	-Relatively high capital costs , need of high skilled labor, - High sludge production that must be treated before disposal -Control of sludge settling is very challenging
	• Rotating biological contactor (RBC)	Low energy consumption , simple to operate , require less maintenance than the activated sludge	-The performance of this method is generally lower than that with activated sludge. However, realistic dimensioning will allow satisfactory qualities of treated water to be reached. -Its capital cost can be 20% higher than that of activated sludge (J. Wiszniowski et al, 2005)
	• Sequencing Batch Reactor (SBR)	-Energy is optimized through control of aeration rate and duration. -Secondary clarifiers are eliminated. -It occupy less space than the activated sludge -very flexible in terms of adjusting reaction time and tank volume to meet variable loading	-Requires skilled personnel and need to be monitored regularly
	• Reed Beds	-Low energy requirements , operational and maintenance costs -Great capacity in treating very low or intermittent flows	-High demand for land or space than in previous methods : need large space -No standards in terms of design
	• Biological Aerated Filters (BAF)	-Elimination of secondary clarifiers removing all the associated costs and operational problems -High removal of ammonium and nitrogen (up to 97%)	-Poor COD removal, the effluent will require a polishing step to meet discharge standards
	• Lagoons	-High treatment efficiency more especially for aerated lagoons. COD removal can be up to 97% -Technically and economically viable at large scales	-High energy consumption - Occupy large space
	• Upflow anaerobic sludge blanket (UASB)	-Low energy consumption - small amount of generated sludge -Biogas production -low operating costs	-challenging start up, need of inoculation and seeding - need an appropriate culture of microorganisms for the anaerobic process to be effective - sensitive to pH and temperature changes
	• Anaerobic filters (AF)	-Low costs and less operational problems due to the Elimination of secondary clarifiers	-Challenging backwashing, there is a need to monitor this operation to

	Treatment method	advantage	limitation
			ensure that a healthy biomass is retained on the support media
	• Moving bed biofilm rector (MBBR)	Uniform and highly effective treatment.	Mechanical stirrer used to ensure that the beds are moving for uniform treatment can make the energy cost higher
	• Membrane Bioreactor (MBR	Great BOD and COD removals 80 and 85% respectively	Membrane fouling and high operating costs
2	**Physicochemical Methods** • Precipitation	 -Suitable for phosphates, nitrates and heavy metals removal -Suitable for pre-treatment to remove high strength ammonia and nitrogen before the biological process	 -Poor COD removals (less than 50%) -Operating costs may be higher because of the use of chemicals
	• Coagulation-Flocculation	COD removal can reach up to 75% for medium and old leachates	-Low COD removals for young leachates (25-38%) - Operating may be higher for coagulation chemicals to be used in the process.
	• Flotation	Appropriate method to remove humic acid after biological treatment. The removal is up to 99%	-Very high operating costs
	• Adsorption	COD removal from old leachates can be up to 70%	Poor COD removal for young leachates
	• Chemical Oxidation and Advance Oxidation Process.	-The Fenton Process in particular is a simple technology, the iron and hydrogen peroxide that are used are cheap. -used to remove refractory organic compounds from leachates after biological treatment. -COD removal efficiency can range from 45-85%	- some types of this method require high demand of electricity for devices such as ozonizers and UV lamps, resulting in high treatment cost. high oxidant doses are needed to achieve complete degradation of pollutants
3	**Combined Biological and Physicochemical Method.**	Can achieve high COD and solid removals because this method combined biological and physic-chemical methods	Capital and operating costs may be higher due to multiplicity of unit processes.
4	**Membrane Technology** • Microfiltration (MF)	 Used to remove dyes, bacteria, oil emulsion, particles size from 0.1 to 10 microns , - acts as pre-treatment for other membrane processes	 Membrane fouling and maintenance costs can be higher
	• Ultrafiltration (UF)	-Used to fractionate organic matter , remove virus , colloidal substances , particle sizes from 0.01 to 0.1 micron -acts as a pre-treatment for reverse osmosis	Membrane fouling and maintenance costs can be higher
	• Nanofiltration (NF)	-Used to remove aqueous salts, synthetic dyes, sugars, particles size from 0.01 to 0.001	Membrane fouling and maintenance costs can be higher
	• Reverse Osmosis (OR)	-Very high quality of generated effluent, -Very high COD removal (up to 99%)	Membrane fouling, high maintenance and costs and high capital costs.

