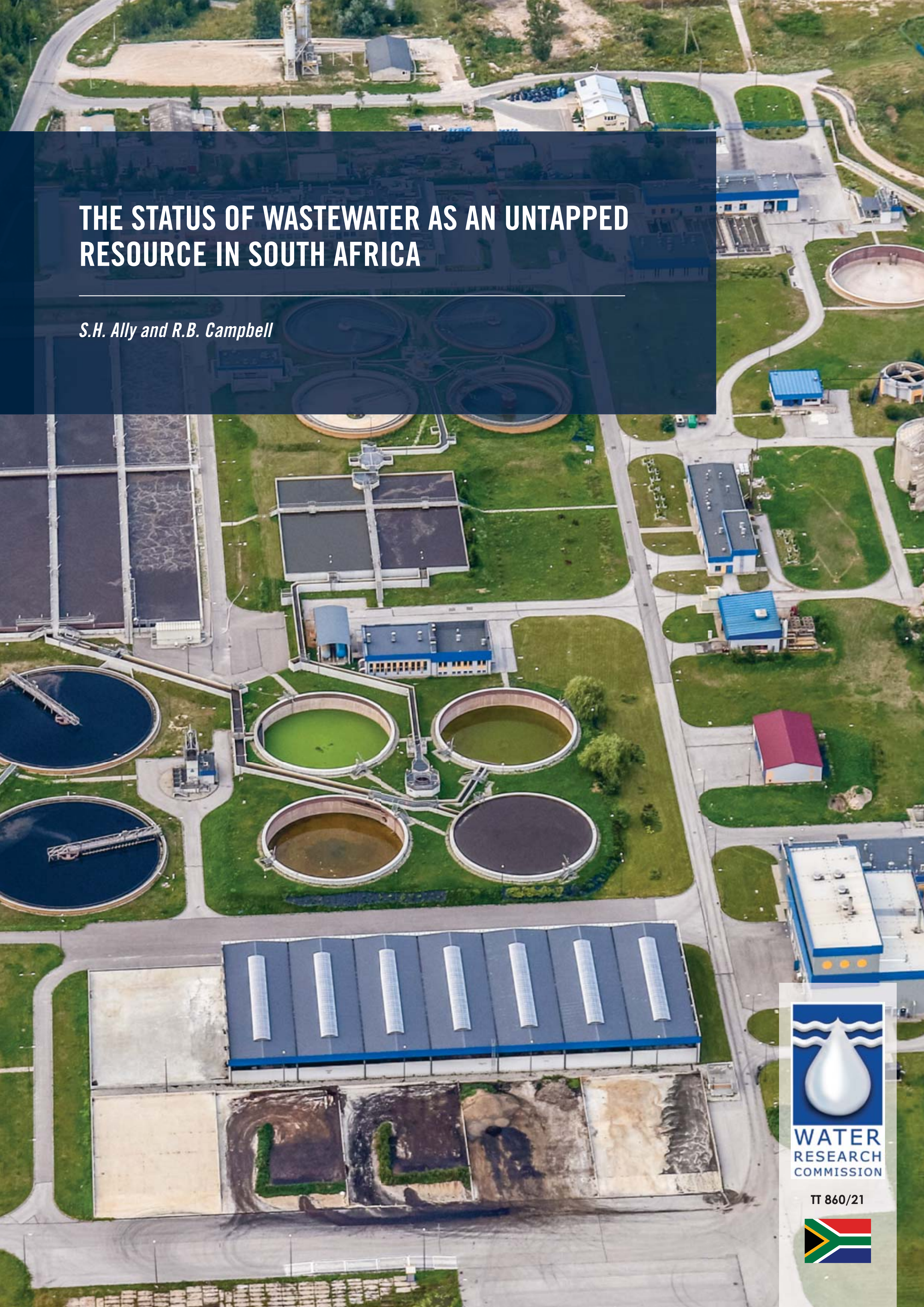

THE STATUS OF WASTEWATER AS AN UNTAPPED RESOURCE IN SOUTH AFRICA

S.H. Ally and R.B. Campbell

WATER RESEARCH COMMISSION

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Water Research Commission

by

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Coexist Science (Pty) Ltd

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EXECUTIVE SUMMARY

This study reviews municipal wastewater management in South Africa and assesses the country's progress toward the United Nations Sustainable Development Goal 6 (SDG6), specifically SDG Target 6.3, which defines indicators for sustainable management of wastewater and ambient water quality. The study's starting point is that wastewater should be seen as an "untapped resource", rather than a liability. The project's aims are:

1. To map out current challenges associated with sustainable wastewater management, including quantifying the national environmental and health impacts, using specific case studies.
2. To consolidate key research work achieved to date in South Africa in support of achieving Target 6.3 and also identify current gaps.
3. To establish a more detailed analysis of existing opportunities within the wastewater sector as part of tracking national progress on Target 6.3 in support of achieving SDG 6.

SDGs are not legally binding, but countries should establish a national framework to achieve the goals and are responsible for their tracking progress. Target 6.3 aims to improve water quality by reducing pollution and halving the amount of untreated wastewater. The target has two indicators, "the proportion of wastewater safely treated" and, "the proportion of bodies of water with good ambient water quality". This study has aimed to shed light on South Africa's current status with respect to both indicators.

Methods

This study was conducted in 2019 and early 2020, and is a review and compilation of published research and news reports, the proceedings of the 2019 conference of the Academy of Science of South Africa, the InterAcademy Partnership Sustainable Development (SDG 6) Workshop, and interviews and correspondence with stakeholders in the wastewater sector. The most recent municipal wastewater services data from the Department of Water and Sanitation (DWS) has also been reviewed and summarised.

Findings

According to DWS, 52% of sewage is treated safely and 59% of surface water bodies have good ambient water quality. However, a 2014 study showed that 62% of 50 major water bodies were hypertrophic (have very high nutrient concentrations) and more than 50% suffered from cyanobacterial blooms, while the Vaal, Crocodile and Olifants river catchments suffer from on-going increases in salinity and sulphate levels. There are also numerous local surface and groundwater pollution problems.

The quality of surface water across the country is deteriorating due to poor quality municipal effluent, but also due to discharges from industry and agriculture. Coupled with persistent water shortages and droughts in many parts of South Africa, it is clear that there is a need to fix the problems in the wastewater sector and also to start making better use of wastewater.

South Africa faces serious wastewater and sanitation challenges, as shown by the many reported breakdowns in municipal waste and wastewater infrastructure over the past 20 years, some of these with very significant health and environmental impacts. While access to sanitation services has improved, there are on-going problems. Almost 60% of the population have access to sewered sanitation, most of these in urban areas. More than one-third of South Africans use pit, chemical or bucket latrines, and over two million people have no access to any form of sanitation. Wastewater Treatment Plants (WWTPs) work at 90% of capacity on average, and some are over capacity. There is little spare treatment capacity in the metros, and this poses a threat of exceeding capacity, as on-going urbanisation increases the load on the WWTPs. In a topical side note, recent research from the Netherlands and United States indicates that testing raw sewage may be useful indicator of levels of coronavirus infection (COVID-19) in communities.

There are many opportunities to improve wastewater management and move towards meeting SDG Target 6.3, and, in general, the water sector can benefit from more integrated thinking such as the Circular Economy or Cleaner Production frameworks. Wastewater plants in South Africa should be managed and maintained so that they consistently meet DWS's minimum discharge requirements. This will allow for additional re-use opportunities. Greywater recycling, especially in un-sewered communities, must be a key area of attention. There are opportunities for WWTPs to produce biogas for on-site electricity generation, and to recover nutrients from wastewater. Sewage sludge is useful for its nutrient and soil-structuring benefits. The expected impacts of climate change on wastewater systems must be considered, and also the entire paradigm of using water as medium to transport human wastes, as exemplified in the Sanitation Transformation Initiative (Saniti). Funding for sustainable water management must be improved through implementation of wastewater charges and by using the Municipal Infrastructure Grant (MIG).

The institutional and social barriers against wastewater re-use include gaps in infrastructure, governance, data gathering and monitoring, wastewater charges not being applied and economic barriers, such as high costs for new or modified infrastructure. There are also social barriers, such as the perception of wastewater as "pollution", and public health concerns about emerging contaminants such as pharmaceuticals and endocrine disruptors.

Implications

In order to achieve sustainable wastewater management in South Africa, a comprehensive overhaul of the entire municipal wastewater system is needed, including renewed commitment to good sanitation by politicians, improved governance, improved skills levels, investment in repairs, maintenance and new infrastructure and improved monitoring and enforcement. Re-introducing the Green Drop certification system may be useful.

Government should review and implement wastewater charges, and other financial arrangements, including the Municipal Infrastructure Grant, to help fund wastewater beneficiation. There is a need to educate policy makers and the public about the benefits of re-using and recycling wastewater, to address negative perceptions, and to develop guidelines and issue regulations for greywater, including health regulations, covering greywater use in both sewered and non-sewered areas. Given the current poor reliability of Eskom power, and structural weaknesses in electricity supply that are likely to persist for the foreseeable future, new WWTPs and upgrades to existing plants should include biogas-based energy recovery and on-site power generation.

With regard to the Sustainable Development Goals, DWS should set clear and published targets for SDG 6, and resource the effort accordingly in partnership with civil society and researchers, and report on progress annually. In the light of the findings of this report, the following topics are considered to be important research priorities:

a) Dry-disposal sanitation vs. water-based sanitation
b) Decentralised wastewater treatment systems for rapidly-growing cities
c) Long-term effects of using greywater for irrigation on soil, groundwater, crops and health
d) Emerging contaminants in wastewater
e) The implications of climate change for wastewater management in South Africa

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ACRONYMS & ABBREVIATIONS

CBO	Community Based Organisation
CER	Centre for Environmental Rights
CMA	Catchment Management Agency
CME	Compliance Monitoring and Enforcement
CMF	Catchment Management Forums
CoGTA	Department of Cooperative Governance and Traditional Affairs
CSO	Civil Society Organisation
DEA	Department of Environmental Affairs
DWA	Department of Water Affairs
DWS	Department of Water Affairs and Sanitation
DWS	Department of Human Settlements, Water and Sanitation
DWAF	Department of Water Affairs and Forestry
IWRM	Integrated Water Resource Management
IWULA	Integrated Water Use License Authorisation
MWe	Mega Watts electrical (usually the electricity produced from MWth)
MWth	Mega Watts thermal (the amount of heat energy generated)
MWWTP	Municipal Wastewater Treatment Plant
NWA	National Water Act
NWRS	National Water Resource Strategy
SALGA	South African Local Government Association
TDS	Total Dissolved Solids
WSA	Water Services Authorities
WSP	Water Services Providers
WDCS	Waste Discharge Charge System
WWTP	Wastewater Treatment Plant

GLOSSARY

Cleaner production	is the continuous application of an integrated preventative environmental strategy applied to processes, products and services to increase overall efficiency and reduce risks to humans and the environment. Cleaner production is one of the key ways to ensure sustainable development. It aims to increase production and productivity through more efficient use of water, raw materials and energy to reduce wastes and emissions of any kind at source rather than deal with them afterwards.
Eutrophication	refers to the enrichment of water with (plant) nutrients (specifically silicates, nitrates and phosphates).
Salinity	is the measure of quantity of total dissolved inorganic solids, or salts, present in water.
Wastewater	is water that is of no further immediate value for the purpose it had been used or produced for because of its quality, quantity and time of occurrence.

1. BACKGROUND TO THE STUDY

1.1 LOCAL BACKGROUND

South Africa currently ranks very low (123rd out of 187) in terms of the Human Development Index, which includes a consideration of access to clean water and safe sanitation. According to the 2011 Statistics South Africa Census, only 57% of the country's population was connected to sewerage systems. A large number of municipalities in the country provided only limited water supply and solid waste removal services (Ntombela, 2013). More recent data from the Department of Water and Sanitation (DWS) shows some improvement in domestic wastewater management, with 59% connected to sewered systems. Over 20 million people, one-third of the population use pit, chemical or bucket latrines, while more than two million people, over 4% of the population still have no formal sanitation (see Section 5).

More than 40% of surface water bodies and more than half of the rivers in South Africa do not have good ambient water quality. Much of this deterioration can be largely attributed to the discharge of poor quality municipal and industrial wastewater, as well as runoff from agricultural areas.

There have been numerous failures in municipal wastewater management systems over the past 20 years, and associated public health and environmental crises. The root causes of these failures lie in poor planning, management and inadequate investment in maintenance and new infrastructure to meet changing demands.

1.2 THE UN SUSTAINABLE DEVELOPMENT GOALS AND WORLD WATER DEVELOPMENT REPORT 2017

In 2015, all 193 member states of the United Nations General Assembly adopted the 2030 Agenda for sustainable development, with its 17 sustainable development goals (SDGs) and 169 global targets.

Climate change impacts public health, food and water security, migration, peace and security, and sustainable development cannot be achieved without climate action. Consequently many of the SDGs are intimately linked to climate change concerns.

Even though SDGs are not legally binding, countries are expected to establish national frameworks for achieving the 17 goals (Table 1). Countries have the primary responsibility for follow-up and review, at the national, regional and global levels with regard to the progress made in implementing the goals and targets (United Nations, 2018).

Table 1. The 17 Sustainable Development Goals

Goal	SDG	Goal	SDG	Goal	SDG	Goal	SDG
1	No Poverty	**6**	Clean Water and Sanitation	**11**	Sustainable Cities and Communities	**16**	Peace and Justice Strong Institutions
2	Zero Hunger	**7**	Affordable and Clean Energy	**12**	Responsible Consumption and Production	**17**	Partnerships to achieve the Goals
3	Good Health and Well-being	**8**	Decent Work and Economic Growth	**13**	Climate Action		
4	Quality Education	**9**	Industry, Innovation and Infrastructure	**14**	Life Below Water		
5	Gender Equality	**10**	Reduced Inequality	**15**	Life on Land		

The UN's 2017 World Water Development Report entitled *Wastewater: The Untapped Resource* highlighted the vital importance of improving the management of wastewater globally for humanity's common future. Over 80% of wastewater worldwide was released into the environment without treatment, and over 800 000 deaths globally in 2012 were reported as having been caused by contaminated drinking water, inadequate handwashing facilities or inappropriate sanitation services. There was also worsening global water pollution in most rivers across Africa, Asia and Latin America.

Information was limited, with only 55 out of the 181 countries being able to provide adequate information on the generation, treatment and use of wastewater. Most only had partial data, and some had no data at all, thereby impeding the research and development necessary to craft innovative technologies and adapt existing ones to local specifications and needs.

The report concluded that the challenge of achieving sustainable water and sanitation for all is significant, and strong political will and commitment are required. Further, there is no standard approach that suits all countries. Finding sustainable development pathways will be challenging for water-insecure countries, especially for least developed countries. This is because many of these countries have limited water supplies, and inadequate professional and institutional capacity. It is often poor countries that are subjected to extremes of droughts and floods, and to provide reliable and safe water and sanitation under extreme conditions typically requires costly infrastructure.

However, there was a growing consensus that these challenges could be met by adopting a more integrated approach to the management and allocation of water resources for different purposes, including the protection of ecosystems upon which societies and economies depend. The concept of integrated water resources management (IWRM) was reflected in the 2030 Agenda and required governments to consider how water resources link different parts of society, and how decisions in one sector may affect water users in other sectors[1] .

Like SDG 6, the 2017 World Water Development Report recommended global response actions for sustainable wastewater treatment, and management based on reducing pollution at source, removing contaminants from wastewater flows, reusing reclaimed water and recycling useful by-products (WWAP, 2017).

1.3 PROJECT AIMS AND SCOPE

The South African Government's responsibility to provide clean water and sanitation for all – in the face of significant difficulties – and its commitments to the UN Agenda 2030, are motivations behind this study. While there has been substantial research aimed at improving wastewater management in South Africa in recent years, it is important to critically assess the country's progress towards SDG Target 6.3. An important shift in our approach to wastewater is needed to achieve Target 6.3, namely a change in perspective, from viewing wastewater as waste, or medium for disposal of waste, to viewing it as a valuable resource. Progress towards SDG Target 6.3 and considering wastewater as a resource are clearly linked, as the more wastewater is valued, recycled and re-used, the less wastewater will be discharged into water bodies, to the benefit of community health and the environment.

[1] "*IWRM is a process which promotes the coordinated development and management of water, land and related resources, in order to maximise the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems*." IWRM is a process and therefore it does not offer a single universal approach to water management. Water resources, development priorities, and social and economic issues are all location and context specific, but experience shows that successful implementation of IWRM requires a strong enabling environment, sound investments in infrastructure, clear, robust and comprehensive institutional roles and responsibilities and effective use of available management and technical instruments (Lenton and Muller, 2009).

With that background, the project aims are as follows:

1. To map out current challenges associated with sustainable wastewater management, including quantifying national environmental and health impacts, using specific case studies.
2. To consolidate key research work achieved to date in South Africa in support of achieving Target 6.3, and also identify current gaps.
3. To establish a more detailed analysis of existing opportunities within the wastewater sector, as part of tracking national progress on Target 6.3, in support of achieving SDG 6.

2. SUSTAINABLE DEVELOPMENT GOAL 6

This section provides further details on SDG 6 and on progress which has been reported to date towards Target 6.3.

2.1 SDG 6 – RATIONALE AND TARGETS

Of the 17 UN Sustainable Development Goals, SDG 6 calls for clean water and sanitation for all people. There are eight targets under SDG 6, as shown in Table 2 (United Nations, 2018).

The rationale behind SDG 6 is that water is needed to ensure healthy ecosystems, which in turn can improve the quantity and quality of freshwater, as well as overall resilience to human-induced and environmental changes. Many people still lack access to safely managed water supplies and sanitation facilities. Water scarcity, flooding and lack of proper wastewater management hinder social and economic development. Increasing water efficiency and improving water management are critical to balancing the competing and growing water demands from various sectors and water users.

SDG 6 is founded on an IWRM approach, and aims to balance the needs of different users fairly. It expands the UN Millennium Development Goals' (MDG) focus on drinking water and basic sanitation to include water, wastewater and ecosystem resources. SDG 6 covers all aspects of fresh water in the context of sustainable development and includes eight separate targets that aim to address the entire water cycle:

- 6.1. Provision of drinking water
- 6.2. Sanitation and hygiene services
- 6.3. Treatment and re-use of wastewater and ambient water quality
- 6.4. Water-use efficiency
- 6.5. IWRM including through trans-boundary cooperation
- 6.6. Protecting and restoring water-related ecosystems
- 6.a. International cooperation and capacity-building
- 6.b. Local participation in water and sanitation management.

The targets are designed to be universally applicable and ambitious, and each government should incorporate them into national planning processes, policies and strategies based on national realities, capacities, levels of development and priorities.

SDG 6 recognises that ambient water quality and wastewater are interrelated. If the discharge to the environment is of poor quality then the receiving waters will subsequently worsen in quality. All users of the receiving waters would then have to adequately treat the water before use, to ensure that it is safe for consumption and use. Furthermore, given the centrality of water to life and health, other goals and targets cannot be achieved without progress on water, thus promoting Goal 6 to being of paramount importance. Accomplishing the other SDGs will require assuring clean water and sanitation for all (United Nations, 2018).

Table 2. United Nations Sustainable Development Goal 6 Targets

Target	Aspect	Indicators and custodian agencies
6.1	Universal and equitable access to safe and affordable drinking water	6.1.1. Proportion of population using safely managed drinking water services (WHO, UNICEF)
6.2	Adequate and equitable sanitation and hygiene. End open defecation. Special attention to needs of women and girls in vulnerable situations	6.2.1a Proportion of population using safely managed sanitation services (includes hand washing hygiene) (WHO, UNICEF) 6.2.1b Proportion of population using a handwashing facility with soap and water available (WHO, UNICEF)
6.3	Improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe re-use globally	6.3.1 Proportion of wastewater safely treated (WHO/United Nations Human Settlements Programme (UN-Habitat/United Nations Statistics Division (UNSD)) 6.3.2 Proportion of bodies of water with good ambient water quality (United Nations Environment Programme/UNSD)
6.4	Increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity	6.4.1 Change in water-use efficiency over time (Food and Agriculture Organization of the United Nations (FAO)) 6.4.2 Level of water stress: freshwater withdrawal as a proportion of available freshwater resources (FAO)
6.5	Implement integrated water resources management at all levels, including through trans-boundary cooperation as appropriate	6.5.1 Degree of integrated water resources management implementation (0–100) (United Nations Environment Programme) 6.5.2 Proportion of trans-boundary basin area with an operational arrangement for water cooperation (United Nations Educational, Scientific and Cultural Organization (UNESCO)/United Nations Economic Commission for Europe (UNECE))
6.6	Protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes	6.6.1 Change in the extent of water-related ecosystems over time (United Nations Environment Programme/Ramsar Convention)
6.a	Expand international cooperation and capacity building support to developing countries in water and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and re-use technologies	6.a.1 Amount of water and sanitation-related official development assistance that is part of a government-coordinated spending plan (WHO/United Nations Environment Programme/Organisation for Economic Co-operation and Development (OECD))
6.b	Support and strengthen the participation of local communities in improving water and sanitation management	6.b.1 Proportion of local administrative units with established and operational policies and procedures for participation of local communities in water and sanitation management (WHO/United Nations Environment Programme/OECD)

Adapted from United Nations, Department of Economic and Social Affairs (2017)

2.2 SDG TARGET 6.3

The specific aim of SDG Target 6.3 is to improve water quality, wastewater and safe re-use. The aim is to, by 2030, have improved water quality by reducing pollution, eliminating dumping and minimising release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe re-use globally (United Nations, 2018).

2.2.1 Progress toward Target 6.3 globally

According to the UN's *Sustainable Development Goal 6 Synthesis Report 2018*, agriculture (including irrigation, livestock and aquaculture) was by far the largest water consumer, accounting for 69% of annual water use globally. Industry (including power generation) accounted for 19% and households for 12%. Most wastewater from municipal, industrial and agricultural sources is discharged back into water bodies without treatment. If not treated, this pollution further reduces the availability of fresh water for drinking and other uses, and also degrades ecosystems (United Nations, 2018).

The report found that freshwater pollution was prevalent and increasing in many regions worldwide. Preliminary estimates of household wastewater flows, from 79 mostly high and middle income countries, showed that only 59% is safely treated. For these countries, it was further estimated that safe treatment levels of household wastewater flows with sewer connections and on-site facilities are 76% and 18%, respectively. Although water quality problems are largely associated with developing countries, they also persistent in developed countries and included the loss of pristine quality water bodies, impacts associated with changes in hydromorphology as well as the rise in emerging pollutants and the spread of invasive species.

The full extent of industrial pollution globally is not known as discharges are generally poorly monitored and seldom aggregated at the national level. Although some domestic and industrial wastewater was treated on site, limited data was available and aggregated for national and regional assessments.

As shown in Table 2 and discussed in the following sections, there are global indicators which are used to track progress towards each of the targets. Target 6.3 has two indicators, 6.3.1, "proportion of wastewater safely treated" and 6.3.2, "proportion of bodies of water with good ambient water quality" (United Nations, 2018).

2.2.2 Indicator 6.3.1 – global status

The proportion of wastewater safely treated assesses actual treatment performance based on effluent quality data and discharge permits. Further, it must consider two components:

- The percentage of safely treated domestic wastewater flows
- The percentage of safely treated industrial wastewater flows

Figure 1 shows household and industrial wastewater flow paths, from generation to disposal in the receiving waters.

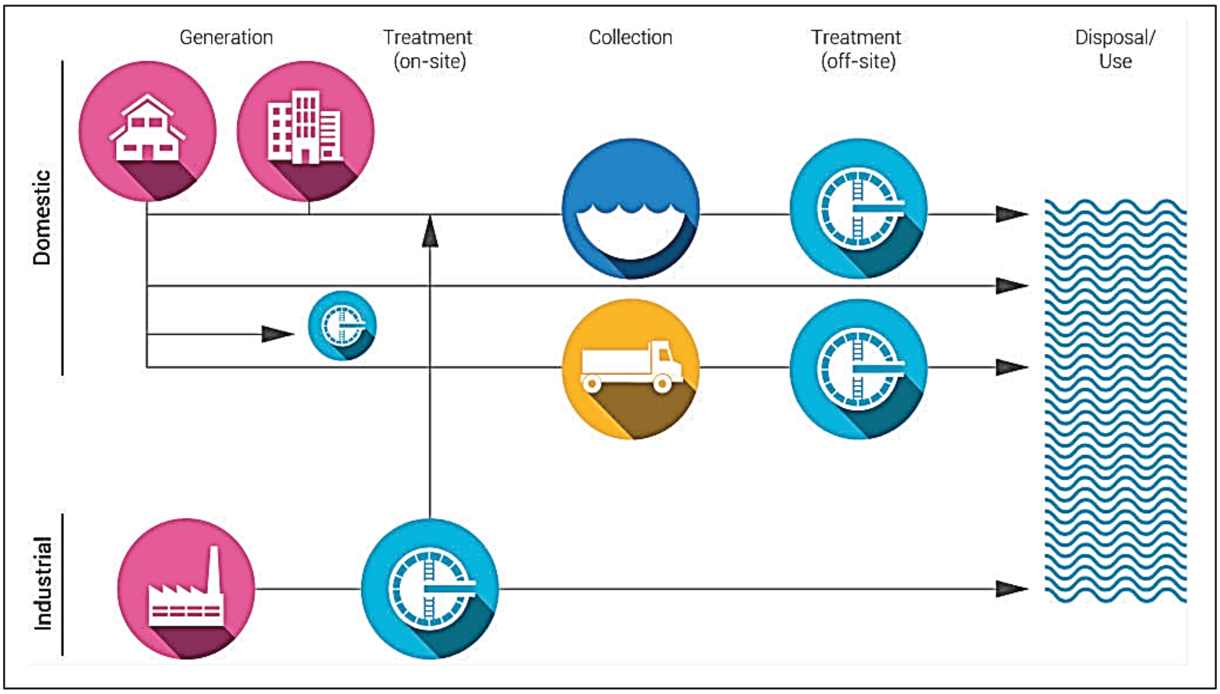


Figure 1. Wastewater flows from generation to disposal

(Adapted from SDG6 Synthesis Report United Nations, 2018)

Wastewater monitoring comprises the tracking of:

- Household wastewater treatment on site and off site to national standards
- All wastewater generated by the users
- Industrial discharges to sewers and environment
- The proportion of wastewater re-used or recycled.

Preliminary findings estimated for domestic wastewater have been made for 79 countries, but are from mainly high and middle income countries and exclude most of Africa and Asia (United Nations, 2018):

- Insufficient data was available to make estimates for industrial wastewater.
- 71% of domestic wastewater flow was collected in sewers, 9% was collected by septic tanks and the remaining 20% was not collected, as shown in Figure 2.
- 59% of all domestic wastewater flows was collected and safely treated. The untreated 41% presented risks to the environment and public health.
- 76% of domestic wastewater flows collected in sewers was safely treated.
- 18% of domestic wastewater flows generated by households with on-site facilities was safely treated in septic tanks.
- Estimates should be considered as upper limits because data are skewed towards higher-income countries, and there are data gaps on treatment performance, and other sources and sinks of wastewater.
- Data on industrial discharges are poorly monitored and seldom aggregated at national level.
- Comprehensive reporting on indicator 6.3.1 was impeded by major data gaps relating to on-site treatment of domestic wastewater.

Figure 2 illustrates domestic wastewater collection and treatment in high to middle income countries. Even in these countries, 20% of wastewater is not collected for treatment, so it is reasonable to assume that for less affluent countries a greater percentage of wastewater is not collected. Also, of the domestic wastewater that was collected, 41% remained untreated and the percentage of treated wastewater that was re-used was not reported. Again, it can be assumed that of the wastewater that is actually collected in poorer countries, a larger proportion is untreated (United Nations, 2018).

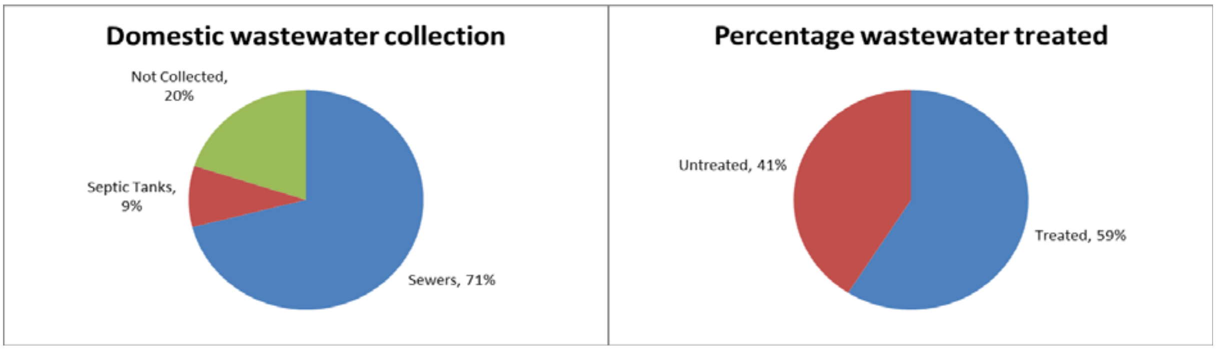


Figure 2. High to middle income countries' domestic wastewater collection and treatment

Further findings from the report were that:

- In 22 of the 79 countries with data, the safe treatment level of household wastewater flows was 50% or less.
- Less than 25% of the population was connected to sewered wastewater services in 102 countries, located mainly in Africa and Asia.
- High income countries are predominantly connected to sewers and the treatment plant performance rates are higher.
- Low and middle income countries have predominantly on-site facilities and very few collect data for on-site facilities.
- Only 28 of 79 countries assessed the success of treatment by comparing effluent data with a national or regional standard. The rest based their results on the expected performance of the treatment methods.
- Treatment performance is affected by overloading, unpermitted industrial discharge, and poor operation and maintenance standards.
- National standards for wastewater quality vary significantly, in terms of parameters monitored, as shown in Table 3, which makes it difficult to compare performance between different countries.

Table 3. National standards for wastewater quality: parameters tested

Parameter	%
Nutrients	
Ammonia Nitrogen	16
Phosphate	18
Ammonium nitrogen	20
Nitrate nitrogen	22
Total phosphate	69
Total nitrogen	77
Organics	
DO	14
COD	93
BOD	96
Pathogens	
Faecal streptococci	9
Ecoli	24
Total coliform	26
Fcoli	33
Chemicals	
Chloride	29
Fluoride	34
Arsenic	38
Solids	
Fat, oils and grease	44
TSS	93

Adapted from United Nations (2018). The number shows the percentage of high income countries that test for the listed constituents.

Figure 3 shows the proportion of treated to untreated industrial wastewater for several European countries. There is great variability between the surveyed countries. Insufficient data was available to estimate industrial wastewater flows to sewers and directly to the environment, or treatment level of industrial effluent. One problem with monitoring and reporting is that wastewater data is kept at a local government level, and not aggregated at the national level (United Nations, 2018).

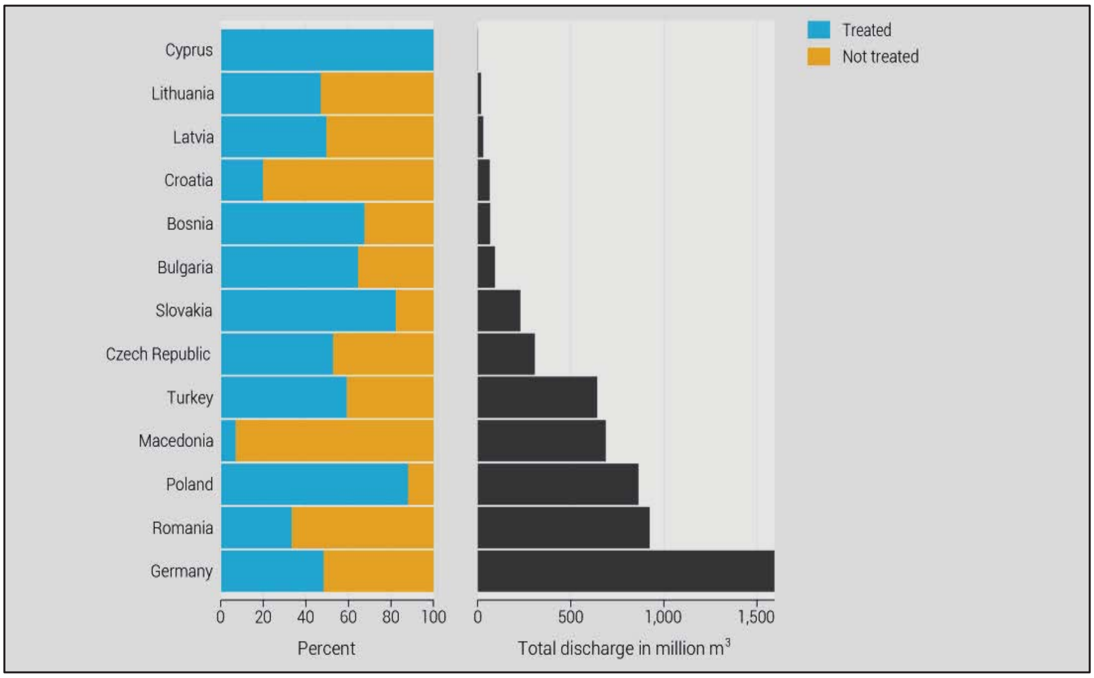


Figure 3. The percentage of safely treated industrial wastewater flows

Adapted from United Nations, 2018.
"Not treated" could include discharges that do not need treatment

Results from a survey on wastewater treatment and re-use in the League of Arab States countries are shown in Figure 4.

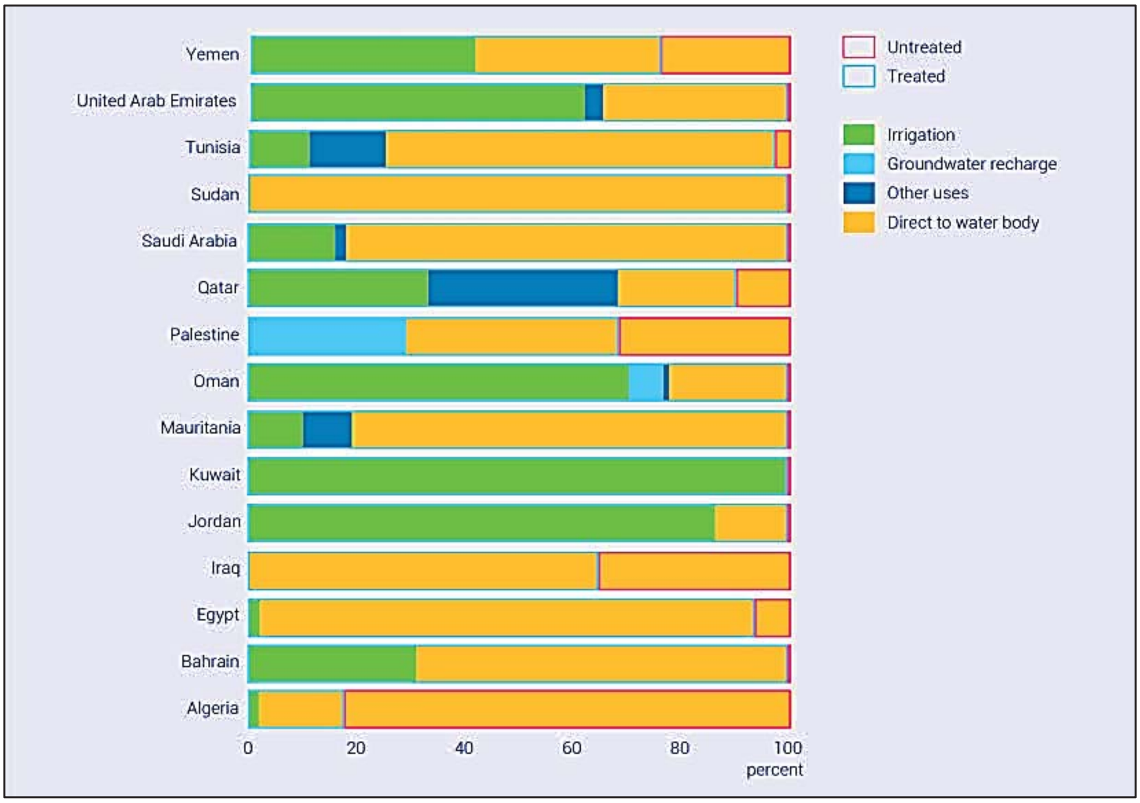


Figure 4. Water re-use in the Arab States

Adapted from United Nations, 2018

In these countries, most of wastewater re-use is for irrigation and most wastewater was treated before discharge. Jordan, Kuwait and Oman use secondary treatment prior to the water being used in agriculture (United Nations, 2018).

2.2.3 Applying Indicator 6.3.1 in South Africa

In order to monitor this indicator for South Africa, evaluations should ideally include:

- Estimation of total wastewater generation by households (from surveys and population records)
- Estimation of total wastewater generation by economic activities (from industry inventories), focusing initially on a few economic activities (according to the 80:20 principle)
- Estimation of proportion of wastewater received and treated from utility/institutional records.

Monitoring should aim to become more accurate and refined over time. The household component also should include data from global indicator 6.2.1 “Proportion of population using safely managed sanitation services”. To capture the full aim of Target 6.3, other indicators are needed specifically on water recycling and re-use.

Indicator 6.3.1 helps define the wastewater resource, in that data collected for Indicator 6.3.1 helps to quantify the status and potential of wastewater as a resource. The indicator estimates the amounts of wastewater from different sources (households and economic activities), what percentage of this is safely treated and potentially available for immediate re-use, and how much is already being re-used or recycled.

2.2.4 Indicator 6.3.2 – global status

The proportion of bodies of water with good ambient water quality. Ambient water quality refers to natural, untreated water in rivers, lakes and groundwater, and represents a combination of natural and anthropogenic influences (United Nations, 2018).

Indicator 6.3.2 gives indirect information on the wastewater resource. It is monitored by measuring physical and chemical water quality parameters. Most natural water bodies now receive wastewater discharge due to human activities, so good ambient water quality indicates that wastewater entering the water body has been treated to a safe level. Good ambient water quality is an indirect indicator that wastewater being discharged into the water body did not decrease the overall water quality and thus may be considered a good quality water resource, and vice versa.

Monitoring and assessing water quality is essential, but natural variability in water bodies caused by differences in natural factors such as geology and climate means that it is not practical to set global ambient water quality standards or targets. Each country must define “*good ambient water quality*” and set its own standards and targets based on its specific conditions. These should ensure the aquatic ecosystem is healthy and that there is no unacceptable risk to human health arising from intended use of the water without prior treatment. The selected core parameters for indicator 6.3.2 are simple to measure and are a good starting point for countries with less-developed monitoring capacities (Table 4).

Table 4. Selected parameters for monitoring SDG indicator 6.3.2

Parameter	River	Lake/Dam	Groundwater
Dissolved Oxygen	X	X	
Electrical Conductivity	X	X	X
Nitrogen	X	X	
Nitrate			X
Phosphorus	X	X	
pH	X	X	X

Information from low and middle income countries shows the following:

- Ambient freshwater quality is at risk globally. Freshwater pollution is prevalent and increasing in many parts of Latin America, Africa and Asia. The lack of water quality monitoring in many parts of the world did not allow for an exact global estimate of water pollution.
- "Monitoring programmes can be perceived as expensive, but compared to the relative value of the water resources, and the savings made by making science-based decisions, these costs are minimal" (Lovett et al., 2007).
- Increasing population and economic activity increases water pollution due to the emphasis on economic activity at the expense of environmental quality.
- Public concern is often the instigator of change. Once there is sufficient pressure on relevant authorities to respond to rising pollution by initiating control measures aimed at reducing the pollution, only then a response is formulated to the rising pollution. If control measures are sufficient, the intensity of water pollution peaks, and levels of organic pollution, nutrient loading and pathogen contamination gradually diminish.
- Water quality problems persist even in high income countries, including the continued loss of pristine quality water bodies and also effects associated with changes in hydromorphology, the rise in emerging pollutants and the spread of invasive species.
- Figure 5 highlights various pressures on water quality relative to increasing development. Actions can be taken to mitigate or avoid the effects, once drivers are identified (United Nations, 2018).

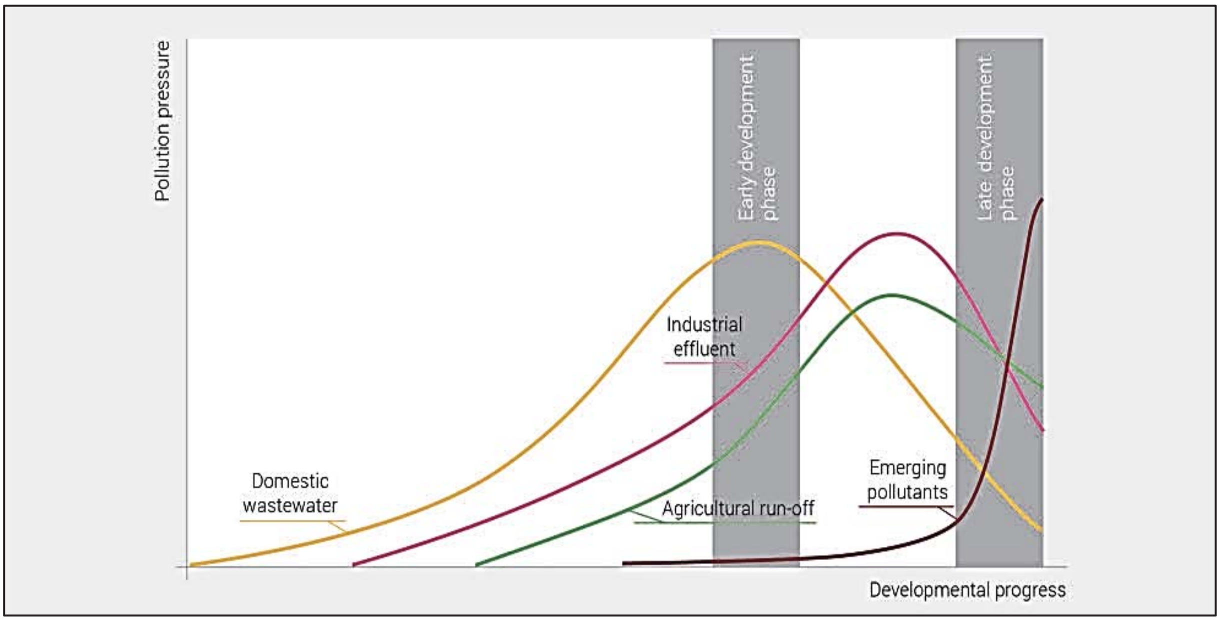


Figure 5. Changes in the threats to water quality with development phase of countries

(Adapted from United Nations, 2018)

South Africa is considered a upper-middle income or moderately developed country, but due to a combination of factors, the volume of domestic wastewater has increased while treatment levels have not kept up. This situation seems to have placed many South Africans in the “early phase” of development of Figure 5, as the major threat to ambient water quality for many is poorly treated or untreated domestic wastewater.

2.2.5 Applying Indicator 6.3.2 in South Africa

DWS and municipalities routinely monitor surface water quality at many locations throughout the country and data for the parameters listed in Table 4 is widely available. However, data quality and frequency of data collection varies.

3. PROGRESS TOWARDS SDG 6 IN SOUTH AFRICA – DEPARTMENT OF WATER AND SANITATION PERSPECTIVE

The implementation of SDG 6 was discussed during a conference hosted by DWS in partnership with the Department of Science and Technology (now called Department of Science and Innovation) and scientific research institutions, the Academy of Science of South Africa (ASSAf) and the InterAcademy Partnership (IAP), in July 2019. At the workshop, a DWS representative explained that the DWS was mandated to guarantee the implementation of SDG 6, which was to ensure access to water and sanitation for all, and outlined the related targets, goals and indicators. The key points of the DWS presentation were:

- South Africa is unlikely to reach SDG 6 by 2030, but is making progress.
- In terms of water quality (Target 6.3):
  - 52% of effluent was treated and discharged safely through the WWTPs (Indicator 6.3.1).
  - 59% of surface water bodies have good quality water (Indicator 6.3.2).
- There is a comprehensive water quality management strategy in place, and draft water quality management policy has been developed.

Speakers at the conference called for greater political commitment to improving the water and sanitation sector, and the need for cooperation among all involved, including researchers. An overall decline in the frequency and quality of monitoring in the sector has resulted in reduced confidence in the available data, and a national audit of water and wastewater data is needed (ASSAf, 2019 and DWS, 2019).

The reported results for Target 6.3 show that South Africa is not unusual, when compared with the global data discussed in Section 2.2. However, at the time of writing, it has not been possible to obtain further details from DWS, specifically:

- The underlying data for the reported results, and its accuracy; and
- Results for previous years, which would allow conclusions to be drawn about rate of progress towards the target.

As such, the DWS results should be considered a snapshot of the current conditions, which has not been independently verified. As recommended in Section 12, DWS should publish details of the current status of SDG 6 indicators, and provide regular progress reports, including access to the underlying data.

4. THE NATIONAL POLICY AND LEGAL FRAMEWORK FOR WASTEWATER

This section presents the policy framework and South African laws governing wastewater management. In general, current wastewater management strategies in South Africa are in line with global norms and standards, and are adequate and thorough. The problems facing the country with regard to wastewater are not, in general, ones of policy or inadequate legislation. They stem rather from a lack of political will and of sufficient technically skilled personnel, poorly trained staff, a lack of preventative maintenance, aging and failing infrastructure and the resulting insufficient capacity within the treatment works and infrastructure.