3. DISCUSSION

Numerous surveys performed recently show that the current technologies are inadequate for two main reasons: they are either outdated or not used and maintained properly resulted in poor performance or failure (Snyman et al.,2006). Specifically, studies showed that flow balancing is not done properly or lacking in many facilities. Maturation ponds are either lacking or totally not used properly as they are being overfilled with sludge and reeds (Figure 3) (Snyman et al.,2006). Many facilities do not even have maturation ponds as they do not understand how important they are for disinfection and polishing (Haarhoff and Van der Merwe,1996).

Figure 3: Example of maturation pond filled with sludge (Snyman et al.,2006)

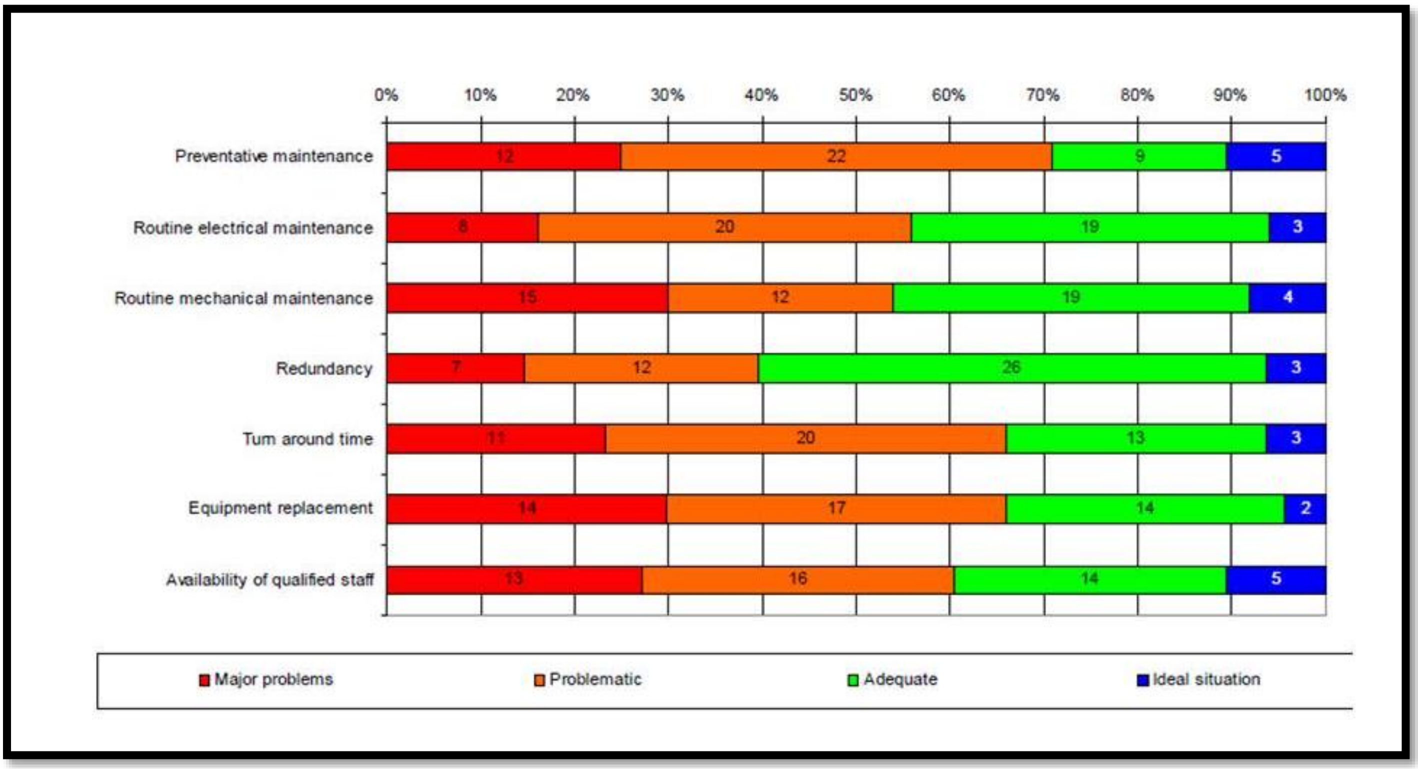

Figure 4: Statistics on the operational state of various wastewater treatment plants (Snyman et al.,2006)

The disinfection step is the major problem in over 60% of facilities that have been surveyed. The problems stem from wrong design of disinfection facilities, wrong use of disinfection technology and problems with managing chlorine. Over 20% of surveyed facilities do not properly use screening to deal with grit (Snyman et al.,2006). Pond systems are also not utilized properly and rely mainly on long and extended aeration. Sludge is often just let to sit and dry out without any efforts to disinfect it. In fact, over 80% of surveyed plants did not dispose sludge in safe and required way (Snyman et al.,2006). Amazingly, survey also noted that none of the surveyed plants showed required compliance with disposing sludge as required by SA Sludge Guidelines Snyman et al.,2006. One of the most significant issues that have been discovered during surveys is the issues with maintenance. Figure 6 shows the results (Snyman et al.,2006).

In over 30% the maintenance was so bad that it required urgent intervention (Snyman et al.,2006). Only 10% of plants maintained decent maintenance and over 60% needed some sort of intervention. As a result, the environmental impacts of all these issues have been very significant as shown on Figure 5 (Snyman et al.,2006).

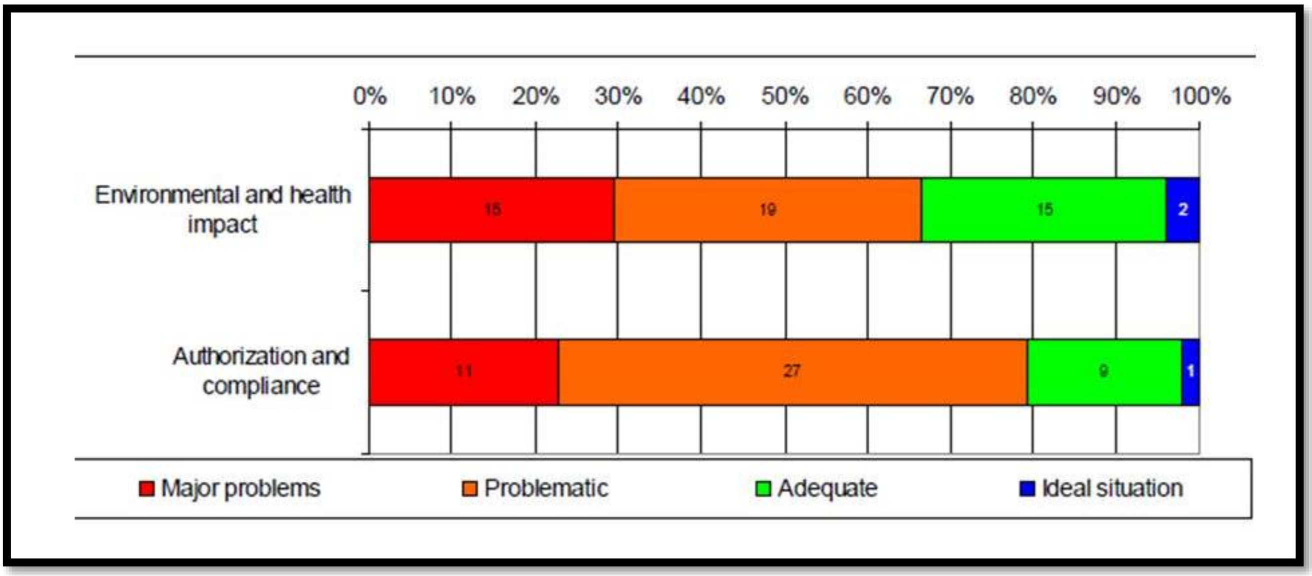

Figure 5: Environmental, health impact and compliance regarding wastewater treatment plants in South Africa (Snyman et al.,2006)