4.1 NATIONAL WATER MANAGEMENT LAWS

National laws are promulgated to promote a healthy aquatic system that is maintained on a sustainable basis while allowing for justifiable social and economic development. The main laws that govern and protect water resource in South Africa are:

- The Constitution of South Africa (Act No.108 of 1996)
- The Water Services Act and secondary legislation (Act No.36 of 1998)
- The National Water Act and secondary legislation (Act No.108 of 1997)
- The Municipal Systems Act (Act No.32 of 2000)
- The Municipal Structures Act (Act No.117 of 1998)
- Strategic Framework for Water Services
- National Water Services Regulation Strategy
- National Water Policy Review

Decentralisation of management of water resources have resulted in many stakeholders that have varying degrees of direct and indirect influence in all three spheres of government, civil society, public owned entities, NGOs, and the private sector. Figure 6 and Table 5 show the stakeholders as identified by legislation and outlines their roles and responsibilities.

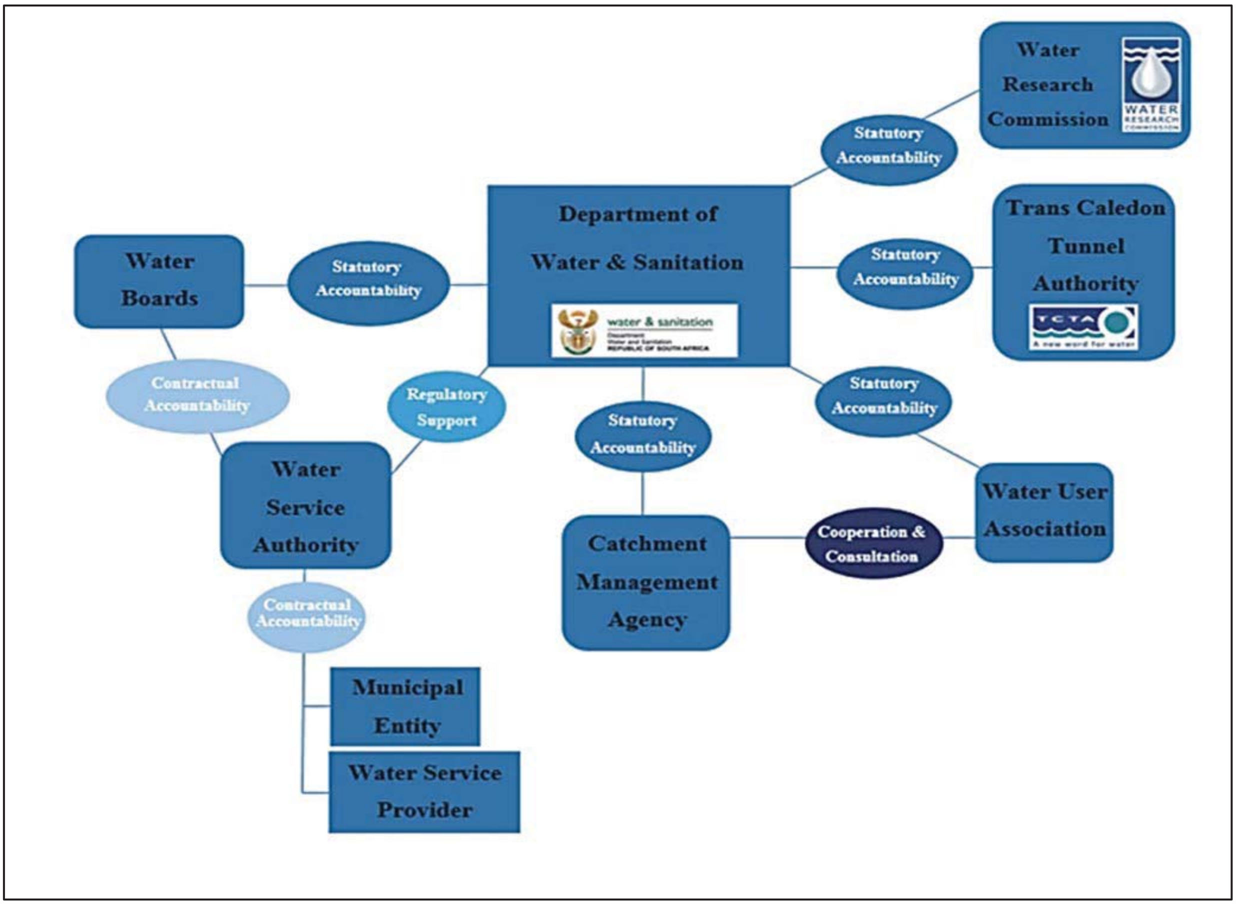


Figure 6. The relationship between water sector stakeholders

(Adapted from McDonald and Fell, 2016)

Table 5. Water sector stakeholders and their roles

Water Institute	Role and responsibility
Department of Water and Sanitation (DWS)	National government department that provides regulatory role, national and regional water resource management and the implementation of strategic programmes and initiatives
Water Services Authorities (WSA)	Municipalities responsible for the provision of water and sanitation at local level
Water Services Providers (WSP)	Organisations that provide water and sanitation services under contract to WSA
Municipal Entities	Municipal-owned organisation that can be a WSP
Water Boards	State-owned entities responsible for providing bulk water and sanitation services to other water institutions such as WSA, WSP and Municipal Entities
Catchment Management Agencies	Affiliation of stakeholders at local level that have a common interest in water use and allocation
Water Use Associations	Affiliation of stakeholders at local level that have a common interest in water use and allocation
Trans Caledon Tunnel Authority	State owned entity responsible for financing and implementing bulk water and sanitation infrastructure projects
Water Research Commission	Coordinates water sector research

Adapted from McDonald and Fell, 2016

Chapter 3 of The National Water Act (NWA) (Act No. 36 of 1998) specifically addresses the protection of water resources. In recent years, the Minister of Water and Sanitation highlighted the need for an ‘integrated water approach that entails a sustainable and holistic value chain of water supply from source to tap and from tap back to source (Government Gazette, 2017). In the budget vote for the DWS in May 2015, the Minister said: “The second pillar, ‘Improving the Water Mix’, involves the increased use of a variety of water sources in addition to our current reliance on surface water. These shall include groundwater, water harvesting, water-recycling and the re-use of treated acid mine water” (South African Government, 2015).

The White Paper on Basic Household Sanitation (2001) stated that the minimum acceptable basic level of sanitation was a system for disposing of human excreta, household wastewater and refuse, which was acceptable and affordable to the users, safe, hygienic and easily accessible and which did not have an unacceptable impact on the environment, and a toilet facility for each household.

4.2 APPLICATION OF THE WASTE HIERARCHY FRAMEWORK TO WATER MANAGEMENT

South Africa, like many other countries, is moving towards the implementation of a waste hierarchy approach, as set out in the National Waste Management Strategy (NWMS), which has been given legal effect through the National Environmental Management: Waste Act (Act No. 59 of 2008). The waste hierarchy emphasises a move away from landfilling, towards waste minimisation, re-use and recycling. It was estimated that 90% of urban households and 47% of rural household have access to adequate levels of service and government would ensure access to basic waste collection services by 2020 (NWMS, 2011).

The waste hierarchy is the order of priority of actions to be taken to prevent and then reduce the amount of waste generated, as well as to improve the overall waste management process. Waste prevention/avoidance is always the preferred option and is followed by reduce, re-use, recycling, final treatment and disposal, as shown in Figure 7.

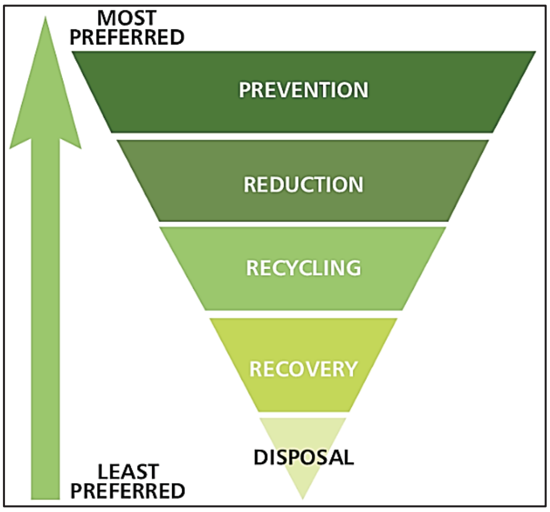


Figure 7. The waste hierarchy

(Adapted from UNEP, 2011)

These same principles should be applied to water, and especially the overall reduction in the use of potable water. This change in perspective would help to address the scarcity of water in South Africa and would also reduce the volumes of wastewater and the need for treatment and disposal.

This is particularly the case for municipal wastewater. Like other waste, wastewater is a burden on society and it incurs costs in processing and energy before it can be safely released into the environment. It has been suggested that no other intervention has a greater impact upon a country's development and public health than the provision of clean drinking water and the appropriate disposal of human waste (UNEP, 2011).

4.3 THE GREEN DROP CERTIFICATION PROGRAMME

While access to sanitation is improving in South Africa, municipal WWTPs are suffering from poor operation, servicing and maintenance. This has a particularly negative impact on water resources and the provision of a range of other ecosystem goods and services. Many WWTP are not fully compliant with legal requirements for wastewater discharge into the environment and the majority of plants require interventions.

In an effort to address this, in 2008 the DWS (formerly Department of Water Affairs [and Forestry] DWA/DWAF) initiated a method of incentivising municipalities to produce a higher quality effluent, viz. the Green Drop Certification Programme. The Green Drop certification programme was also intended to ensure that these treatment works progressively improved their operations, so as not to impact negatively on the water bodies into which they discharge their final product. The system aimed at awarding water services authorities with Green Drop Status if they complied with wastewater legislation and other best practices required by the Department of Water Affairs. This incentive-based regulatory approach was a first for South Africa and was internationally regarded as unique in the water regulatory domain. The effluent quality monitoring indicators for the Green Drop were:

- Microbiological: Faecal coliforms
- Chemical: COD, Ammonia and nitrates, ortho-phosphate
- Physical: pH, Suspended solids, Electrical conductivity

As of May 2011, 32 of the 1 237 municipal wastewater treatment plants were certified to the Green Drop standard. For example, the City of Tshwane had a municipal Green Drop score of 63.8%, ranking 9th out of the 12 Gauteng municipalities. However, the municipality experienced a deteriorating Green Drop score with 7 of the 10 plants showing trends of increased risk profiles between 2009 and 2011 (Komen, 2013).

The Green Drop certification programme was proactive, but seems to have lost momentum, and critics such as the NGO AfriForum have raised the following issues regarding DWS management of the programme and municipal wastewater systems in general:

- Deteriorating openness and transparency from the DWS, which was one of the strong features of the original programme, with earlier Green Drop reports published in hard copy and announced at formal functions with full media coverage. Since the last published report in 2012, there has been no further data released.
- Although recent data from DWS showed a general positive upward trend in WWTPs' performance, and more than half of all WWTPs scored above 50%, the rest scored less and clearly need attention.
- It was positive that central and local government was putting capital funds into rehabilitation as well as building of new WWTPs. But there had been inefficient application of such funds.
- Lack of consultation with all stakeholders (Afriforum, 2019).

Municipalities are obliged to provide basic sanitation services and national government must protect our water resources. If by not adequately maintaining infrastructure, the State allows partially treated or untreated wastewater to overflow into rivers, then it can be regarded as one of the biggest polluters in South Africa.

4.4 OPPORTUNITIES IN WATER GOVERNANCE - ACTIVE CITIZEN INVOLVEMENT

Citizens who play an active role in water quality can create greater awareness, raise water quality as a priority on political agendas, and provide practical support to the regulator for monitoring and reporting. For example, the Mvula Trust offered support to the Rietspruit Forum to implement steps towards compliance with the Green Drop Campaign. It found that by collaborating with the regulator and local government officials, the obstacles to compliance could be identified and the Green Drop process vastly improved. Catchment Management Forums (CMF) provided a good platform for such collaborative engagements, and the engagement, in turn, strengthens CMF (Munnik et al., 2011).

With regard to industrial wastewater, Industry Waste Management Plans (IWMP) can include voluntary producer responsibility schemes for particular waste streams, whereby producers, importers or retailers take responsibility for the waste generated by their products beyond point-of-sale and choose the most effective way of meeting their responsibilities.

The National Waste Act also provides for the declaration of mandatory extended producer responsibility (EPR) schemes, whereby the Minister prescribes how a waste stream should be managed and the required funding mechanism to do so. Mandatory EPR schemes can be declared when voluntary schemes provided for by the IWMPs have failed to effectively manage a waste stream. These principles and regulatory framework are as applicable to industrial wastewater as other (solid/chemical) waste streams.

5. SOUTH AFRICAN MUNICIPAL WASTEWATER DATA

This section is a summary of DWS data on municipal wastewater volumes, services and treatment capacity in South Africa, and the eight major metropolitan municipalities.

There are nine (9) provinces in South Africa comprising eight (8) metropolitan, 44 district and 226 local municipalities. The metropolitan municipalities (metros) are:

- Buffalo City (East London)
- City of Cape Town
- Ekurhuleni Metropolitan Municipality (East Rand)
- City of eThekwini (Durban)
- City of Johannesburg
- Mangaung Municipality (Bloemfontein)
- Nelson Mandela metropolitan Municipality (Port Elizabeth)
- City of Tshwane (Pretoria)

The online DWS database (DWS, 2020) was accessed for national and regional wastewater data, which is summarised in Table 6 and Table 7, with Figure 8 and Figure 9 showing the data graphically.

Table 6. Provincial access to basic services

Region	Population	Flush toilet (A)	Flush toilet (B)	Chemical toilet	Pit latrine (A)	Pit latrine (B)	Bucket latrine	No Sanitation
Eastern Cape	6 503 426	2 711 656	116 317	615 975	2 256 799	275 336	44 962	472 848
Free State	3 038 661	2 199 702	64 269	176 915	236 282	172 032	104 090	85 213
Gauteng	15 343 460	13 561 386	299 926	840 235	301 550	1 647	233 458	104 764
KwaZulu-Natal	11 534 505	4 476 617	350 769	1 921 392	2 764 424	1 130 325	156 637	728 743
Limpopo	5 758 409	1 094 442	129 551	86 380	1 797 691	2 306 797	33 207	309 613
Mpumalanga	4 683 503	1 923 370	123 153	245 803	819 569	1 264 866	34 438	272 256
North West	4 106 541	1 836 919	155 915	110 927	797 276	1 023 921	16 671	164 729
Northern Cape	1 244 082	839 136	69 581	16 636	127 743	87 421	45 988	57 071
Western Cape	6 826 587	6 450 284	179 200	36 948	6 058	1 528	108 467	43 690
National	**59 039 174**	**35 093 512**	**1 488 681**	**4 051 211**	**9 107 392**	**6 263 873**	**777 918**	**2 238 927**

Flush Toilet (A) connected to sewage system
Flush Toilet (B) with septic tank
Pit latrine (A) with ventilation
Pit latrine (B) without ventilation
Data as at April 2019 with 95% confidence

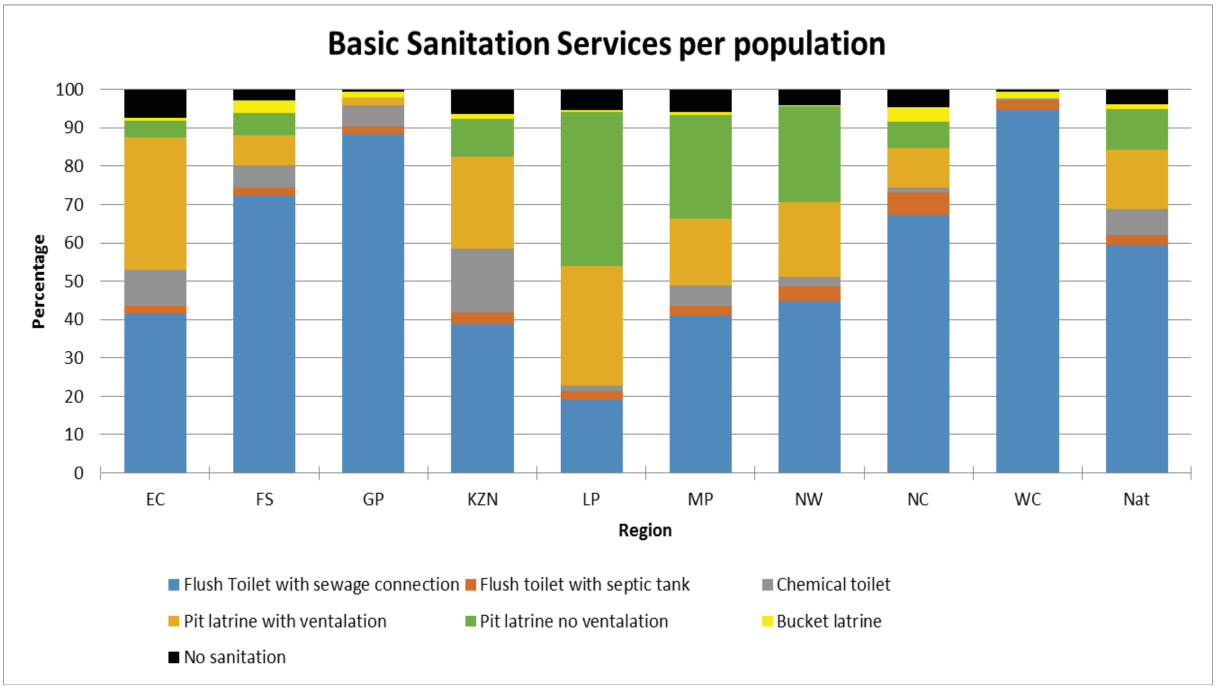


Figure 8. Basic sanitation services per population per region

Table 6 and Figure 8 show that there are differences between the provinces with respect to basic sanitation services per person, with Gauteng and the Western Cape performing the better and having the greater percentage of flush toilets with a sewage connection. Table 7 and Figure 9 provide the sanitation statistics for the eight metros.

Table 7. Population access to sanitation within the metros

metro	Population	Flush sewage (A)	Flush (B)	Chemical toilets	Pit latrine (A)	Pit latrine (B)	Bucket latrine	No sanitation
Buffalo City	775 872	599 969	23 645	31 159	97 890	0	1 413	14 117
Nelson Mandela Metropolitan Municipality	1 176 111	1 143 509	32 396	0	206	0	0	0
Mangaung Municipality	843 608	591 702	18 252	89 159	107 697	0	16 698	19 979
City of Cape Town	4 351 757	4 147 760	74 295	25 384	62	0	83 182	21 038
City of Johannesburg	5 674 824	5 237 302	91 357	78 770	166 705	0	83 943	16 639
City of Tshwane	3 756 308	3 013 804	78 235	514 069	87 091	1 365	38 043	23 646
Ekurhuleni metropolitan Municipality	3 862 672	3 540 646	35 446	155 600	11 015	0	75 178	44 631
City of eThekwini	3 856 877	2 713 870	162 508	623 069	188 554	6 684	62 390	99 764
Total for all metros	**24 298 029**	**20 988 562**	**516 134**	**1 517 210**	**659 220**	**8 049**	**360 847**	**239 814**

Flush Toilet (A) connected to sewage system
Flush Toilet (B) with septic tank
Pit latrine (A) with ventilation
Pit latrine (B) without ventilation
Data as at April 2019 with 95% confidence

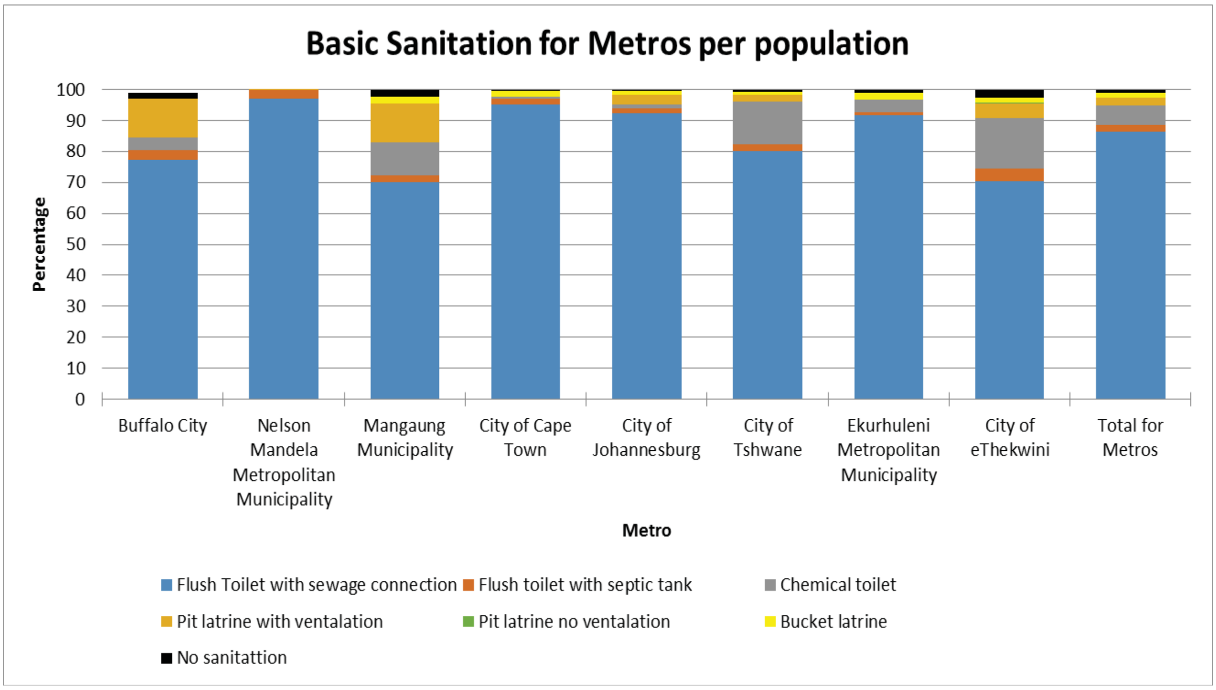


Figure 9. Basic sanitation services per population per metro

Service delivery levels within the metros is higher than that of the provinces, with a minimum of 70% of the population having flush toilets with sewage connection. Table 9 shows that the operational capacities of WWTPs in the metros are almost at their maxima, with an average demand of 90% of capacity. Mangaung and Ekurhuleni both exceed their WWTP operational design capacity. Thus safe population growth within the metros is limited from the sanitation service delivery aspect. The current COVID-19 pandemic is causing serious financial hardship to much of the population and an additional influx of rural people to the metros is highly likely once the pandemic passes.

Figure 10 and Figure 11 show the sewage treatment per person for the provinces and the metros.

In 2012, the Department of Public Works of South Africa published guidelines of sewage generation per capita. These are shown in Table 8.

Table 8. Domestic sewage flow litres per capita per day

Housing Standard	Number of houses per hectare	Volume (ℓ/capita/day)
Below average	20 or more	80 to 150
Average	3 to 20	120 to 200
Above average	3 or less	180 to 500

From Department of Public Works (2012)

From the data, Eastern Cape, Limpopo, Mpumalanga and the Northern Cape are considered below average to average for sewage generation, but this is most likely a result of the lower levels of connectivity to the sewers. Free State and the Western Cape are average with Gauteng, KwaZulu-Natal and North West all above average generators of sewage, in excess of 180ℓ per person per day.

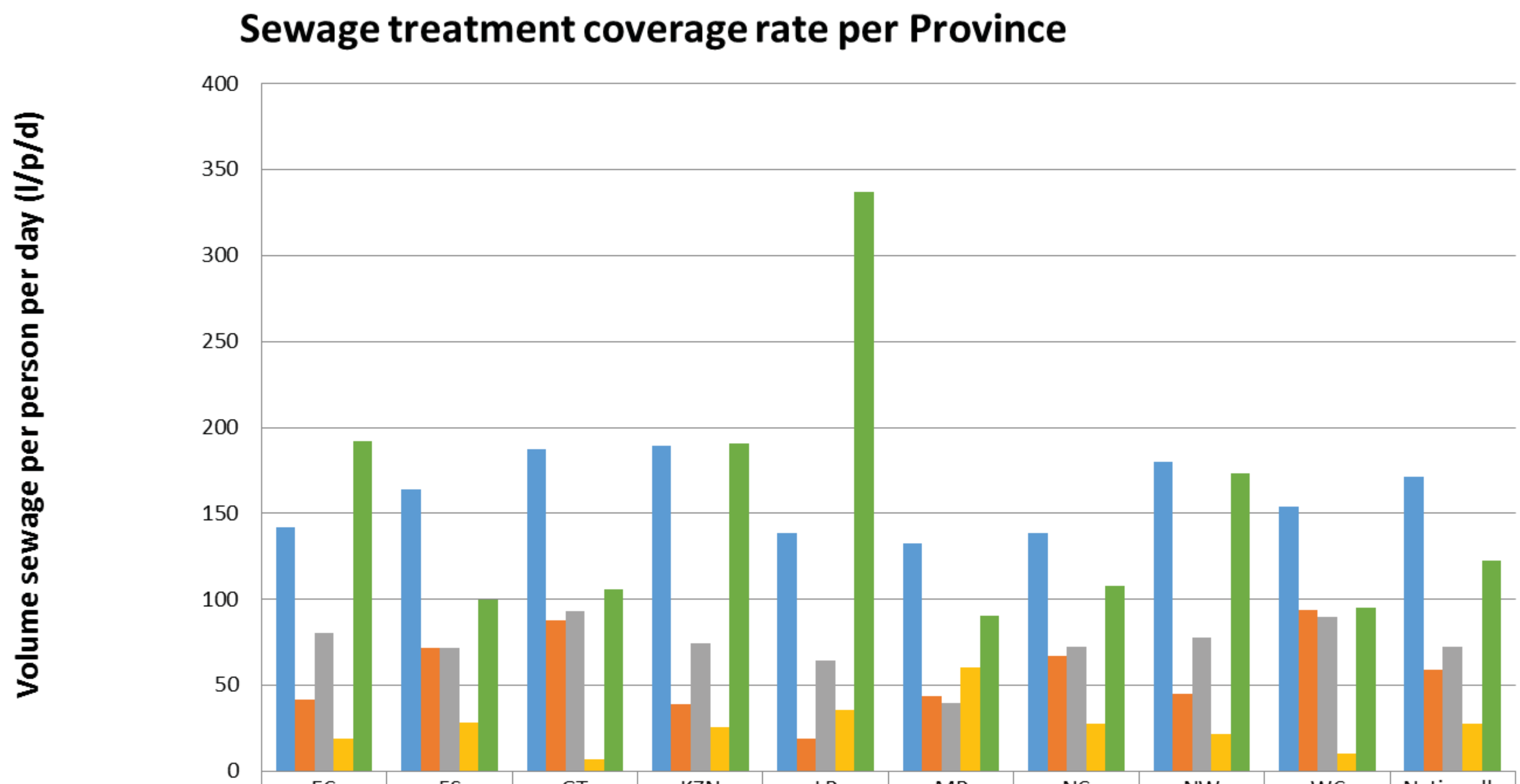
Theoretically, at the current WWTP capacity, if all the people in the country were to be connected to the sewer system, Limpopo would have the greatest operational problems as its operational capacity would rise to 337% capacity. The only provinces that would still be operating within design capacity would be Free State, Mpumalanga and the Western Cape.

Table 9. WWTP capacities per person

	Total Population	Sewered population	Percentage sewered	WWTP design capacity (Mℓ/d)	WWTP operational capacity (Mℓ/d)	Operational Capacity (%)	Number of treatment plants	Wastewater per population (ℓ/p/d)	Wastewater per connected population (ℓ/p/d)
Municipal data									
Buffalo City	775 872	599 969	77	105.3	91.5	86.8	19	117.9	152.5
NMB	1 176 000	1 144 000	97	206.7	147.9	71.6	8	125.8	129.3
Mangaung	843 608	591 702	70	112.8	118.2	104.8	12	140.2	199.8
City of Cape Town	4 352 000	4 148 000	95	774.9	762.5	98.4	31	175.2	183.8
City of Johannesburg	5 675 000	5 237 000	92	1 043.0	972.0	93.2	9	171.3	185.6
City of Tshwane	3 756 000	3 014 000	80	618.6	486.7	78.7	23	129.6	161.5
Ekurhuleni Municipality	3 863 000	3 541 000	92	677.4	729.4	107.7	17	188.8	206.0
City of eThekwini	3 857 000	2 714 000	70	733.5	536.6	73.1	28	139.1	197.7
Total for metros	**24 298 480**	**20 989 671**	**86**	**4 272.3**	**3 844.8**	**90.0**	**147**	**158.2**	**183.2**
Local Municipalities	**18 803 000**	**11 531 000**	**61**	**3 357**	**1 686**	**50.2**	**720**	**89.7**	**146.2**
District Municipality	**15 938 000**	**2 574 000**	**16**	**661.5**	**476.1**	**72.0**	**420**	**29.9**	**185.0**
Provincial data									
EC	6 503 426	2 711 656	42	476.5	384.9	80.8	166	59.2	141.9
FS	3 038 661	2 199 702	72	501.8	360.6	71.9	109	118.7	163.9
GT	15 343 460	13 561 386	88	2 723.5	2 538.4	93.2	78	165.4	187.2
KZN	11 534 505	4 476 617	39	1 142.4	848.4	74.3	280	73.6	189.5
LP	5 758 409	1 094 442	19	237.1	151.9	64.1	111	26.4	138.8
MP	4 909 831	2 136 651	44	713.4	283.5	39.7	139	57.7	132.7
NC	1 244 082	839 136	67	160.55	116.1	72.4	135	93.3	138.4
NW	4 106 541	1 836 919	45	424.3	331.2	78.1	74	80.7	180.3
WC	6 826 587	6 450 284	94	1 108.0	992.1	89.5	195	145.3	153.8
Nationally	**59 039 000**	**35 094 000**	**59**	**8 291**	**6 007**	**72.5**	**1287**	**101.7**	**171.2**

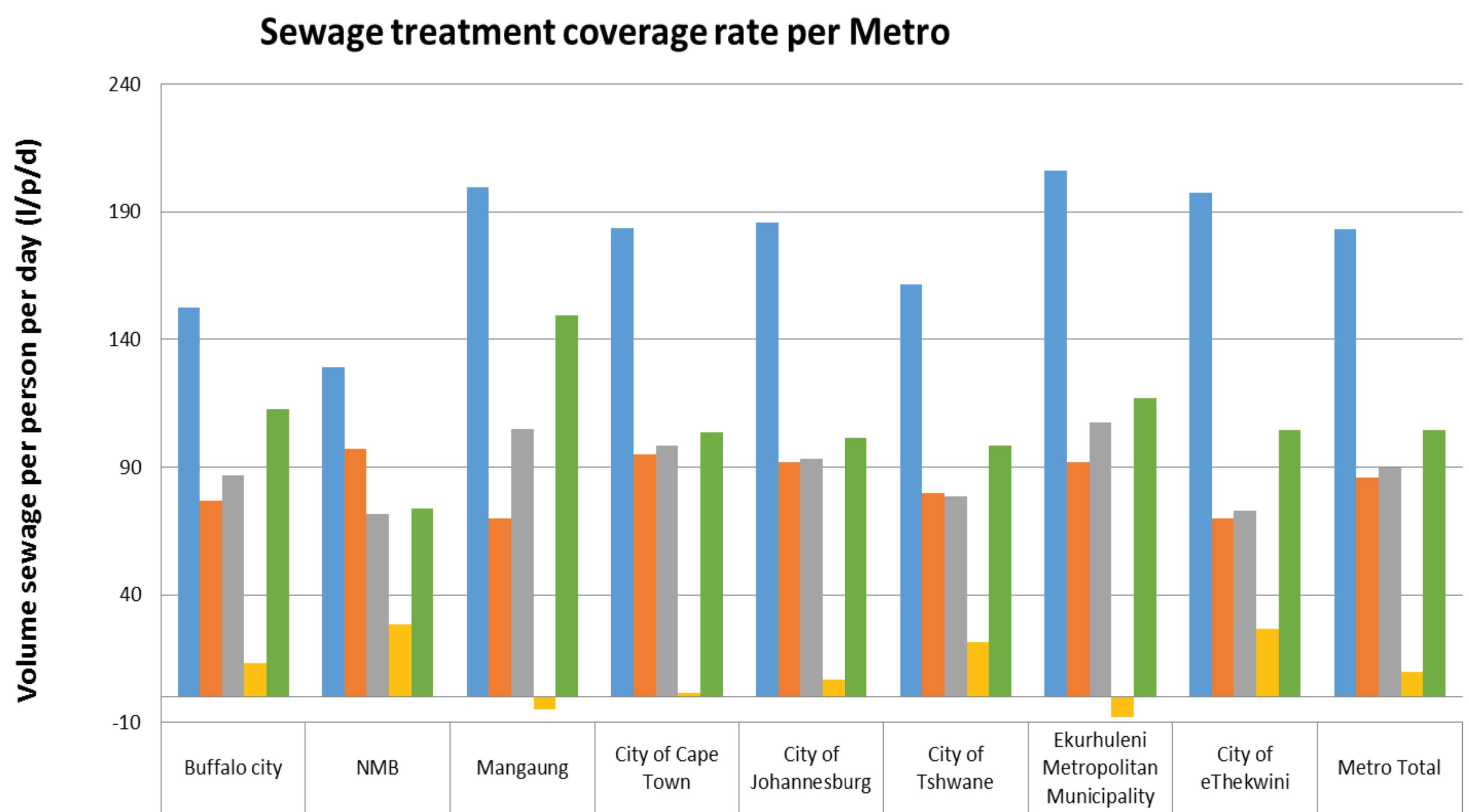
There is no differentiation between industrial and domestic waste and some data is rounded off.

Data from DWS database



	EC	FS	GT	KZN	LP	MP	NC	NW	WC	Nationally
Volume per person per day (l/p/d)	141.9	163.9	187.2	189.5	138.8	132.7	138.4	180.3	153.8	171.2
Percentage of population connected (%)	42	72	88	39	19	44	67	45	94	59
Operational capacity (%)	80.8	71.9	93.2	74.3	64.1	39.7	72.4	78.1	89.5	72.5
Spare Operational Capacity (%)	19.2	28.1	6.8	25.7	35.9	60.3	27.6	21.9	10.5	27.5
Operational Capacity at 100% sewered (%)	192.3	99.8	105.9	190.4	337.2	90.3	108.0	173.4	95.3	122.8

Figure 10. The sewage volume per population per province



	Buffalo city	NMB	Mangaung	City of Cape Town	City of Johannesburg	City of Tshwane	Ekurhuleni Metropolitan Municipality	City of eThekwini	Metro Total
Volume per person per day (l/p/d)	152.5	129.3	199.8	183.8	185.6	161.5	206.0	197.7	183.2
Percentage of population connected (%)	77	97	70	95	92	80	92	70	86
Operational capacity (%)	86.8	71.6	104.8	98.4	93.2	78.7	107.7	73.1	90.0
Spare Operational Capacity (%)	13.2	28.4	-4.8	1.6	6.8	21.3	-7.7	26.9	10.0
Operational Capacity at 100% sewered (%)	112.8	73.8	149.7	103.6	101.3	98.3	117.0	104.5	104.6

Figure 11. Sewage volume per population per metro

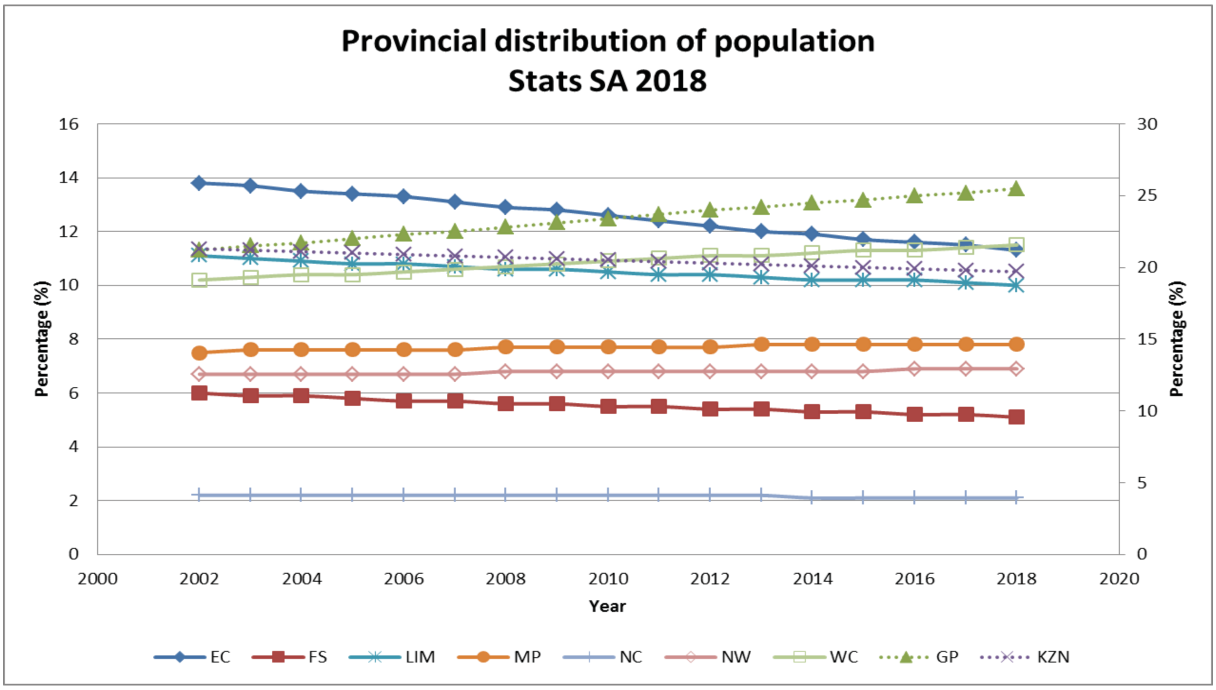


Figure 12. Provincial distribution of population (2000-2018).

Gauteng and KZN on the RHS axis

Of the metros, Nelson Mandela Bay was the best performing as it has the highest percentage of population connected to the sewers and the greatest spare operational capacity. Buffalo City, NMB and Tshwane have the least sewage generation per capita. The lowest performing metros were Mangaung and Ekurhuleni as they are already operating above design capacity. If all of the metro residents were connected to the sewers at the current WWTP capacity, then only Nelson Mandela Bay and Tshwane metros would be operating within design capacities. This highlights the limited spare capacity of the metros' WWTPs.

Thus, important challenges related to wastewater in South Africa are the overall lack of adequately-sized infrastructure and maintenance of WWTPs, which has resulted in many cases of raw sewage flowing untreated back into the receiving waters. South African cities are growing quickly, and their current water management systems cannot keep up with the growing demand. Currently Gauteng and the Western Cape experience the greatest inflow of migrants, as shown in Figure 12, and this trend is expected to increase (StatsSA, 2018).

Both the Western Cape and Gauteng have already shown their vulnerability to water scarcity in recent years, as have most other provinces. Climate change and population growth will, no doubt, render the country still more vulnerable to water shortages. Nonetheless, this situation provides an impetus for improved urban wastewater management using multi-purpose technologies for water re-use, and the recovery of useful by-products. In order to counter the impending (and existing) capacity shortages, the country, and especially the metros, lower overall water usage and wastewater generation, by means of educational initiatives and other measures. Reduced wastewater influx to WWTPs from already connected residents will free up additional capacity for new connections. This should be done before spending resources on capital intensive projects such as upgrades and new treatment works. The limits on operational capacity will become a larger problem in the near future as urbanisation continues.

6. SURFACE WATER QUALITY IN SOUTH AFRICA

SDG Target 6.3 sets out to improve ambient surface water quality, and this section provides some background on important water quality indicators, and an overview of surface water quality in South Africa based on recent published data.

Water quality refers to the physical, chemical and biological characteristics of water with regard to how suitable the water is for its intended use (DWA, 2011). According to the National Water Act, water quality relates to all the aspects of a water resource, including in-stream flow (quantity, pattern, timing, water level and assurance), natural water quality (physical, chemical and biological characteristics), in-stream and riparian habitat (character and condition) and aquatic biota (characteristics, condition and distribution).

South Africa is faced with water quality challenges which are mainly induced by human activity. These are associated with industries that produce chemical effluent, mines that introduce metals and acids to water resources, wastewater treatment works that discharge untreated or poorly treated effluents introducing excessive nutrients, phosphates and coliforms, and agriculture which uses pesticides, herbicides and fertilisers introducing salts and toxic substances into the water. Some commonly occurring water quality problems in South Africa are summarised in the following sections.

6.1 VARIABLES THAT AFFECT WATER QUALITY

6.1.1 Salinity

Salinity is the measure of quantity of total dissolved inorganic solids, or salts, present in water. Dissolved salts in freshwater systems come from rainwater runoff in the catchment, agricultural return flows and urban and industrial run-off. Increased salinity of water leads to reduced crop yields, scale formation and corrosion of water pipes and changes in freshwater biotic communities (DEAT, 2006). High levels of salinity are a major limiting factor in the fitness for use of water. Salinisation is a persistent water quality problem throughout most of South Africa.

Some river systems are naturally saline due to geological conditions, for example in the northern, western and eastern Cape. In some areas, groundwater shows high levels of salinity which are above the recommended concentrations for human use (Ashton, 2009). In these cases, aquatic ecosystems have often naturally adapted to the salinity levels.

6.1.2 Eutrophication

Eutrophication is the enrichment of water with plant nutrients (mainly nitrates and phosphates). This encourages the growth of microscopic green plants and algae, and can promote the growth of cyanobacteria, presenting a toxic threat to aquatic fauna and human users of the water (DEAT, 2006). Eutrophication causes the depletion of oxygen in water which may lead to mass mortalities of biota. Sources of nutrients include domestic wastewater treatment, application of fertilisers on crops and subsequent return flows, and various industrial and mining processes.

6.1.3 Micro-pollutants

Serious incidents of health impacts to people and animals have occurred through uncontrolled exposure to micro-pollutants. This resulted in increased attention on the presence of metals, carcinogens, synthetic chemicals, pharmaceuticals, veterinary and illicit drugs in water (Ashton, 2009 and Olujimi, 2010). Pollution of this type tends to be highly localised and associated with specific industries or activities. Further, ingredients in cosmetics, personal care products and food supplements may concentrate endocrine-disrupting chemicals in the environment. These pollutants may also enter water through accidental spills and via stormwater runoff after rainfall events. Aquatic biodiversity is particularly at risk from micro-pollutants and endocrine disrupting chemicals since the aquatic environment is a sink for hormonally-active chemicals, including industrial chemicals, pesticides, organo-chlorides, pharmaceuticals, natural and synthetic oestrogens or phytoestrogens (Olujimi 2010; van der Merwe-Botha 2010).

6.1.4 Microbiological pollutants

Water contaminated by bacteria is the medium for the spread of diseases such as dysentery, cholera, skin infections and typhoid. Many of these diseases can be attributed to poor sanitation practices arising from poorly maintained, or a lack of adequate sanitation infrastructure, and is a widespread problem in South Africa (DWAF, 2004). Some recent examples are explored in Section 7.

6.1.5 Sediments

Run-off from land-based activities such as agriculture or poorly designed developments (e.g. untarred roads), carries sediment into rivers. Some secondary effects of increased sediment load are that the useful lifespan of dams is decreased, due to a loss of storage capacity, the lifespan of pumps and pipes is diminished, and the integrity of rivers is compromised through sedimentation. Sedimentation can have substantial economic implications in terms of infrastructure maintenance costs as well as increased costs to manage the water resource.

6.2 SURFACE WATER QUALITY DATA

Figure 13 shows four indicator variables (chloride, sulphate, total dissolved solids and nitrates) based on data from the National Chemical Monitoring Programme for Surface Water (DEAT, 2006). The results only show large changes, so visible trends such as the sulphate and total dissolved solids increases in the Olifants WMA most likely reflect the effects of mining activities. Increases in salinity at coastal sites are, however, often the natural result of seawater mixing in estuaries. The large changes in salinity evident along the Great Fish river are the result of transferring low-salinity water from the Orange River system into a naturally saline environment.

At the scale of the maps in Figure 13, many local water chemistry problems are not visible. For example, Figure 13 does not show recorded microbial pathogens, trace metals or organic compounds, which may be of great importance at the local scale. The Vaal, Crocodile and Olifants river systems are severely affected by salinity, which could be attributed to mining activities. In general, the compounded effects of agriculture, industry, mining and urban development have cause a deterioration in the quality of water and its fitness for use. The main contributors to microbial pollution are a lack of proper sanitation facilities, the rapid increase of un-serviced informal settlements and ageing and overloaded municipal infrastructure (DEAT, 2006).

In a recent review article, Verlicchi and Grillini (2020) analysed surface and groundwater quality in South Africa and Mozambique reported in 44 peer-reviewed articles published between 2001 and 2019. Microbial pollution was a widespread concern, as was the concentration of dissolved metals. They noted that nickel was reported as consistently occurring at higher concentrations than the national water quality standard. A striking finding was that micro-pollutants, especially the pharmaceutical compounds including ibuprofen, acetylsalicylic acid, clozapine and estriol were found at higher concentrations than in European rivers in several studies.