Clearly the South Africa's wastewater treatment technology can be improved. For example many wastewater facilities in Europe and other countries use reverse osmosis to treat wastewaters (Harding, 2018). This process is very efficient yet it is expensive and the technology is sophisticated (Bartels et al.,2005). Similar can be said about UV disinfection that is better than chlorine, yet it is also more expensive and the personnel needs a lot of training to operate it properly Gehr et al.,2003. Based on data and results outlined in this study it appears however that South African wastewater treatment facilities will not necessarily benefit from more modern and expensive technology because they lack trained and skilled personnel that will be needed to operate and maintain the technology that will be even more sophisticated (Snyman et al.,2006). Current technology in use has good track records (i.e. chlorination, maturation ponds, sludge disposal, etc), this technology has been well tested and can deliver decent results (Grady et al.,2011). Yet even with this existing technology the personnel fail to use and maintain it properly. Hence, investing in technology without training and supervising personnel will be counterproductive and frankly a waste of money at this point. In summary, it appears that at this point that the major problem with current South African wastewater technology is not the technology per se, but the ways it is used and maintained.

4. CONCLUSIONS

The issue of water resources is an important problem that South Africa and the entire continent is currently facing. As the population grows it requires more water resources and puts the strain on existing water resources. The climate change and global warming put additional strain on water resources. The problem is made worse by constant contamination of water sources by both industrial and domestic wastewaters. Domestic and industrial waters have different composition where domestic wastewaters have more organic content, while industrial wastewaters have more heavy metals in it. The treatment also differs, yet many small rural treatment facilities are ill equipped to deal with heavily contaminated industrial wastewaters from mining operations. The effect of wastewaters on the environment is detrimental as it negatively affects both human health and aquatic ecosystems. For that reason, treatment is extremely important. The current wastewater treatment technology is somewhat outdated yet it cannot be even properly used and maintained in its current form. The examples include inappropriate use of chlorination process or the lack of use of very important maturation ponds and so on. Most troubling however is the fact that the personnel is poorly trained and not skilled enough to even properly operate the existing and somewhat outdated technologies. Not only they are not operated properly, they are also not maintained properly delivering poor or plain failed performances. While the more sophisticated technologies exist like for example reverse osmosis, it is not clear if South Africa will benefit from them at this stage as the personnel clearly has troubles operating even less sophisticated and widely used wastewater treatment technologies.

REFERENCES

[1] Adewumi, J. R., Ilemobade, A. A., & Van Zyl, J. E. (2010). *Treated wastewater reuse in South Africa: overview, potential and challenges*. Resources, Conservation and Recycling, 55(2), 221-231. .https://doi.org/10.1016/j.resconrec.2010.09.012

[2] Ašperger, D., Dolar, D., Košutić, K., Kušić, H., Božić, A.L. and Domanovac, M.V., 2018. 8 Water and wastewater treatment engineering. *Environmental Engineering: Basic Principles*.

[3] Bartels, C., Wilf, M., Andes, K., & Iong, J. (2005). *Design considerations for wastewater treatment by*

reverse osmosis. Water Science & Technology, *51*(6-7), 473-482. https://doi.org/10.2166/wst.2005.0670

[4] Bwapwa, J. K. (2015). Investigation and analysis on key issues deteriorating water quality in a water-scarce country: Case of South Africa, Michigan state university, USA, September 2015, International conference on natural resources management.