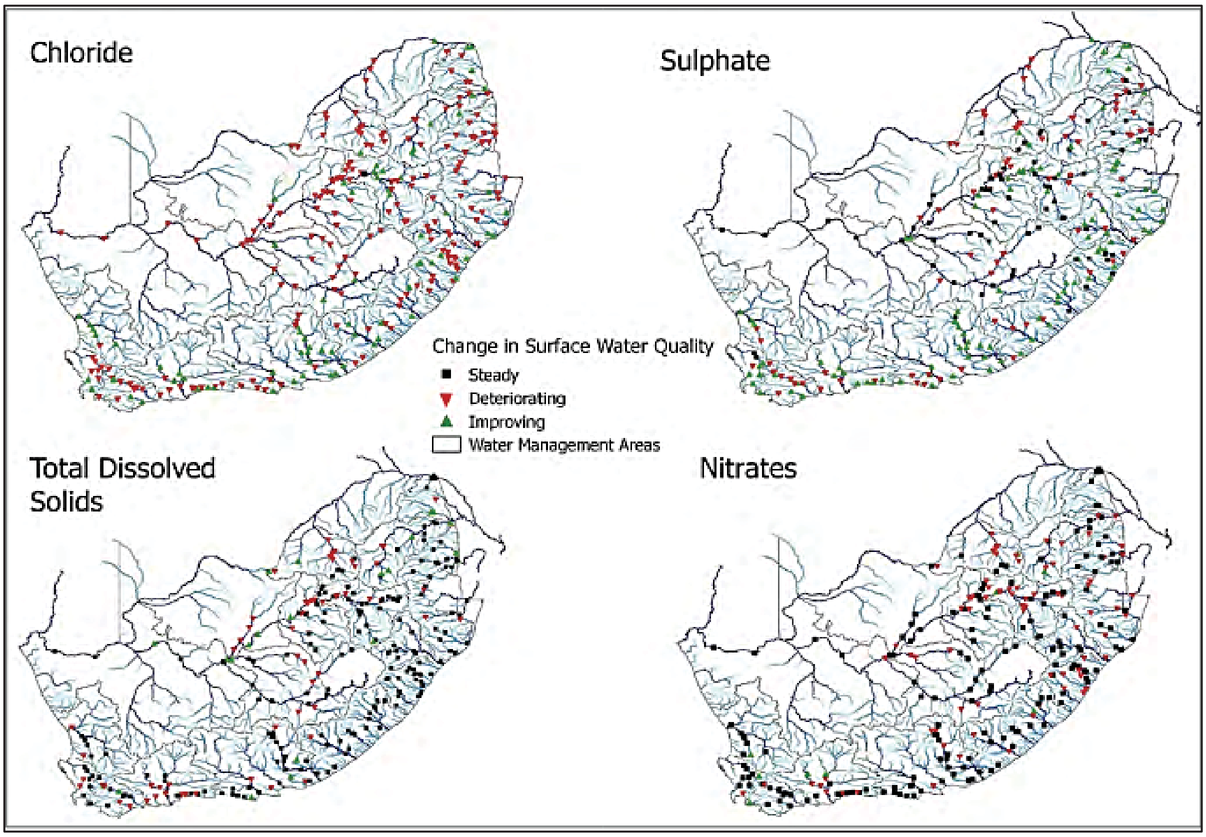


Figure 13. Surface water quality trends for chloride, sulphate, TDS and nitrate

Adapted from DEAT, 2006

6.3 TROPHIC STATES OF MAJOR DAMS

Eutrophication in South Africa is mainly caused by inadequately treated sewerage effluents that are discharged into river systems. Other sources of high nutrient loads resulting in eutrophication include industrial effluents, agriculture, households, and urban and road surface runoff. The DWS National Eutrophication Monitoring Programmes uses chlorophyll and phosphorus levels to assess the status of dams. Dams are classified as either mesotrophic, oligotrophic, eutrophic or hypertrophic. Data from the monitoring programme indicates that some dams are severely impacted, particularly those in the urbanised areas. A number of dams are classified as hypertrophic namely: Hartebeespoort, Bon Accord, Bospoort, Roodeplaat, Roodekopjes, Glen Alpine, Mutshedzi, Albasini, Bronkhorstspruit, Spitskop, Nagle and Shongweni Dams (Harding 2011; Oberholster and Ashton 2008).

Hypertrophic dams are defined as those that have a very high nutrient concentration and water quality problems are serious and may be continuous (DWAF, 2004). Matthews and Bernard (2014) found that of 50 water bodies in South Africa, 62% was hypertrophic and 26 had cyanobacterial blooms which posed a high health risk from surface scums. Scums became more common between 2005 and 2011 in four of those water bodies.

In summary, the main threats to surface water quality are due to municipal wastewater discharges, and wastewater or runoff from agriculture, mining and industry. Pollution has been apparent at both the local and regional scales for decades, and is a growing problem, as illustrated by the case studies in the following section. For the purposes of tracking progress towards SDG Target 6.3, regular assessment and publication of national ambient water quality data is essential.

7. SOUTH AFRICAN WASTEWATER CASE STUDIES

This section presents a selection of news items and research findings from the past 20 years dealing with the detrimental effects of poor wastewater management on public health and the environment, and some of the causes of this multifaceted problem.

One factor is insufficient maintenance: in 2007, the CSIR estimated that the current replacement cost of all municipal engineering infrastructure and buildings (excluding housing) would have been at least R300 billion. Given the poor state of much of this, and that repair and refurbishment would be required in addition to planned maintenance, international norms suggest that approximately 4% of the replacement value should on average be spent per annum on maintenance (excluding for disposal and replacement), amounting to about R12 billion per annum. However, municipalities were on average budgeting for less than half of this in 2007 (Department of Public Works, 2007).

Other studies have reported a diverse set of weaknesses in municipal wastewater governance, including understaffing, low morale, poor managerial guidance and decision making, lack of maintenance, poor operating procedures, personnel not suitably trained for their respective duties, aging infrastructure and WWTPs being undersized (CER, 2012).

7.1 THE VAAL RIVER SEWAGE SPILLS

The Integrated Vaal River System (IVRS), which supplies Gauteng and the North West with drinking water, is critically important to SA, supporting about 60% of the economy. About 45% of the country's population lives in the area supplied by water from the IVRS via Rand Water. More than a million people live in the most affected Vaal district municipality, Sedibeng, which includes Emfuleni, according to Stats SA's 2011 census. Though updated official statistics are not available, only about 53% of the Sedibeng population has access to piped water, while the rest use groundwater, run-off and other sources, including untreated water directly from tributaries and the Vaal River (Business Day, 2018).

The Vaal River supplies about 50% of Gauteng's water. Raw sewage spills regularly into the river from pump stations in the Emfuleni municipality on the northern bank of the Vaal River, posing environmental and health risks, as shown in Figure 14.

Figure 14. The effects of raw sewage flowing into the Vaal River

Taken from Independent Online (2019) and The South African (2018)

Communities affected by the pollution include Vereeniging, Sebokeng, Boipatong and Sharpeville. After a public outcry, the Finance Minister announced in the medium-term budget policy statement in October 2018, that the army had been called on to assist with engineering and other expertise to resolve the crisis at the Vaal river system.

Ageing infrastructure, vandalism and theft had left water treatment works in the area dysfunctional and unable to provide clean water to local communities. In places, sewage was spilling into streets, homes and schools.

The deployment of the army follows years of sewage-related problems. About 150-million litres of sewage was spilling into the Vaal via its Rietspruit tributary every day, according to environmental group Save, who were granted seven court orders compelling the municipality and the DWS to fix the problem. The Co-operative Governance and Traditional Affairs (CoGTA) Deputy Minister conceded that the Vaal river contamination was a national crisis and said national intervention was needed (The Daily Maverick, 2018).

The South African National Defence Force (SANDF) said it was making headway with the Vaal river rehabilitation project. In a statement on 17 January 2019, the SANDF said it had deployed technical teams to restore infrastructure at the polluted Vaal river system caused by raw sewage flowing into the river from pump stations in the Emfuleni Municipality. Other progress cited by the SANDF included the deployment of the SA Army Engineer Formation to the Emfuleni Municipal Area, as well as the drawing up of the scope of work, which focuses on the upgrading of sewer treatment works and pump stations. The South African Human Rights Commission called the situation at the Vaal river a human rights crisis, as a site inspection by the Commission revealed a *prima facie* violation of the rights of access to clean water, clean environment and human dignity.

However, as of end-January 2019, the SA National Defence Force (SANDF stopped work at the Sebokeng Wastewater Treatment Plant and sources of sewage pollution of the Vaal River in the Emfuleni district, until R873 million was released by National Treasury. The SANDF had made considerable progress, but it was unable to rebuild the collapsed waste-water system until government funds were released. SANDF appealed to the private sector for funding and expertise to complete the repairs, while National Treasury said it was working on a funding model for the intervention (Business Day, 2019).

More recently, in January 2020, the Minister of Human Settlements, Water and Sanitation issued a statement to assure the community of Emfuleni that the problem of sewage spillage would be solved, and gave Ekurhuleni Water Care Company (ERWAT) until June 2020 to complete its repair work (DWS, 2020).

7.2 HAMMANSKRAAL WATER CONTAMINATION

In October 2019, the City of Tshwane was supplying the residents of Hammanskraal and the surrounding areas with potable water as a direct result of the poor water quality of the Leeukraal Dam, a source of water for Hammanskraal. The old infrastructure and under-staffing of the Rooiwal Wastewater treatment works were to blame for the crisis, with the plant needing a staff complement of 90 personnel but operating with about 56 people. The plant receives 60% of all the wastewater in Tshwane. Poor quality water effluent flows into the Apies river which feeds the Leeukraal dam. The CSIR had independently tested the water and found it unfit for human consumption. The lack of planning has now resulted in crisis spending and will cost over R2 billion over 2 phases. (News24, 2019).

7.3 UPPER VAAL BLOEMHOF DAM

A 2007 estimate by environmental scientists found an annual flow of 910 million kilograms a year of faeces, urine and waste into the Bloemhof dam. In 2014, a water contamination crisis killed three babies, hospitalised five and caused over 500 cases of diarrhoea, resulting in the mayor being removed from office. While it was suspected that the water contained *E. coli* bacteria, the National Institute for Communicable Diseases ruled out cholera. In another incident in 2019, supplies of tap water were cut off in order to reduce the possibility of the community drinking potentially polluted water supplies. The community had to have water delivered by water tankers, while the local municipality did emergency maintenance and cleaning of the water treatment plant (Independent Online, 2019).

7.4 CHOLERA EPIDEMICS

A total of 265 people died in a cholera epidemic in 2000/01, in five provinces, mostly in KwaZulu-Natal. Over 117 000 people were infected. It was the largest outbreak in Africa for the reporting period. The epidemic was directly attributed to the government's policy of cost recovery for water, when new charges for water supply were implemented in August 2000. The additional costs were too high for many people and they returned to traditional, untreated water sources, and were consequently infected by drinking contaminated water. The epidemic was considered a national emergency and the government promised to provide 6 kilolitres of water a month free to every household (Mugero, 2001).

A 2006 study of two communities affected by the epidemic showed improvements in that most people had access to piped water and used ventilated improved privies (toilets). But there were frequent reports of interrupted water supply due to vandalism, burst pipes and non-payment, and the government had not kept their promise of providing free water. As a result, many people were storing water, another risk factor for cholera. The incidence of diarrhoea among children was also associated with extreme poverty, as are problems accessing sufficient water, the ability to pay for water and the household having prior experience of cholera. All these factors — in particular the continued cycle of water-related disease in households over time — point to poor health conditions and continued vulnerability to disease among those living in extreme poverty (Hemson, 2006).

In January 2009, there was a smaller cholera outbreak in South Africa affecting several provinces, with at least 15 people dying of the disease and over 2 000 people infected. The worst-hit province was Limpopo. In Zimbabwe, a major epidemic broke out in August 2008, which killed over 2 000 people by January 2009, and infected more than 40 000, although the health department stated that the South African outbreak could not be blamed on Zimbabwe, but rather on the fact that over 10% of South Africans still did not have access to safe drinking water (Chauke, 2009; Mail & Guardian, 2009).

7.5 UNDER-FIVE MORTALITY AND DIARRHOEAL DISEASE

Diarrhoea is one of the most common diseases caused by water pollution. It is most often caused by water-borne viruses but bacteria and parasites from water contaminated with faeces are also common causes. Under-five mortality is an important indicator of child health and a measure of a population's socio-economic well-being. South Africa has not yet achieved complete reporting of births and deaths in the civil registration system and, as a result, estimation of mortality is often derived from census and survey data, by employing indirect demographic estimation techniques or through modelling.

StatsSA (2013) used 2011 census data to derive the under-five mortality rates (U5MR). Findings from this study highlight a downward trend in U5MR nationally from 75 deaths per 1 000 live births in 2006 to 34 per 1000 in 2016. The decline in deaths amongst infants may be partially due to increasing access to clean water over the seven (7) year period. Diarrhoeal disease is the second leading cause of death in children under-five years old, and is responsible for killing around 525 000 children worldwide every year (StatsSA, 2013). Diarrhoea can last several days, and can leave the body without the water and salts that are necessary for survival. In the past, for most people, severe dehydration and fluid loss were the main causes of diarrhoea deaths. Now, other causes such as septic bacterial infections are likely to account for an increasing proportion of all diarrhoea-associated deaths. Children who are malnourished or have impaired immunity, as well as people living with HIV are most at risk of life-threatening diarrhoea.

However the U5MR by population group showed a stark racial discrepancy: White (14.8) - Asian/Indian (21.8) - Coloureds (30.2) - Black Africans (52.4). The under-five mortality differentials by province also show clear spatial differentials in South Africa (Figure 15). At provincial level, Western Cape and Gauteng had the lowest U5MRs of 24.5 and 34.3 deaths per 1 000 live births, respectively, while Free State and KwaZulu-Natal had the highest U5MRs at 68.4 and 62.6 deaths per 1 000 live births respectively (StatsSA, 2013).

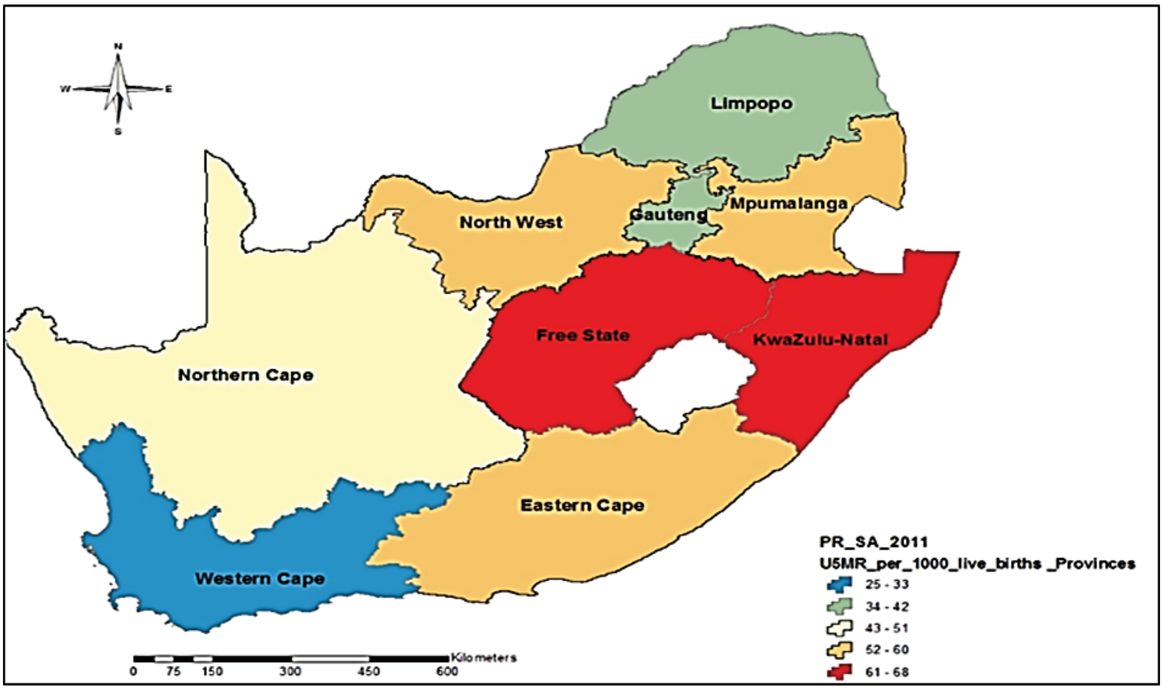


Figure 15. The under-five mortality rate by province

(Adapted from StatsSA, 2013)

7.6 TYPHOID FEVER

Typhoid fever remains endemic to many parts of South Africa, including KwaZulu-Natal, Limpopo and the Transkei, with a 2005 outbreak occurring in Delmas, Mpumalanga. Health spokespersons reported that there were 380 cases of diarrhoea, 30 suspected cases of typhoid fever and nine confirmed cases. The outbreak originated in the town’s water supply, suspected to have been contaminated with human faeces (Mail and Guardian, 2005).

7.7 JUKSKEI RIVER SEWAGE RELEASES AND BLOCKED INFRASTRUCTURE

Kings (2018) reported that recent releases of raw sewage into the environment, including the Jukskei River were due not only to ageing and poorly maintained infrastructure, but also rapid development of properties along the Jukskei river, a 25% under-recovery for water sales (i.e. municipal water bills not being paid), and blockage of networks by objects like used nappies and building rubble. It was estimated that Johannesburg Water required R25-billion to repair and expand infrastructure.

At the time of Kings' report in 2018, the Northern Works plant outside Johannesburg had been releasing untreated sewage for a decade and the Greater Kyalami Conservancy was reporting that spills happened at least once a month. Sewage was flowing into the Jukskei, then the Crocodile River and then into Hartebeespoort Dam, which is the main source of drinking and irrigation water for the eastern part of the North West Province. Haartebeespoort Dam suffers from eutrophication and the Department of Water Affairs (now DWS) had spent R900 million in the decade from 2004 to rehabilitate the dam. However, sewage pollution flowing into the dam has undermined the rehabilitation efforts (Kings, 2018).

Figure 16. The polluted Jukskei River

Photograph: Kings (2018).

7.8 DEGRADED WETLANDS, KLIP RIVER, GAUTENG

Durgapersad (2005) studied the effects of wetlands on water quality and invertebrate biodiversity in the Klip and Natalspruit rivers in Gauteng, and found that the river water quality along the Klip river system was deteriorating due to effluents entering the system from industries, WWTPs, informal settlements, urban and agricultural runoffs. This was damaging the health of wetlands along the river. Vermaak (2009) confirmed that the state of the Klip river was dire due to the disappearance of wetlands, and highlighted that the remaining wetlands along the Klip river are not healthy or developing sufficient reed populations to reduce the impact of the sewage, industrial and mining effluents. If the wetlands within the Klip river collapse completely, the water quality will worsen along the Klip river, Vaal river and in the Vaal Barrage, and this will impact negatively on the downstream users (Mothetha, 2016).

7.9 SEWAGE TREATMENT WORKS FAILURES, EASTERN CAPE, 2006

A study by Momba et al., 2006 showed that in the Buffalo City and Nkonkobe Municipalities of the Eastern Cape Province, the poor operational state and inadequate maintenance of the municipalities' sewage treatment works, i.e. design weaknesses, overloaded capacity and faulty equipment and machinery, were causing a major pollution problem that impacted on the quality of water resources, and resulted in marine water quality which did not meet regulatory standards (Momba et al., 2006).

7.10 RED TIDES IN THE OCEAN

The Daily Maverick reported on 5 December 2018 that after light rain in November, the Zandvliet Wastewater Treatment Works (WWTP) had discharged millions of litres of what was observed to be raw, unfiltered sewage into the Kuils river, via a channel known by locals as the Kakrivier ("Shit river"), which was bulldozed for this purpose by the City of Cape Town. That these discharges happened just after two light rainfalls suggests that stormwater had entered the sewage system and the Zandvliet

WWTP had overflowed.

According to the Daily Maverick (2018), the treatment works was discharging sewage along the channel on a regular basis. The citizens of Sandvlei along the Kuils river below the discharge point are ill, some having had surgical interventions (for *E.coli* poisoning of the intestine or the cardiac system), or needing to take regular prescription drugs. Staphylococcal skin infections and eczema are common, and anecdotally related to contact with the water. Horses have died from drinking the river water, or suffered from birth defects.

Further downstream, at Macassar, the Kuils river joins the Eerste river and flows in False Bay near the beaches at Strand, Monwabisi (see Figure 17) and Wolfgat. The river discharges into the waves, so the microbial or chemical load it was carrying would tend to stay close to shore. In False Bay, the water tends to circulate clockwise, towards Strand and Gordon's Bay, where historically several marine die-offs have occurred due to "red tides" or other algal blooms (see Figure 18), possibly stimulated by nutrients from sewage. The sewage is known to also have contained chemical pollutants, including pharmaceuticals such as anti-retrovirals (Daily Maverick, 2018).

Figure 17. A tidal pool on False Bay, Cape Town where a sewage leak contaminated the water

(Authors' photos)

Figure 18. Red tide in Strand, Cape Town 2019 and clear conditions (lower photograph)

(Authors' photos)

7.11 AGING INFRASTRUCTURE AND POOR MAINTENANCE

In April 2010, the Water and Environmental Affairs Minister announced the findings of a Green Drop report assessing 449 WWTPs across the country, and stated that R23 billion would be needed to prevent their collapse (Ndaba, 2010). The 2010 Green Drop report indicated that 55% of sewage plants scored below 50%. The last Green Drop report, published in 2014, showed that 25% of plants were in a critical state, and another 25% considered high risk (Makhafola, 2018). More recently, in July 2018, the Institute for Security Studies (2018) reported that two-thirds of WWTPs did not meet the minimum standards.

8. WASTEWATER AS A PATHOGEN INDICATOR (COVID-19)

The primary focus of this report is wastewater as a resource, but wastewater has shown itself to be an important early warning indicator of pathogens. On 31 December 2019, the World Health Organisation (WHO) reported a cluster of pneumonia cases in Wuhan, China. The SARS-CoV-2 virus was confirmed as the causative agent of Coronavirus Disease 2019 (COVID-19), which has subsequently spread worldwide.

The presence of pathogenic viruses in wastewater is well documented and has been used as early warnings of hepatitis A and norovirus outbreaks (Hellmer et al., 2014, Montazen et al., 2015). Wang et al., 2020, found that the faeces of 44 of 153 samples (29%) from infected patients tested positive for SARS-CoV-2. Since shedding happens early in the disease's progression, before patients show any symptoms, it was suspected that evidence of the virus might be found in wastewater, even before residents have been tested. This was confirmed recently when microbiologists at the research institute KWR in the Netherlands detected SARS-CoV-2 in influent sewage at a Dutch WWTP. The method used did not differentiate between inactive and infectious particles and the findings indicated that the concentration of the virus at the WWTP was low (Medema, 2020).

The virus is sensitive to temperature and disinfectants, which inactivate the virus. Primary viral transmission is in air droplets from an infected person coughing or sneezing or by contact with contaminated surfaces. As a result of this and with no epidemiological signals that sewage workers are at risk, the risk of SARS-CoV-2 transmission via sewage is considered low and with current protective measures, basic hygiene and standard practices these workers are deemed safe. There is also no current evidence to date to oppose this view.

However, the risk of transmission of the virus that causes COVID-19 from the faeces of an infected person is still unknown. It is also not known if the virus is still infectious after shedding in sewage. It is expected to be low based on data from previous outbreaks of related coronaviruses, such as SARS and Middle East respiratory syndrome (MERS), and there has been no confirmed faecal-oral transmission of SARS-CoV-2 to date. Nonetheless, it should be noted that SARS-CoV-2 has been detected in stool of infected people and on toilet surfaces in hospitals treating COVID-19 patients. (Centres for Disease Control and Prevention, 2019).

The Dutch results suggest that the testing of sewage water could be used as a tool to measure the virus circulation in cities or smaller municipalities. No SARS-CoV-2 material was detected in the effluent discharged from the WWTP in this study, confirming that the new virus did not survive the treatment process. The presence of the virus in influent wastewater at WWTPs could be used as an indicator for virus infections in the population and could signal a new outbreak, for instance after a lockdown is lifted, and also be used in general to help monitor the effect of measures put in place to mitigate the spreading of the pandemic.

Testing of wastewater through the duration of the pandemic could help determine whether the coronavirus is disappearing in the population ('flattening of the curve') or whether it is returning in a city or municipal area served by a WWTP. Hotspots may be identified and resources deployed based on monitoring results, and guide authorities to implement correct management strategies, such as the optimal timing of lockdowns and other measures. Wu et al*.,* 2020, have been testing influent wastewater at treatment plants in the United States, and have found higher concentrations of the virus than expected from the known infected population, suggesting that this approach could be used to estimate actual population infection rates when individual testing is limited.

These results are similar to those from the 2005 SARS epidemic, when Chinese microbiologists showed that SARS-CoV had been detected in the sewage water of Chinese hospitals where SARS-patients were treated. SARS was detected in untreated sewage for up to 14 days (Centres for Disease Control and Prevention, 2019).

In South Africa, Osuolale (2017) detected bacteria and viruses in wastewater treatment plants in Buffalo City, Eastern Cape. It was also shown that treated wastewater effluent may still contain infectious human viruses in this case. There is currently no requirement in South Africa to monitor viral concentrations in wastewater before discharge.

9. OPPORTUNITIES TO EXPLOIT THE WASTEWATER RESOURCE

Recent water policy has taken a more integrated view of the human water cycle, and considered wastewater within emerging sustainability paradigms, such as the circular economy, cleaner production, seeing wastewater as a resource, not a liability, and taking a pragmatic "fit-for-purpose" approach to water quality. There has also been an abundance of research and practical case studies considering the viability of nutrient and energy recovery from urban wastewater. This section reviews some of this research and recent examples, from South Africa and internationally.

9.1 PARADIGMS – THE CIRCULAR ECONOMY

The circular economy (CE) is a concept in which products, materials (and raw materials) should remain in the economy for as long as possible, and wastes should be treated as secondary raw materials that can be recycled for process and re-use. This distinguishes it from a linear economy based on the, '*take-make-use-dispose*' system, in which waste is usually the last stage of the product life cycle. According to Neczaj (2018), the main reasons for implementing a circular economy in Europe include:

- limited availability of raw materials,
- dependence of the European economy on the import of raw materials affected by high prices and market volatility,
- uncertain political situation in selected countries, and
- decreasing competitiveness of the European economy in global economies.

Urban wastewater treatment plants can be an important part of circular sustainability due to integration of energy production and resource recovery during clean water production. WWTPs should become "ecologically sustainable" technological systems. The main drivers for developing wastewater industry are global nutrient needs and recovery of water and energy from wastewater (Mo and Zhang, 2013).

For example, phosphate rock has been listed as a critical raw material by European Commission, so its recovery from renewable resources has gained importance. Cordell et al., 2009 estimated that 20% of the mineral phosphorus consumed was excreted by humans, and estimated that it was possible to supply the mineral phosphorus market by recovery of phosphorus from excreta streams (including domestic animals). Potassium could also be recovered from these waste streams. Moreover, effluent from WWTP is relatively easily recycled for agricultural use, industrial processes and other beneficial purpose reducing demand for potable water (Cordell et al*.,* 2009).

With regard to energy consumption, most WWTPs were designed to meet the requirements for the effluent quality without consideration of energy requirements. According to the European Benchmarking Cooperation, the average electricity consumption for wastewater treatment was 33.4 kWh/PE, where PE is the 'population equivalent'. Energy consumption of sewage treatment plants in Europe and the United States ranges between 0.15–0.7 kWh/m^3, depending on the type of plant. The requirements for reduced carbon emissions will require increasing energy efficiency in WWTPs (WssTP, 2018 and Hansen, 2013), and the opportunities for energy recovery from biogas produced on site (Neczaj, 2018), discussed in Section 9.7 below will be part of improving energy efficiency.

9.2 PARADIGMS - CLEANER PRODUCTION AND ITS APPLICATION TO URBAN WASTEWATER MANAGEMENT

The urban water and waste management situation may be usefully addressed from a "cleaner production" angle. Cleaner production interventions have been extremely successful in the industrial sector. By evaluating the current urban water management system from a cleaner production point of view, the urgency to re-think current practices/concepts in the light of sustainability becomes evident.

The cleaner production concept developed over the past two decades, has brought some innovative environmental thinking into the industrial sector, especially in terms of waste avoidance/reduction and use of substitutes (Nhapi and Gijzen, 2005). The principles of cleaner production as applied to water management are shown in Table 10.

Table 10. Cleaner production principles applied to water management practices

Principle	Current practice	Proposed remedy
Use the lowest amount of input material	The supply of 130 to 350 ℓ of drinking water per capita per day, while less than 2 ℓ is used for drinking	Low water or dry sanitation Water saving interventions
Substitute material of higher quality for lesser quality if it does not affect the end product	Water purified to drinking water standards is used to flush toilets, clean floors, wash cars or to irrigate the garden.	Re-use greywater Rainwater harvesting
Do not mix different waste /flows	Already in the household various wastewater flows are combined (urine and faecal matter, grey and black water). After disposal into the sewer this combined waste is mixed further with industrial effluents, and urban runoff. This practise makes re-use of specific components in the mixed waste flow less attractive and less feasible.	Convert waste for re-use Select treatment based on by and side products Separate waste stream (e.g. stormwater and sewers)
Evaluate other uses of by-products before treatment and disposal	Domestic sewage is discharged into open water resources either with or without prior treatment. Only a few examples of wastewater re-use or (by-) product recovery final disposal. from wastewater exist	

Water reclamation, or the direct use of treated sewage effluent to replace a proportion of the fresh water demand, is regarded as a non-conventional approach to water management. However, water reclamation is becoming increasingly common internationally, especially in countries which have water shortages.

For sustainable wastewater management to succeed it is necessary to separate industrial and domestic waste before any treatment, so as to avoid contamination. Technologies that treat wastewater should be rational, sustainable, and cost-effective. Waste components may be converted into useful ones such as the conversion of COD into energy, incorporating N, P and K into proteins, and using effluent as water for agriculture and aquaculture. Wastewater treatment can be accomplished in aerobic or anaerobic systems but anaerobic systems appear to be more favourable because of energy recovery and cost-effectiveness. Anaerobic systems can produce biogas which will offset running costs. Sustainable wastewater treatment should therefore use anaerobic systems as a first step treatment (Nhapi and Gijzen, 2005). However, Naidoo et al., 2016 found that of the 975 WWTP technologies applied nationwide, only 29 were anaerobic systems.

9.3 PARADIGMS - WASTEWATER IS AN UNTAPPED RESOURCE

The principles of Sustainable Development with respect to wastewater are fundamentally based in gaining value from wastewater, not just simply pollution abatement. Thus any wastewater that is adequately treated may be re-used, and could be an additional revenue source for enhancing and paying for wastewater management. Once any industry uses water, it will produce wastewater, whether directly during its processing or indirectly from others in its supply chain. Thus the generation of unnecessary wastewater should be restricted, while simultaneously viewing the wastewater generated as a valuable resource.

Globally, the major water users are agriculture and power generation, which together account for 90% of water withdrawals. For other industries, about 60% of water usage is indirect, and industrial sectors use more water indirectly than directly in their supply chains. The food and beverage industry accounts for 30% of indirect withdrawals (Blackhurst et al., 2010). The major water users of water in South Africa are:

- Agriculture 67%
- Urban 18%
- Mining 5%
- Rural 4%
- Afforestation 3%
- Power generation 2%
- Transfers out of SA 1% (GreenCape, 2017)

In contrast, the financial values of water sales per sector in South Africa are:

- Municipal water services 58%
- Mining 11%
- Trade 8%
- Food, beverages, Tobacco 7%
- Business 5%
- Manufacturing 4%
- Agriculture 2%
- Financial and other services 2%
- Government services 2%
- Heath and other 1% (GreenCape, 2017)

As agriculture is the largest water user, the sector should encourage water savings as well as expand the use of appropriately treated wastewater. This wastewater may also be used for other major water users such as power generation (process and cooling water) and thus alleviate water shortages.

During water scarce periods, municipalities increase water tariffs through water conservation by-laws and this directly motivates companies to reduce water consumption. There is a growing demand by homeowners, schools, sports fields and developers for recycled wastewater that could be used for irrigation.

9.4 PARADIGMS - FIT FOR PURPOSE WATER TREATMENT

Reclaimed water is increasing worldwide. However, water re-use is more complicated than conventional water resources (e.g., in its infrastructure requirements) and generally has higher costs than conventional water. Different water re-use applications require various grades of water quality, resulting in a number of required treatment levels. The production of higher quality water than required can result in overtreatment, leading to unnecessary cost and overuse of resources. If the quality of the required water is of a low enough standard, then a relatively cheaper treatment regime is required. Table 11 provides the US EPA’s guidance on water re-use opportunities at each level of water treatment.

Table 11. EPA suggested wastewater use after treatment

Increasing levels of treatment ⟹			
Primary Treatment	**Secondary Treatment**	**Tertiary treatment**	**Advanced**
Sedimentation	Biological, Oxidation, Disinfection	Chemical coagulation, filtration, disinfection	
No use recommended at this level	• Surface irrigation of orchards and vineyards • Non-food crop irrigation • Restricted landscape • Groundwater recharge of non-potable aquifers • Wetlands, wildlife habitat, stream augmentation • Industrial cooling processes	• Landscape and golf courses irrigation • Toilet flushing • Vehicle washing • Food crop irrigation • Unrestricted recreational impoundment	Indirect potable re-use: Groundwater recharge of potable aquifer and surface water reservoir augmentation

(Adapted from US EPA, 1991, 1992)

Fit-for-purpose water treatment is the process of providing water with water quality and quantity to meet the end user's water demand. Thus the level of treatment is matched to its intended use without expending unnecessary funds, energy, emissions and pollutants, while minimising other environmental costs. Lower treatment costs encourage the expansion of water re-use at a time when other new sources of water are growing scarcer. Currently, worldwide uses for fit-for-purpose treated water include irrigation (agricultural and landscape), groundwater recharge, industrial use, recreational impoundment, wildlife habitat, toilet flushing, planned indirect potable use, silviculture (forestry), vehicle washing, construction, environmental applications, dune stabilisation, firefighting, drinking water and non-potable water (Chhipi-Shrestha, 2017).

Water re-use is likely to become more prevalent in many municipalities in future, with some already having implemented this, or at feasibility stage. The City of Cape Town and the town of Beaufort West have already implemented water re-use programmes, with Beaufort West having implemented direct potable re-use, and the City of Cape Town using treated wastewater effluent for irrigation and industrial process water. The Ekurhuleni Metropolitan Municipality in Gauteng has conducted a feasibility study for wastewater re-use for future implementation (Pocock and Joubert, 2018).

9.5 WASTEWATER RE-USE

Treated wastewater from WWTPs is re-used for irrigation, industrial purposes, toilet flushing, and groundwater replenishment worldwide, reduces the demand for freshwater and has resulted in higher quality of surface waters, which now receive less effluent. Nutrients contained in the wastewater used for irrigation reduce the need for the application of additional commercial fertilisers. It is recommended to use effluent from secondary treatment for irrigation of non-food crops, while effluent from tertiary treatment may be used for irrigation of food crops. Florida is the leading U.S. state in urban wastewater re-use, where more than 45% treated wastewater is used for landscape irrigation (Neczaj, 2018).

Water re-use scenarios, both potable and non-potable, have been compared with water desalination, conventional potable water production and water importation scenarios. Although different system boundaries and different system scales were studied, all studies reviewed recommended reusing treated wastewater instead of desalination for its lower environmental impacts and energy consumption. With respect to the environmental impact of additional treatment requirements for potable re-use, tertiary treatments such as ultrafiltration membranes do not increase the environmental load significantly (Mo and Zhang, 2013).

9.5.1 Urban re-use

Urban re-use includes urban irrigation, commercial uses such as car washing, fire protection, toilet flushing, dust control and concrete production. Residential irrigation is the major urban re-use application, which can comprise around half of the total residential water consumption. Replacing freshwater with reclaimed water for urban irrigation can greatly reduce cost and water stress, especially during the peak seasons.

The US EPA recommends secondary treatment for restricted landscape use, and tertiary treatment for unrestricted recreational area irrigation, landscape and golf course irrigation, toilet flushing, as well as vehicle washing. The human exposure factor for urban re-use is higher than that of agricultural irrigation and industrial re-use. Thus, special care should be taken to avoid potential health problems. Moreover, urban re-use may require dual systems for reclaimed water delivery, which may result in high costs. Urban re-use has been widely applied in the United States and Florida is the leading state in urban re-use, reusing 44% of the total reclaimed water for landscape irrigation, while California re-uses 21% of the reclaimed water for this purpose (Mo and Zhang, 2013).

9.5.2 Re-use of municipal wastewater in South Africa

In South Africa, treated sewage effluent which meets the DWS general discharge standard in all instances is potentially suitable for all re-use applications, including, in many cases non-potable domestic use. Non-potable domestic use would depend on the pH, virus and parasite content of the water. Effluent from treatment plants which have permitted raised faecal coliform levels may possibly be used in some irrigation applications, depending on the level of faecal coliforms in the water and on the type of irrigation application. However, in 1998, the total water reclamation in South Africa was less than 3% of the available treated sewage effluent (Grobicki and Cohen, 1998). It is likely that this figure has increased since then, but there is potential for wider adoption.

Currently in South Africa, municipal water re-use projects that are operational include:

- Beaufort West - direct potable re-use.
- George - indirect potable re-use for surface water recharge.
- Mossel Bay - re-use for industrial purposes.
- Potsdam WWTP in Cape Town - re-use for irrigation purposes (see below for more details).
- eMalahleni water reclamation plant (Mpumalanga) - treats mine wastewater for municipal use.
- Optimum coal water reclamation plant (Mpumalanga) - beneficiates mine wastewater
- Outeniqua WWTP - effluent used to augment surface water resources.

Direct potable re-use options in Durban (eThekwini Municipality), Port Elizabeth, Cape Town and Hermanus are at advanced planning stage. A schematic of direct and indirect potable treatment is provided in Figure 19.

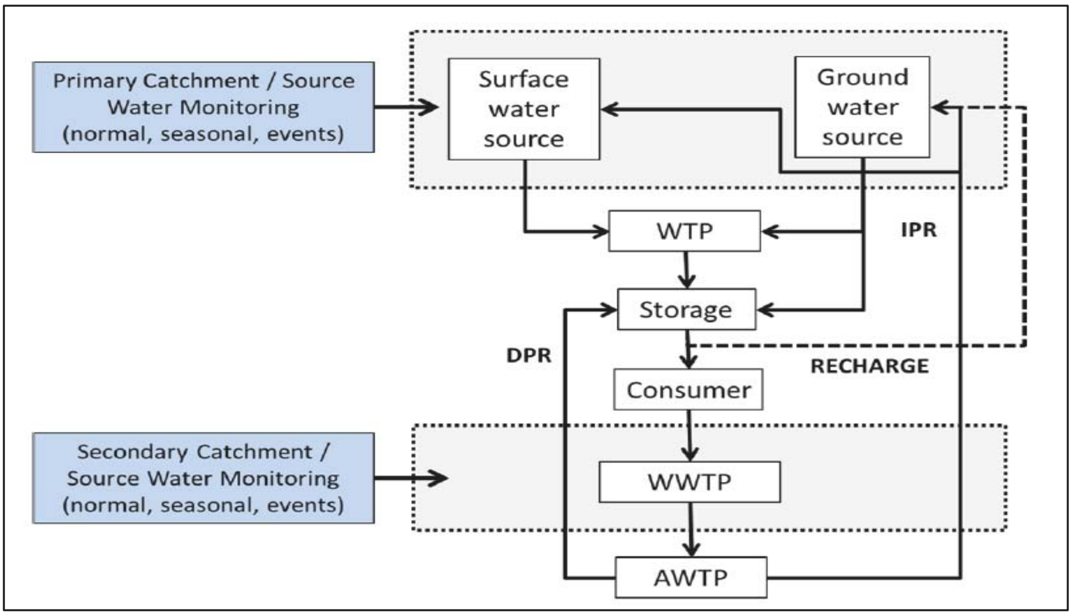


Figure 19. Direct and indirect potable drinking water reclamation

Adapted from Swartz et al., 2015

EXAMPLE: DECENTRALISED WASTEWATER TREATMENT SYSTEM (DEWATS)

The Decentralised Wastewater Treatment System (DEWATS) (Musazura et al., 2018) can provide a potential sanitation solution to residents living in informal settlements, with the treated effluent produced being used on agricultural land. The DEWATS is a modular system with only four components. The anaerobic baffled reactor and anaerobic filter of the DEWATS degrade blackwater and greywater to produce biogas and treated wastewater with a low chemical oxygen demand. Crop irrigation with DEWATS effluent was comparable in its results to tap water plus fertiliser, so this use is considered more beneficial than discharging the treated effluent into the environment. However, there may be institutional barriers to implementation of this system, legal requirements and the costs to monitor the quality of the discharged effluent.

EXAMPLE: POTSDAM WWTP

In 2006, the Western Cape government reported that the Potsdam Wastewater Treatment Plant in Milnerton, built at a cost of R19 million, was expected to generate an additional 38 million litres (mega litres) of non-potable water per day for the Blaauwberg area. The potential for treated effluent use could be expanded to 170 million litres per day at an average cost of less than R2.24 per kilolitre – or a third of the cost of fresh drinking water. This amounted to 40% of the total summer wastewater usage and 30% of the annual supply from the new Berg River Dam project (Western Cape Government, 2006).

The re-use of treated effluent was deemed most cost-effective to meet the rising demand for water. At that time, an average of only 30 million litres per day (7%) of the City's total wastewater was used during summer replacing potable drinking water.

The new system increased the treated effluent volume with up to 20 million litres per day to be made available for agricultural use. Potsdam currently provides non-potable water to the Milnerton golf course, the Theo Marais sports fields, Sappi Paper, four schools in Milnerton and Table View, public open spaces and the Table View beachfront dunes, and there is potential to supply the oil refinery, Sappi and local farmers. The scheme also provides the bulk infrastructure for future extensions to other industrial users and residential developments in the area. A new development on the farm De Grendel used the treated effluent for domestic irrigation. Prior to the installation of the treatment system, Potsdam's effluent water was discharged into the Diep river estuary which feeds into Milnerton Lagoon (Western Cape Government, 2006).

This is an example of a WWTP that is currently treating its effluent to fit-for-purpose use, and is probably the most technically advanced plant in South Africa. Dual reticulation for Potsdam to supply treated effluent to households for urban garden irrigation should be investigated.

9.5.3 Direct potable re-use

Direct potable re-use refers to introducing treated wastewater directly into a water distribution system without intervening storage. Using the reclaimed water to augment potable supply can improve overall water supply reliability, especially in coastal or drought areas. Unlike non-potable re-use, dual systems for water delivery can be avoided. However, direct potable re-use has high requirements for water treatment, which are likely to increase the operational costs. Planned potable recycling has taken place at Windhoek in Namibia since 1968 (Anderson, 1996). The towns of Cloudcroft in New Mexico and Big Springs in Texas in the US re-use treated wastewater for direct potable use, and extensive research on direct potable re-use has been conducted in the cities of Denver, Tampa and San Diego (Mo and Zhang, 2013).

Where direct potable drinking water reclamation (DPR) is implemented, the WWTP’s catchment is divided into a primary and a secondary catchment. The primary catchment covers natural water sources and the secondary catchment collects domestic and industrial effluents, and is controlled by a pollution monitoring and management program. For both direct and indirect potable re-use, additional treatment may be required to treat the current WWTP effluent to a better quality before recharge or re-use (Mo and Zhang, 2013).

9.5.4 Indirect potable re-use

In indirect potable re-use, high quality WWTP effluent is discharged directly into groundwater or surface water sources, with the intent of augmenting drinking water supplies (Neczaj, 2018).

Indirect potable re-use includes processes such as groundwater recharge and discharge of treated wastewater to surface or groundwater which is subsequently used for municipal water supply. Groundwater recharge can alleviate land subsidence and seawater intrusion in coastal groundwater areas. It also provides water storage and further treatment for subsequent retrieval and re-use of the reclaimed water. Furthermore, groundwater recharge eliminates the need for surface storage facilities, and problems such as evaporation losses, algal blooms resulting in deterioration of water quality, and creation of odours. The US EPA (2004) recommended nutrients and residual solids removal prior to groundwater recharge. Recharge of under-treated wastewater may increase the danger of aquifer contamination while recharge of over purified water may expose the water to exterior contaminants. Not all recharged water can be recovered; this is due to movement beyond the capture zone of the extraction well or mixing with poor quality groundwater (Mo and Zhang, 2013).

EXAMPLE: GROUNDWATER RECHARGE IN ATLANTIS, SOUTH AFRICA

Groundwater recharge or the replenishment of aquifers, is a practice widely used in the management of water resources. Aquifer storage and recovery wells are particularly useful in semi-arid areas with a marked rainy season, as they may be used for recharge when surplus water is available and pumped water when the water is needed. Typical recovery efficiencies in aquifer storage and recovery systems are found to be up to 70%, although it is suggested that most schemes can be developed to 100%, with the exception of transmissive, highly saline aquifers (Grobicki and Cohen, 1998).

The major South African example of aquifer storage and recharge is in Atlantis in the Western Cape, where the town's potable water is supplied primarily from the aquifer, with extensive recharge. There are two large infiltration basins, covering an area of approximately 500 000 m^2 some 500 m up-gradient of the extraction point, recharging of the order of 2 x 10^6 m^3/a with treated domestic effluent.

Stormwater runoff from the town is also used for recharge of domestic supplies. In addition, effluent of greater salinity from industrial wastewater treatment is used to recharge an area close to the coast. This creates a mound of more saline groundwater which maintains a balance between the sea and the potable aquifer. The resulting effective hydraulic dam creates additional storage, while non-potable water escapes into the ocean. Stormwater from first flush rainstorms is diverted to the non-potable infiltration areas. In South Africa, there are also a number of small cases where farmers augment borehole supplies through small earth dams (Grobicki and Cohen, 1998).

9.5.5 Greywater

Greywater is defined as household wastewater generated from kitchen sinks, bathroom sinks, showers and/or baths, and laundry discharges, but excludes toilet inputs, and can be re-used in lieu of freshwater for toilet flushing and irrigation activities. An advantage of recycling greywater is that greywater is a plentiful, alternative source of urban water that is relatively easy to treat as greywater has low concentrations of organic pollutants and pathogens. Greywater comprises 50 – 70% of total domestic wastewater despite containing only 30% of the organic fraction and 9 – 20% of the nutrients. Studies have shown that 30-50% of potable water may be saved by recycling greywater for irrigation and toilet flushing (Siang Oh et al., 2017). Greywater-reusing households' demand for potable water is reduced by 30-50% (Roesner et al*.,* 2006).