[5] Bwapwa, JK ,(2018), Review on Main Issues Causing Deterioration of Water Quality and Water Scarcity: Case Study of South Africa , Environmental Management and Sustainable Development , Vol. 7, No. 3

[6] Dolph, C.L., Hansen, A.T. and Finlay, J.C., 2017. Flow-related dynamics in suspended algal biomass and its contribution to suspended particulate matter in an agricultural river network of the Minnesota River Basin, USA. *Hydrobiologia*, *785*(1), pp.127-147. https://doi.org/10.1007/s10750-016-2911-7

[7] DWAF (Department of Water Affairs and Forestry). (2004a). National water resource strategy. First edition. September 2004. Department of Water Affairs and Forestry: Pretoria, South Africa.

[8] Eddy, L. J. (2011). *Sewage wastewater management in South Africa* (Doctoral dissertation).

[9] Friedrich, E., & Kretzinger, D. (2012). *Vulnerability of wastewater infrastructure of coastal cities to sea level rise: A South African case study*. Water SA, 38(5), 755-764. https://doi.org/10.4314/wsa.v38i5.15

[10] Gleick, P. H. (2000). *A look at twenty-first century water resources development*. Water International, *25*(1), 127-138. https://doi.org/10.1080/02508060008686804

[11] Gehr, R., Wagner, M., Veerasubramanian, P., & Payment, P. (2003). *Disinfection efficiency of peracetic acid, UV and ozone after enhanced primary treatment of municipal wastewater*. Water research, *37*(19), 4573-4586. https://doi.org/10.1016/S0043-1354(03)00394-4

[12] Gehr, R.L., 2018. *Theory and practice of water and wastewater treatment*. Wiley-Blackwell.

[13] Gosling, S.N. and Arnell, N.W., 2016. A global assessment of the impact of climate change on water scarcity. *Climatic Change*, *134*(3), pp.371-385. https://doi.org/10.1007/s10584-013-0853-x

[14] Grady Jr, C. L., Daigger, G. T., Love, N. G., Filipe, C. D., & Leslie Grady, C. P. (2011). *Biological wastewater treatment* (No. Ed. 3). IWA Publishing.

[15] Haarhoff J, Van der Merwe B. Twenty-five years of wastewater reclamation in Windhoek, Namibia. Water Science and Technology. 1996 Jan 1;33(10-11):25-35. https://doi.org/10.2166/wst.1996.0658

[16] Halder, J.N. & Islam, M.N., 2015. Water pollution and its impact on the human health. *Journal of environment and human*, *2*(1), pp.36-46.

[17] Harding, G.E., 2018. *Developing methods to access sensitive industrial wastewater information in South Africa (with treatment in mind)* (Doctoral dissertation, University of Cape Town).

[18] Ifeanyichukwu MJ.(2008), *New leachate treatment methods*, Master's thesis , water and environmental engineering , department of chemical engineering , Lund University , Sweden

[19] Igbinosa, E. O., Obi, C. L., & Okoh, A. I. (2011). *Seasonal abundance and distribution of Vibrio species in the treated effluent of wastewater treatment facilities in suburban and urban communities of Eastern Cape Province*, South Africa. The Journal of Microbiology, 49(2), 224-232. https://doi.org/10.1007/s12275-011-0227-x

[20] Kivaisi, A. K. (2001), *The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review*. Ecological Engineering, 16(4), 545-560. https://doi.org/10.1016/S0925-8574(00)00113-0

[21] Kupoluyi, A.Y., Alarape, S.A. & Adeyemo, O.K., 2018. Impact of industrial effluents on Alaro river in Oluyole industrial estate, Ibadan and its suitability for aquatic life. *Sokoto Journal of Veterinary Sciences*, *16*(1), pp.38-44. https://doi.org/10.4314/sokjvs.v16i1.6

[22] Lettinga, G. (1996), *Sustainable integrated biological wastewater treatment*, Water Science and Technology, *33*(3), 85-98. https://doi.org/10.2166/wst.1996.0061

[23] Mara, D., & Horan, N. J. (Eds.). (2003). *Handbook of water and wastewater microbiology*. Academic press.

[24] Masindi, K. and Abiye, T., 2018. Assessment of natural and anthropogenic influences on regional groundwater chemistry in a highly industrialized and urbanized region: a case study of the Vaal River Basin, South Africa. *Environmental earth sciences*, *77*(20), p.722. https://doi.org/10.1007/s12665-018-7907-3

[25] Mhlanga, F. T., & Brouckaert, C. J. (2013). *Characterisation of wastewater for modelling of wastewater treatment plants receiving industrial effluent*. Water SA, 39(3), 403-408. https://doi.org/10.4314/wsa.v39i3.9

[26] Naik, P.K., 2017. Water crisis in Africa: myth or reality?. *International Journal of Water Resources Development*, *33*(2), pp.326-339. https://doi.org/10.1080/07900627.2016.1188266

[27] Nataraj, S. K., Hosamani, K. M., & Aminabhavi, T. M. (2006). *Distillery wastewater treatment by the membrane-based nanofiltration and reverse osmosis processes*. Water Research, 40(12), 2349-2356. https://doi.org/10.1016/j.watres.2006.04.022

[28] Odjadjare, E. E. O., & Okoh, A. I. (2010). *Prevalence and distribution of Listeria pathogens in the final effluents of a rural wastewater treatment facility in the Eastern Cape Province of South Africa*. World Journal of Microbiology and Biotechnology, *26*(2), 297-307. https://doi.org/10.1007/s11274-009-0174-4

[29] Qureshi, A.S., Hussain, M.I., Ismail, S. and Khan, Q.M., 2016. Evaluating heavy metal accumulation and potential health risks in vegetables irrigated with treated wastewater. *Chemosphere*, *163*, pp.54-61. https://doi.org/10.1016/j.chemosphere.2016.07.073

[30] Ras, C., & Von Blottnitz, H. (2012). *A comparative life cycle assessment of process water treatment technologies at the Secunda industrial complex*, South Africa. *Water SA*, *38*(4), 549-554. https://doi.org/10.4314/wsa.v38i4.10

[31] Ravndal, K.T., Opsahl, E., Bagi, A. and Kommedal, R., 2018. Wastewater characterisation by combining size

fractionation, chemical composition and biodegradability. *Water research*, *131*, pp.151-160. https://doi.org/10.1016/j.watres.2017.12.034

[32] Ricart Casadevall, S., Rico, A. and Ribas Palom, A., 2019. Risk-Yuck Factor Nexus in Reclaimed Wastewater for Irrigation: Comparing Farmers' Attitudes and Public Perception.

[33] Sancho, I., Licon, E., Valderrama, C., de Arespacochaga, N., López-Palau, S. and Cortina, J.L., 2017. Recovery of ammonia from domestic wastewater effluents as liquid fertilizers by integration of natural zeolites and hollow fibre membrane contactors. *Science of the total environment*, *584*, pp.244-251. https://doi.org/10.1016/j.scitotenv.2017.01.123

[34] Schoen, M.E., Xue, X., Wood, A., Hawkins, T.R., Garland, J. and Ashbolt, N.J., 2017. Cost, energy, global warming, eutrophication and local human health impacts of community water and sanitation service options. *Water research*, *109*, pp.186-195. https://doi.org/10.1016/j.watres.2016.11.044

[35] Snyman, H., Van Niekerk, A. M., & Rajasakran, N. (2006, May). *Sustainable wastewater treatment–what has gone wrong and how do we get back on track*?. In Proc. WISA 2006 Conference. Water Institute South Africa, Midrand, SA.

[36] Struyf, E., Bal, K. D., Backx, H., Vrebos, D., Casteleyn, A., De Deckere, E., ... & Meire, P. (2012). *Nitrogen, phosphorus and silicon in riparian ecosystems along the Berg River (South Africa): The effect of increasing human land use*. Water SA, 38(4), 597-606. https://doi.org/10.4314/wsa.v38i4.15

[37] Wright, A., & du Toit, I. (1996). *Artificial recharge of urban wastewater, the key component in the development of an industrial town on the arid west coast of South Africa*. Hydrogeology Journal, 4(1), 118-129. https://doi.org/10.1007/s100400050101