Common greywater treatment units in Japan consist mainly of aerobic treatment or membrane filtration followed by disinfection. The greywater generated in buildings is used to flush toilets and to fill artificial ponds or fountains. A report in 1997 showed that Japan had successfully reclaimed a total of 206 million m^3 water per annum with the implementation of greywater recycling systems (Siang Oh, 2017).

In South Africa, government's focus on improving access to basic water and sanitation, so that all people could have access to basic water by 2008 and basic sanitation by 2010, has led to the connection of low-income settlements to municipal water sources on an increasing scale. However, this has occurred without giving adequate attention to greywater management in those areas which are non-sewered. Problems related to greywater management are likely to be exacerbated as basic services are provided to more people. The total volume of greywater that is generated on a daily basis in these areas was estimated at just over 500 000 m^3. This amounts to about 185 million m^3 a year – equivalent in volume to a medium sized dam such as Voëlvlei Dam outside Cape Town, or about 50% of the present water demand of that city (The Water Wheel, 2007).

Households in these settlements often consume less water per capita than less densely-settled areas but in the absence of suitable conveyance systems in these areas, people generally dispose of their greywater on the ground outside their homes (Figure 20). The resulting total pollution load, particularly from densely populated settlements, has the potential to create a host of environmental and health impacts. This includes the pollution of nearby estuaries, wetlands and streams, mosquito breeding (from ponding of greywater), contamination of drinking water supplies and odour nuisance from the stagnant water.

According to Carden et al., 2007 the quality of greywater in non-sewered areas differs significantly to the greywater that is generated in higher income, sewered areas, in that there is a greater variation in the concentration of the various pollutants (such as sodium and phosphorus). At its most concentrated, it should be considered hazardous. There is also risk of transmitting waterborne diseases, if the greywater has been cross-contaminated with faecal waste. Children are especially at risk, as they often play in this dirty water.

Figure 20. Typical greywater in a non-sewered area

Depending on the household, the water can contain soap, shampoo, toothpaste, washing powder, disinfectants, shaving cream, bleach and household cleaning chemicals. The water may also contain cooking oil, hair, fat and fibres from fabrics. Greywater is unlikely to contain disease organisms (such as *E. coli*) of the same magnitude as in toilet waste (unless laundry tubs or basins are used to rinse soiled clothing and babies' nappies). This runoff is frequently channelled into the stormwater drains. In some cases settlements are serviced by stormwater drains and canal systems that channel wastewater directly into surface water bodies. Such canals are frequently unsightly, unhealthy and contribute to the overall deterioration of the urban environment.

Greywater is generally unfit for use except under controlled conditions. However, greywater can potentially be used in pour-flush toilets, irrigation of gardens, lawns, shrubs and trees, as well as dust control. Investigations into the use of greywater for irrigation of food crops are still continuing (see following section). In densely-settled areas, where greywater use initiatives are generally not feasible (complexes and flats), local authorities should provide greywater disposal systems that either treat the greywater on-site or convey the greywater to a sewerage system (Carden et al., 2007).

EXAMPLES: GREYWATER RE-USE FOR HORTICULTURE AND AGRICULTURE

At Ain El Beida in Jordan, kitchen greywater and ablution wastewater from the bathroom (i.e. excluding the water used to wash nappies) was re-used directly for food crop irrigation. The greywater was generated by 15 participating families, where kitchen greywater was collected from a discharge pipeline located at either the kitchen sink or from a pipeline modified to divert the water to the plantations. Through this pilot-scale project, families who re-used greywater for irrigation reduced their food expenses and water consumption, and some families were able to sell their surplus of food crops. This indirectly helped to reduce food and water stress levels in the community. The simplicity and cost effectiveness of a decentralised greywater treatment system makes it an attractive option for remote areas, such as rural villages, that have no access to pipelines connected to centralised treatment facilities. Condominiums, apartments, or office buildings with high population densities and high freshwater consumption rates can also benefit from then adoption of decentralised greywater treatment systems (Siang Oh et al., 2017).

The Water Wheel of July/August 2005 reported that ARC Infruitec-Nietvoorbij had initiated a project to determine the effect of greywater irrigation on the quality and yield of tomatoes and beans. The project also focused on the effect of greywater on infiltration tempo, permeability and element content of three types of soil, sand, loam and clay. The greywater was obtained from the shower, hand basin, kitchen sink and washing machine of a typical household and was not filtered before application. The water was added to potted crops using conventional watering cans. Water and soil samples were taken during the course of the trials and analysed for chemical composition.

Results indicated that the use of greywater had no detrimental effect on the production of the tomatoes or beans. In fact, higher production was obtained with the greywater applications compared to municipal water applications, which may partially be attributed to the increased levels of nutrients in the greywater. Chemical analysis of the tomatoes and beans showed an increase in sodium levels and phosphorus levels, with the macro nutrient levels of the plants grown in sandy soil types consistently the lowest compared to those grown in other soil types.

The University of KwaZulu-Natal School of Biological and Conservation Sciences, in collaboration with eThekwini Municipality's Water and Sanitation Unit, conducted trials into the re-use of greywater. Greywater from eight households of the Cato Crest peri-urban settlement was used to irrigate spinach, green pepper, potatoes and madumbes. Drip irrigation was used to water the plants with municipal water, greywater or a commercially available nutrient solution to compare the results. Plant growth was measured weekly, and harvested crops were analysed for microbiological contaminants, including *E. coli*, total coliforms and Staphylococcus.

There was a consistent increase in plant height and yield when the crops were irrigated with the greywater, as compared with municipal water. Analysis showed that contamination of the crops with bacteria was minimal to negligible, indicating that irrigating with greywater did not produce increases in bacterial levels on the final crops. This is despite a 'worst case' scenario being evaluated, with no waiting period between irrigation with greywater and harvesting, and no allowance made for inactivation of bacteria during food preparation, such as cooking (The Water Wheel, 2005).

The separation of urine and greywater at source also allows innovations in their treatment, in terms of both process and localisation. Urine is rich in nutrients and contains few pathogens or heavy metals, and contributes less than 1% to the total wastewater volume. Greywater contains the bulk of household phosphorus, but has low pathogen content, and has readily degradable BOD. Both urine and greywater could be re-used directly or after minimal treatment. Options for the re-use of effluents include agriculture and aquaculture, industrial applications, and urban uses such as public parks, recreational centres, golf courses, fire protection, and toilet flushing.

In all cases, the quality of wastewater and type of re-use define levels of treatment required. In Zimbabwe, sewage effluent has been used on farms in and around Harare, Chitungwiza and Chegutu, for the irrigation of crops such as citrus, animal feed and vegetables, as well as pastures. Duckweed has been used for effluent treatment in Zimbabwe, and the crop can be used to feed chickens (Nhapi and Gijzen, 2005).

9.5.6 Irrigation of trees for forestry and urban greening

While the use of wastewater for agricultural and landscape irrigation is now quite widespread in many countries, wastewater irrigation of trees has had less attention. Shade and street trees and urban green areas are irrigated with treated sewage effluent (e.g. Cairo, Tehran and others in the Middle East, India and the United States), and there are examples of effluent use in forestry. For instance, some communities in Egypt use sewage or drainage water after primary treatment to irrigate woodlots. The trees provide local firewood requirements and poles for sale on the local markets (El-Lakany, 1995). However, large-scale use of wastewater for the irrigation of tree plantations or forests is still relatively limited and, where it is practised, it is generally more for reasons of waste disposal and treatment than for enhanced forestry production.

However, the irrigation of trees may provide additional benefits. When limited pre-treatment is available, it may provide a means of disposal which poses the least risk of disease and environmental damage. The irrigation of trees is likely to pose fewer health risks and be more socially acceptable than the irrigation of crops (CSIRO, 1995).

In addition, under some circumstances irrigated forestry is economically competitive with irrigated agriculture and possibly even more profitable (Armitage, 1985). Integrating trees with irrigated agriculture in the form of windbreaks or boundary plantings, for example, may well be the most economically attractive option in many places (CSIRO, 1995).

The benefits of "greening" urban and peri-urban areas for environmental protection, amenity, recreation and production purposes are being increasingly recognised. Although all cities benefit from having trees in the urban landscape, the benefits are perhaps most obvious arid and semi-arid areas, where natural vegetation is sparse, the elements are harsh and shade is important. In these zones, trees require irrigation at least in the establishment phase, if not throughout their lifetimes. Cities which wish to increase tree numbers and green areas, but where freshwater is scarce, may be able to use wastewater for irrigation. The irrigation of forest plantations, greenbelts and urban green space can contribute to safe wastewater disposal (Braatz and Kandia, undated).

9.5.7 Industrial re-use

The thermal power sector represented around 50% of the total water withdrawal in the US in 2005 (USGS, 2009). Other industries, such as petroleum refineries and chemical manufacturers also require substantial amounts of water. These industries, however, do not require potable water quality and are suitable candidates for the use of reclaimed water. Re-using water also helps the industries to reduce cost and improve sustainability. Current industrial re-use mainly includes cooling water, boiler makeup water and industrial process water (EPA, 2004).

COOLING WATER

In industrial processing, water is typically used to cool process streams and condensers. While air can be used, it is highly inefficient and expensive, and water is unlikely to be replaced in this role. In heavy industry, 50 to 90% of the water used on-site can go towards cooling streams. Cooling also represents the most common use of recycled water with 90% of recycled water used for this purpose.

The use of tertiary-treated recycled water in cooling towers has two advantages. The first is the presence of a low, but significant level of phosphates. While this may present a scaling problem, control of pH will alleviate this. Dissolved phosphate in cooling water helps prevent corrosion of steel. This occurs through the formation of a passive iron phosphate film on the surface of the steel, protecting and substantially slowing the rate at which oxygen can diffuse to the surface. The concentration of phosphate present in the tertiary effluent may be high enough to require no further addition of a corrosion inhibitor.

The second benefit from the use of tertiary treated recycled water comes from the nitrification process, whether this is as part of a pre-treatment or if it occurs naturally in the cooling tower's basin. The nitrification process will produce nitric acid that works as a corrosion inhibitor and an antiscalant. This reduces the need for additional scale control measures.

BOILER FEED WATER

Steam is used for heating and to do mechanical work, such as drive turbines in power stations. Generation of steam can make up a significant portion of the water intake of petrochemical plants, and represents the second-largest water use (after cooling) in power stations. The generation of steam leads to a loss of water from the system. In a steam generation plant, water first undergoes some pre-treatment to remove salts that generate scale or deposits, usually reverse osmosis or ion exchange. After pre-treatment, water passes through a deaerator and an oxygen scavenger is added to reduce corrosion. From here, other treatment chemicals are added to control scaling, corrosion and foaming

Recycled water treated to RO quality has been successfully used for boiler feed in a number of operations in Australia and around the world, with no reported problems (Loretitsch et al., 2005, Alexander, 2007).

INDUSTRIAL WASH WATER

Wash and rinse water is used for cleaning. Washing is generally divided into three broad categories:

- Quality control (washing of a starting material, product or in intermediate stages of production to prevent cross contamination). This requires a moderate to high quality water to prevent contamination.
- Pollution control (scrubbing of gases to remove particulates and water soluble gases). This generally only requires a low quality water as there is little human exposure and no contamination problems.
- General housekeeping (washing of plant, vehicles, floors, palettes, surfaces etc.). This requires moderate quality water, and water should microbiologically clean due to the potential for human exposure.

As mentioned above, the presence of phosphorus and nitrogen compounds in treated wastewater can provide anti-corrosion benefits, and, as discussed in Section 9.4, it is good practice to use water which is "fit for purpose" in terms of its quality, and not of unnecessarily high quality.

WATER FOR TRANSPORT AND SEPARATION

A common use of water in industries is transport and separation. Transport of mineral ores as slurries is often practised where transport by rail or road is not possible, due to difficulties in terrain or the traffic disruption, and the efficient use of a slurry transport and dewatering system, particularly where the water can be internally recycled, is justified.

Mineral processing and separation processes are also highly water intensive. Crushing and grinding processes may use water to prevent dust, while separation processes use water as a medium in hydrocyclone separators and flotation systems. Additionally, some are targeted separations using surface properties to selectively float a desired product. Both of these water-based separation systems may be targeted for recycled water use.

The corrosion protection offered by the presence of phosphates is particularly useful for the protection of pipelines. One additional benefit, particularly to separation processes, is the consistency of recycled water quality, in places where other water sources (such as rivers), may vary in quality with the season (Alexander, 2007).

PROCESS WATER

Water is used in the steel industry for three main purposes: material conditioning, air pollution control and as a heat exchange medium. Boilers and heat exchangers constitute the largest users of water in the industry, with up to 75% of the water intake used in heat transfer. Suitable water qualities depend on the application. In general, secondary or tertiary treated recycled water may be acceptable. For sensitive processes, however, such as hot rolling, electroplating and surface finishing, RO quality recycled water may be required (Loretitsch et al., 2005, Alexander, 2007).

Water re-use in the paper industry would require at least tertiary treatment to remove colour. The control of TDS and colour are two major considerations for recycled effluent, according to experiences from paper plants such as Mondi Paper and SAPPI ENSTRA, which use recycled water. The Mondi Paper mill in the Durban has been operating on recycled water since 1972. Since 2001, it has been receiving 47.5 Mℓ/day of water from the Durban Water Recycling Plant (DWRP). As a result of the DWRP, Mondi has reduced its water costs by 44% (Gaimpietri et al., 1978 and Holtzhausen, 2002).

The DWRP plant supplies both Mondi paper mills and the Sapref refinery with recycled water, and treats about 50 Mℓ/day of the city's wastewater effluent. The facility enables a 7% reduction in municipal demand, a reduction in discharges to the marine outfall and a 60% saving in water input costs for industry. It has also had the effect of dampening municipal water price increase fluctuations (GreenCape, 2017).

TEXTILES

Manufacture and preparation of textiles uses wet processing. Process water is required for most processes, as fabric and yarn undergo multiple cycles of washing and rinsing during production. The process water may need to be pre-treated for the removal of impurities present in surface, ground and recycled waters. The effluent from textile manufacture includes volatile organics, fibres and dyes which have to be removed prior to re-use.

9.6 NUTRIENT RECOVERY

Wastewaters are a source of nutrients nitrogen, potassium, phosphorus and carbon. The nutrient loads in municipal wastewaters are dilute, but add up to significant daily loads, because of the massive volumes generated in urban populations. Nutrient recycling recovers nutrients in the wastewater as soil amendments or fertilisers.

Nutrients can be recovered from raw wastewater sources, semi-treated wastewater streams, and treatment by-products, such as biosolids. From a life cycle perspective, nutrient recycling not only reduces the rate of depletion of resources such as phosphate ores, but also indirectly conserves energy and water. That is because recycling nutrients will reduce the demand for traditional fossil-based fertilisers, consequently save energy and water used to produce the traditional fertilisers (Verster et al., 2014).

Recovery of nutrients from wastewater could have positive impact on environment by reducing the demand for conventional fossil-based fertilisers, and consequently, a reduction in the consumption of water and energy used for production of conventional fertilisers. It also lowers the possibility of eutrophication of the receiving waters, as effluent has reduced nutrient concentrations.

It is possible to recover nutrients from raw wastewater, semi-treated wastewater streams and sewage sludge. Land application of sludge is the oldest method of nutrient recovery, where sludge is spread on the soil surface or ploughed in. Before use, sludge is treated by anaerobic or aerobic digestion, composting, drying and chemical treatment processes. Agricultural application of sewage sludge is widely practised in in Germany and France. The main problems associated with it are health and safety concerns, odour nuisance and public acceptance (Neczaj, 2018).

9.6.1 Phosphate removal by crystallisation

Phosphate is one of the nutrients responsible for eutrophication of water bodies, thus the level of phosphate must be reduced in the effluent discharge to protect the environment, and because the treatment of eutrophic waters to potable standards is more complex than non-eutrophic waters, and more expensive. Phosphate removal is possible with chemical and biological processes. Struvite crystallisation has shown to be an effective clean technology where no or little sludge is produced (Saayman et al., 1994).

Controlled struvite ($MgNH_4PO_4{\cdot}6H_2O$) crystallisation is a method of recycling nutrients by extracting struvite from sludge digester liquors to recover phosphorus, nitrogen and magnesium. Struvite crystallisation has high nutrient recovery rates and is economically feasible (Jaffer et al., 2002). There are three full-scale facilities currently in operation in the US utilising struvite crystallisation technologies (Mo and Zhang, 2013).

The struvite crystallisation process has been implemented at several locations in Europe, where more than 2 million kg P/year is recovered. The main problems associated with struvite crystallisation are the high chemical input costs and unintentional struvite formation, which leads to blocking of valves, pipes and pumps (Neczaj, 2018).

9.6.2 Urine separation

Another option for nutrient recovery is urine separation from the main wastewater stream. It has been estimated that about 70–80% of nitrogen and 50% of phosphorus in wastewater is contained in urine. A theoretical recovery rate of 70% for those elements is possible using urine-collecting systems in toilets. Urine collection systems are used for the purposes of separating urine for land application. However, due to serious technical problems and public acceptance, this technology has not been widely adopted (Cordell, 2009).

The challenges of applying urine separation are that it requires intensive support and involvement from local communities and large-scale new infrastructure installation both at household and the community level, as shown in Figure 21, with the front chamber of the toilet for capturing urine. However, the collection of urine from men’s rooms urinals is relatively straightforward. Another major challenge is to avoid the cross contamination with faeces, which usually contain large amounts of pathogens.

Figure 21. A typical urine separating toilet

Urine separation is promising in terms of maximising nutrient recovery from wastewater, because around 70-80% of nitrogen and 50% of phosphorus in domestic wastewater is contained in urine. Urine separation has been traditionally practised in many developing countries for land application, but has not been widely used in most developed countries due to the intensive construction requirements and lack of public support (Mo and Zhang, 2013).

9.6.3 Re-use of wastewater for agriculture and aquaculture

The main plant nutrients that cause eutrophication problems in water bodies are nitrogen, phosphorus and potassium, and all are increasingly found in wastewaters. It has been estimated that the current mineral reserves for phosphorus will only last for 100-150 years at the current levels of consumption (Nhapi and Gijzen, 2005). Future strategies will thus have to focus on the sustainable, efficient and effective use of available nutrients, so nutrients in domestic wastewater should be recovered and re-used. The current method to limit eutrophication in receiving waters is tertiary treatment of wastewater, but this does not provide any return on investment for municipalities.

The use of macrophytes (plants) for wastewater treatment offers a cost-effective method of linking wastewater treatment to protein production. Nutrients are taken up by macrophytes such as duckweed, water hyacinth or reeds which, when harvested, can be used to feed livestock or fish. The remaining nutrients in effluent can be used for irrigation of crops, pastures or plantations after pathogens have been destroyed in maturation ponds (Nhapi and Gijzen, 2005). This approach has a low energy demand and useful synergy effects between wastewater treatment and nutrient recycling. Despite these advantages, the approach is not widely practised (Kabbe, 2015).

Kgopa et al*.,* 2018 found that treated wastewater from a WWTP exit pond was suitable for irrigation as its quality compared favourably with that of water from boreholes and the South African water quality standards. The effluent only underwent physical, biological and chlorine treatment prior to being discharged.

9.7 ENERGY RECOVERY

The organic matter in raw wastewater contains almost 10 times the energy needed to treat it. Some international wastewater treatment works can produce up to 100% of the energy they need to operate, though it is more likely that 60% of operational energy can be produced. Figure 22 shows the possible paths of waste to energy when using biomass as a feedstock (Burton et al., 2009).

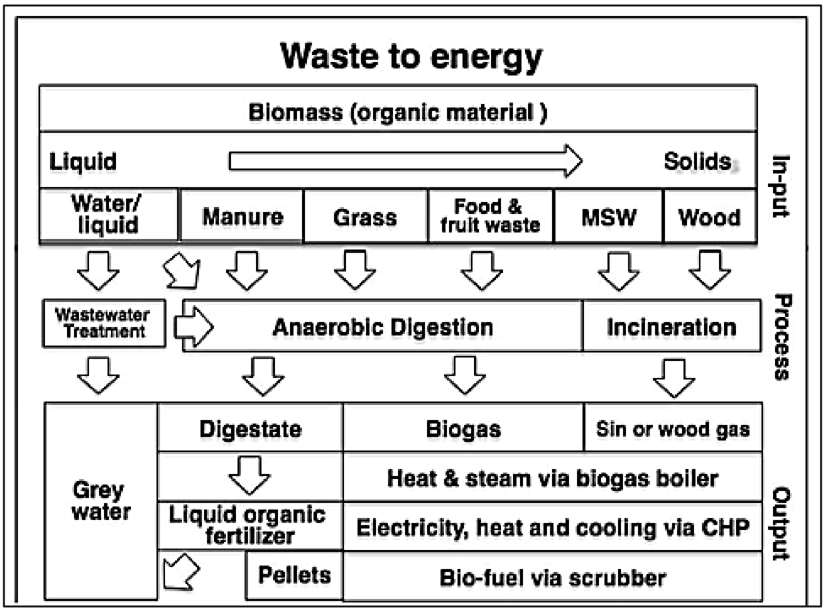


Figure 22. Possible paths for energy from biomass

Energy recovery at WWTP is feasible by means of biogas production, using heat pumps in treatment plant effluents, and energy recovery from various high temperature streams using heat exchangers. Biogas produced by anaerobic digestion (AD) has an energy potential of 6.5 kWh/m^3 (65% methane content). Biogas generation can fluctuate between 0.75 to 1.12 m^3/kg of volatile solid input, and the heating value of biogas is approximately 22.4 kJ/m^3. Biogas can be used for heating and/or electricity generation. The most widely adopted technology for biogas use in WWTPs is known as Combined Heat and Power (CHP), which generates both electricity and heat from biogas (Neczaj, 2018).

Co-digestion of sewage sludge with other biodegradable municipal waste to produce biogas is another option which provides a range of potential economic and environmental benefits. This method does not only allow WWTPs to be energy-neutral but also reduces the cost of municipal and industrial organic waste management. For example, co-digestion of sewage sludge with six different co-substrates has been implemented in Mossberg (Germany) for 10 years. The heat and energy production at Mossberg WWTP is significant higher than the internal demand of WWTP. Excess energy produced is fed into the grid, while excess heat is used to dry dewatered sludge from other WWTPs (Neczaj, 2018).

An estimated 10 000 MWth (megawatts thermal) can be recovered from wastewater in South Africa, Furthermore, the energy potential at WWTPs in South Africa is 850 MWth even with plants at 75% operational capacity. The energy potential from the human faeces component was estimated to be between 509 and 842 MWth.

The three major classes of wastewater with the greatest potential for energy recovery are:

- Sewage (domestic blackwater both from sewers and non-sewer connected households)
- Animal husbandry wastes
- Food and beverage processing wastes.

These results were based on the estimated loads (COD and volume) and potential energy available from them. Biogas seems to be the most appropriate technology for energy recovery in South Africa, as producing biogas from anaerobic digestion is the most common and best understood technology for recovering energy from wastewater.

Algal ponding to produce biodiesel or biomass (for incineration) has potential, but has not been demonstrated on a large scale. Fermentation to produce ethanol was limited in its application to wastewaters, but there was potential. There is significant scope for research and development into waste heat recovery from wastewater.

The potential for energy/electricity generation for a WWTP is of great value as it may be used to provide essential on-site power, thereby reducing energy costs as well as critical power supply and backup during loadshedding and power outages, thus preventing untreated discharges (Burton et al., 2009). Some examples of energy recovery at WWTPs are provided in the following sections.

9.7.1 Wastewater to biogas

Wastewater treatment processes use more than 20% of the total municipal electricity consumption (SEA, 2017). Biogas can be used to meet on site power and thermal energy needs. Export of gas to local industrial users, power producers or for use as a municipal vehicle fleet fuel is also possible. As of April 2019, it was estimated that in the US there was over 260 MW of Combined Heat and Power (CHP) potential at the 1 015 municipal WWTP plants that use anaerobic digesters.

With consistent electric and thermal loads, a need for energy resiliency, a free source of renewable fuel, and the standardisation of biogas pre-treatment methods, many WWTPs with anaerobic digesters are successfully installing CHP systems in the US. This has resulted in the total number of CHP systems at US WWTPs more than doubling from 2010-2017, as shown in Figure 23 (US Department of Energy, 2019).

Figure 23. Map of the US CHP installations

(Source www.energy.gov/chp-installs)

In a wastewater treatment plant, biogas is produced when sludge decomposes in the absence of oxygen, in anaerobic digesters as shown in Figure 24. Anaerobic digesters at WWTPs are large, sealed, heated tanks that allow anaerobic bacteria to digest and break down wastewater sludge. South Africa was one of the first countries in the world to utilise digesters as part of sludge management at WWTP. Digesters at WWTPs were, however, not built to capture and use the biogas produced, but rather to assist in sludge management. In most cases, digesters can be refurbished to allow for biogas collection (SEA, 2017).

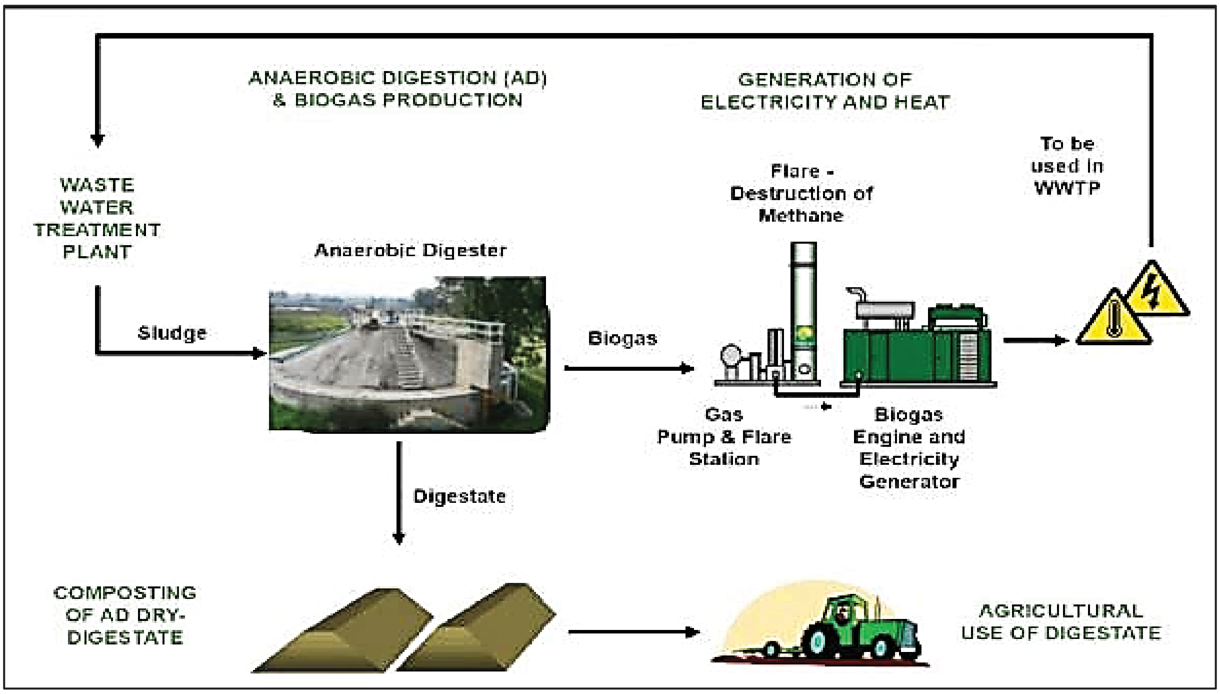


Figure 24. The biogas production process

(Adapted from SEA, 2017)

Biogas simultaneously provides a renewable energy source which can be used for electricity, heat and biofuel production and at the same time the sludge is stabilised and its dry matter content is reduced. This sludge contains valuable chemical nutrients such as nitrogen and potassium, and can be used as an organic fertiliser.

The intervention involves the installation of biogas digesters and CHP plants at wastewater treatment facilities to generate electricity from sludge digestion, which can be used on site to power lights, pumps, control etc. Excess heat can also be used to heat digesters, or in the composting process. Pre-treating the sludge with heat produced from the CHP plant helps break down stronger chemical bonds and makes the protein in organic matter more accessible for biological decomposition (SEA, 2017).

Plants that treat more than 15 Mℓ/day are financially viable but as treatment processes vary, site specifics have to be considered (SEA, 2017). Smaller plants cannot produce a sufficient amount of sludge for viable levels of electricity production.

Benefits of WWTP biogas systems include:

- WWTP can remain operational during power outages
- Operational cost savings
- Improved sludge management through pre-heating to improve biological decomposition
- Sludge is an organic compost which is an additional revenue stream
- Lower volumes of raw sludge to landfills
- Reduced methane and carbon dioxide emissions
- Reduced odours
- Compressed biogas produces a methane of suitable quality to use as fleet vehicle fuel.

Currently, many South African WWTPs have anaerobic digesters, but they are operated to optimise sludge management and not biogas production. Sludge management is integrally part of the operations of the WWTP and most municipalities have drying beds for sludge, which the private sector collects to use as compost. Fully functional digesters will benefit the WWTP by reducing the quantity of sludge going to the drying beds and improve its quality for organic composting (SEA, 2017).

The Johannesburg Water Northern works is a recent case study for biogas to energy in South Africa. A biogas to energy plant was developed within the existing wastewater works, with an installed capacity of 1.1 MW, using four digesters and three CHP engines.

The electricity produced is for own use and supplies 10% of the plant's power requirement. It is estimated that once the digesters have been refurbished, the plant could produce 4.5 MW, approximately 56% of the on-site power requirement. The combined production and use of heat and power leads to an 80% overall efficiency of the plant.

The heat produced is used to pre-treat the sludge, as well as to improve its quality such that it may be sold as organic compost. Johannesburg Water has since proceeded with the second plant at its Driefontein WWTP, and has announced that it envisages similar installations for its Olifantsvlei and Bushkoppie WWTPs. These facilities have the combined potential to produce 8.5 MW of electrical energy. CHP solutions are more financially viable for WWTP that process at least 25 Mℓ/day, based on a financial payback of seven years or less (City Energy, 2012).

This is an example of a technology that is currently being used in South Africa which:

- protects the environment by producing a higher quality sludge having converted waste directly to compost;
- lowers the WWTP's inherent electricity usage and makes it less reliant on Eskom
- reduces greenhouse gas emissions (especially methane) and
- Enables job creation and skills transfer.

The best candidates for CHP are WWTPs that:

- have a consistent high source of organic matter;
- have a need for high reliability;
- are located where there is concern over future electricity prices;
- need to reduce their environmental impact and
- that have a facility expansion or new construction planned within next 3-5 years.

The adoption of this technology would inherently upgrade the WWTP (the digesters) and the addition of the CHP engine increases resilience and reduces the reliance on Eskom for electricity. In the event of grid outages or loadshedding many of the critical systems are still powered. The licensing and authorisations framework has also been investigated and usually includes a water use licence, a waste management licence, environmental authorisation and, possibly, an air emissions licence.

According to Unterlechner (2018), there are currently 15MW of installed biogas plants in South Africa. The Cape Flats WWTP uses biogas to help dry and pellet the wastewater sludge, thereby reducing the on-site disposal costs and environmental burden (i.e. reducing nutrient discharge and helping limit eutrophication of the nearby freshwater lake, Zeekoevlei). The pellets produced have an energy content of ~16.6 MJ/kg and are used by Pretoria Portland Cement Company Ltd. (PPC) factory as additional fuel in their cement combustion kilns. Analysis has indicated that the Cape Flats WWTP could generate enough anaerobic digestion biogas to be self-sufficient in its basic energy requirements, but this is not being actualised (Burton et al., 2009).

Bayside Mall in Cape Town has incorporated waste to energy interventions including anaerobic digestion of organic wastes from the mall in a digester and conversion of biogas into energy. It was expected that the energy generated from the biogas would reduce grid purchases and save about 215 000 kWh/y (Gogela et al., 2017).

9.7.2 Biosolids incineration

Biosolids incineration refers to energy recovery through the combustion of biosolids in fluidised beds or furnaces. This not only generates energy but also reduces waste volume to a minimum, and thus lowering disposal costs. It is estimated that if biosolids incineration were applied to all the WWTP in Texas (USA) it would lower the plants' total electric usage by 57%. Currently Japan, US, Denmark, France, Belgium and Germany utilise around 55%, 25%, 24%, 20%, 15% and 14% of their sludge for incineration (Mo and Zhang, 2013).

The combustion of biomass in the presence of an excess oxygen supply results in complete oxidation and the formation of hot flue gases that are typically used to produce steam to drive electric turbines for electricity production, with an efficiency of approximately 30%. If the heat energy is also captured, providing combined heat and power (CHP), the efficiency can be increased to 80% (Burton *et al.*, 2009).

9.7.3 Effluent hydropower

Effluent hydropower is a technology that uses turbines or other devices installed in pipelines, canals, and aqueducts to generate electricity from effluent water. Aside from energy generation, the effluent hydropower systems can also increase the dissolved oxygen concentration in the treated wastewater (Gaiusobaseki, 2010; Zakkour et al., 2002). The main constraint of this technology is that it requires the effluent to have sufficient kinetic energy to justify the investment. Hence, either the head or the flow rate must be significant in order to optimise a hydropower scheme. It had been estimated that the potential of hydropower capacity in manmade conduits in California was about 255 MW, with an annual production of approximately 1100 GWh (Gaiusobaseki, 2010; Zakkour et al., 2002, Mo and Zhang, 2013).

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Effluent hydropower systems were first applied in two WWTPs in New England in the late 1970s and early 1980s with limited success. Since then, this technology has been applied in states such as California, Massachusetts, and Maine. California, so far, leads in the research and utilisation of effluent hydropower systems (Mo and Zhang, 2013).

9.7.4 Heat pumps

Heat pumps use electricity to recover low-temperature heat from wastewater, and to make this heat available at suitable temperatures for both heating and cooling purposes. In addition to their energy efficiency, heat pumps are very reliable and entail low operation and maintenance costs (Neave, 2010). The heat recovered from heat pumps, however, cannot be delivered over long distances. Thus, heat pumps may only be applied onsite or when there are heating or cooling demands in nearby communities. Heat pumps perform best in moderate temperature regions. A WWTP in Stockholm, Sweden with a maximum hydraulic capacity of 450,000 m^3/d produced about 597,000 MWh low-temperature heat energy using 199,000 MWh electrical energy via heat pumps (ESMAP, 2008).

It has been reported that over 500 wastewater heat pumps are in operation worldwide, with thermal capacities ranging from 10 kW to 20 MW (Schmid, 2008). Large-scale district heating using residual heat from wastewater has been applied in Japan and some European countries (Mo and Zhang, 2013).

9.7.5 Microalgae use for energy recovery

Microalgae technology recovers energy through cultivating microalgae with wastewater, harvesting and converting it to energy products. During the cultivation stage, microalgae take up carbon and nutrients in the wastewater, and therefore reduce waste loadings for treatment. Because microalgae can utilise carbon dioxide much faster than conventional biofuel crops, they also have great potential for carbon dioxide reduction and mitigation. A net energy generation of 9 500 MJ/ton of dry algae through microalgae gasification using effluent water as nutrient source has been produced. Moreover, a negative greenhouse gas emission of 183 kg CO_2e/MJ has been reported from bioalgae technology applications (Mo and Zhang, 2013). See Section 9.8.3 for a discussion of biodiesel production from microalgae.

9.7.6 Microbial fuel cells

Fuel cells are devices that can convert chemical energy into electrical energy. Microbial fuel cells (MFC) operate by using bacteria that oxidise organic matter in the wastewater to transfer electrons to an anode and then via a circuit to the cathode where they combine with protons and oxygen to form water. The difference in the potential coupled to electron flow produces electricity. MFCs are an emerging technology and a number of MFCs have been successfully operated with both pure cultures and mixed cultures that were enriched either from sediment or activated sludge from wastewater treatment plants. Wastewaters of very different characteristics from various sources including sanitary wastes, food processing wastewater, dairy manure, swine wastewater and corn stover (similar to straw) may be used. Essentially, this technology can use bacteria already present in wastewater as catalysts to generate electricity while simultaneously treating wastewater, but its development is hampered by low power output and high material costs (Burton et al., 2009).

9.7.7 Bioelectrochemical systems

Bioelectrochemical systems use biocatalysts for oxidation and/or reduction reactions to produce desired products. It includes microbial fuel cell (MFC) systems and microbial electrolysis cell (MEC) systems. MFCs can reduce sludge production to around 20% of that of conventional treatment, thereby reducing the sludge disposal costs. Power generated in MFCs varies from less than 1 MW/m^2 to 3 600 MW/m^2, with most of them falling between 10 and 100 MW/m^2. Sewage treatment through MFCs in the European Union can save 0.95 million tons of fossil fuel per year and over $2.3 billion of the sludge disposal cost annually (Mo and Zhang, 2013).

9.7.8 Onsite wind and solar power

Onsite wind and solar power is the production of electricity from wind and/or solar energy by taking advantage of the large land area of the WWTPs. WWTPs are usually away from other developments, and thus are good host sites for onsite wind and/or solar power generation. Electricity generated may be used to meet on-site needs, or exported to the grid. Having an on-site power source makes WWTPs more resilient to power outages (Mo and Zhang, 2013).

9.8 OTHER RESOURCES RECOVERABLE FROM WASTEWATER

9.8.1 Olive wastewater processing

In order to render olives palatable, they are cured using a brine solution which produces a high COD, high phenol, acidic and saline wastewater. It is an intensive process, whereby up to 10kℓ of water is consumed per ton of olives. This wastewater is toxic to most microbes and cannot be disposed of in a municipal wastewater treatment plant or the environment. It is usually disposed of in evaporation ponds which produce sludge.

A project funded by the WRC demonstrated a pilot plant that was effective, and technically and financially viable for treating the olive wastewater and recovering antioxidants, producing purified brine water for re-use as well as minimising the amount of disposable waste. The system comprises membrane technology and chromatographic adsorption, and these two unit operations produce purified water for recycling, a minimised waste stream as well as a valuable by-product (The Water Wheel, October 2013).

9.8.2 Metals recovery from wastewater

Certain metal ions are toxic to the aquatic environment and contribute to the pollution of water. Metals may also bio-accumulate in certain organism and pass upwards through the food chain to humans. Many industrial processes produce metal-containing wastewaters which are toxic and in the mining industry, this also represents a loss of product. Traditional methods of metal removal such as ion exchange and precipitation are not cost effective, but micro-organisms such as yeast are known to accumulate metals from dilute metal solutions, thus concentrating them (Duncan and Brady, 1992).

It has been demonstrated that yeast, which is readily available as a waste product of alcohol-based fermentation, and is a relatively cheap source of biological material that requires very little pre-treatment before its use to treat metal-bearing wastewaters. The technology is easily applicable to both high and low concentrations of metals in the wastewater stream. Yeast cells are an effective means of removing metal ions from solution (Duncan and Brady, 1992).

9.8.3 Biodiesel production from microalgae

It is possible to extract oils from microalgae as a feedstock to produce biodiesel fuel. Microalgae have a higher biomass productivity (tons/hectare/year) and lipid yield (kg/kg of algal biomass) than vegetable oil crops. Using municipal wastewater cultivated microalgae for bio-diesel production is an emerging research objective to relieve the water pollution and the global energy crises. Moreover, microalgae biodiesel is a renewable energy source and the photosynthesis of microalgae reduces carbon dioxide emission and utilises nutrients available in wastewater, thereby limiting eutrophication.

The cultivation of microalgae with municipal wastewater can reduce algae cultivation cost, and purify municipal wastewater. It could also reduce the cost of biodiesel production. Studies have shown that the construction of a bacterial and algal symbiosis system in municipal wastewater can not only reduce energy consumption of microalgae culture, but also remove pollutants from the municipal wastewater (Ali et al., 2017 and Wang et al., 2019).

In South Africa, biodiesel could help make the country less dependent on imported fossil fuels. Production of biodiesel from algae is technically feasible but has not been demonstrated economically – its economic feasibility will largely depend on long-term trends in fuel costs.

9.9 WATER HARVESTING

There are opportunities for businesses and households to collect rainwater for use. Stormwater harvesting on a neighbourhood scale could have commercially viable returns and also reduce the influx of stormwater to WWTPs, resulting in lower volumes of effluent for treatment. Thus there is an important link between water harvesting schemes and wastewater treatment, which should be further investigated.

Malls, factories and warehouses usually have sufficient area for harvesting substantial amounts of rainwater and in 2014 the Bayside Mall on-site rain and stormwater harvesting plant in Cape Town was commissioned. It provided an on-site capture, flushing and irrigation function and has shown an internal rate of return of 20% with a payback period of 5 years. It can capture approximately 400kℓ of water during an average Cape Town rainfall event. The use of this water has resulted in a 93% fresh water reduction for public toilet flushing and landscape irrigation (GreenCape, 2017).

Domestic rainwater harvesting and greywater re-use systems are easily installed by homeowners and show returns especially for the summer rainfall areas of the country, but there is limited business case for the winter rainfall areas.

9.10 RE-USE OF WASTEWATER SLUDGE

Municipal sludge is composed of both inorganic and organic materials, large concentrations of some plant nutrients, numerous trace elements and organic chemicals, and some pathogens.The composition of sewage sludge varies considerably depending on the wastewater composition and the treatment processes used. Sludge may be viewed as either an organic and nutrient source to be used beneficially or as a waste to be disposed of.

Beneficial uses of sludge include:

- Use as agricultural fertiliser
- Rehabilitation of mine dumps
- Remediating contaminated soil
- An absorbent
- Nursery growth medium for plants
- Once-off high rate land application
- Capping of landfills
- Beneficial land application at high loading rates
- Ameliorating degraded soils
- Manufacturing pellets from sludge
- Compost
- Making of bricks, paving, artificial rocks.

(Snyman and Herselman, 2006; Herselman and Moodley, 2009).

In addition, the use of sewage sludge in the construction industry is a good example of a circular economy application. Sewage sludge ash can be used for the manufacture of building materials such bricks or tiles, as well as a raw material for the production of cement, concrete and mortar.

It is also possible to recover metals such copper, silver or gold from sewage sludge ash. Finally, there is potential for biotechnology innovations that could produce biodegradable plastics from polyhydroxyalkanoates (PHA) in WWTP biomass (Neczaj, 2018).

9.10.1 Biosolids land application

Biosolids is another term for the organic sludge matter from wastewater plants. It is often used as a soil conditioner. Biosolids land application involves spreading biosolids on the soil surface or incorporating or working biosolids into the soil (EPA, 1999). It may also be treated by at least one of the following processes, depending on the end use: (1) digestion, (2) alkaline treatment, (3) composting, and (4) heat drying. Biosolids treated by digestion or alkaline stabilisation can be used as soil amendment or daily landfill cover. Composting produces highly organic and soil-like biosolids for horticultural, nursery and landscape uses. Heat-dried biosolids can be directly used as fertiliser. In addition to soil conditioning and the reduction in fossil fertiliser use, biosolids land application also reduces the runoff of nutrients from agricultural land, compared with conventional fertiliser.

Land application of biosolids has been widely practised in the US and other countries. It has been estimated that 8.2 million tons of biosolids was produced in 2010, 70% of which used for land application (EPA, 1999). A dry mass of 7-50 kg/year/inhabitant was a rough estimation of biosolids production potential in the WWTPs. In 2004, 49% of the US wastewater solids were used for land application, while 45% were disposed. Another 6% was stored or their final use was not reported (Mo and Zhang, 2013).

9.10.2 Sewage wastewater sludge use as fertiliser – nutrient runoff concerns

Generally the application rate of commercial inorganic fertilisers is determined by the crop nutrient requirements (crop specific) and the prevailing climate, mainly rainfall, and the availability of supplemental irrigation. The Fertiliser Society of South Africa developed a handbook to guide fertiliser advisors and farmers (FSSA, 2007). If sludge is to be used as fertiliser on a widespread basis, it will be important to harmonize sludge application practices with FSSA (2007) to avoid over-addition of nutrients due to combined fertiliser and sludge applications. Excessive nitrogen and phosphorus additions offer no net fertility benefits and cause negative environmental impacts due to nitrate leaching and phosphorus accumulation.

9.10.3 Composting industrial sludge

Sasol piloted a project to beneficiate sludge from its waste streams into compost that could be used to rehabilitate mine dumps, farmlands, and ash heaps. Sasol's Secunda complex generates various sludge waste streams produced from its coal-to-liquids process.

The project uses specialised microbial populations to target, assimilate and biochemically transform the potentially harmful trace elements found in industrial waste sludges into an immobilised and environmentally friendly form. Sasol intended to have the compost legally classified, as the quality of compost produced from the biosludges tested compared well with that of commercial compost (Sasol, 2014).

9.10.4 Remediation of mine dumps

For the practical purpose of re-establishing good plant growth on rehabilitated mine areas and dumps, a fertile surface soil material must be reinstated, and addition of organic matter is beneficial to soil fertility, particularly in re-establishing the nitrogen cycle. Suitable organic matter additions include sewage sludge, manure or compost, but the much of this is broken down by microbial action and lost (Chamber of Mines of South Africa, 2007), and rehabilitated areas may require on-going organic matter amendments.

9.10.5 Sludge as landfill cover material

Stabilised sludge can be used as daily or final cover on general or hazardous landfills. Sludge with a solids content of 50% will increase the water holding capacity of the final cover of the landfill facility, and has high odour absorbing abilities.

9.11 FUNDING FOR WASTEWATER BENEFICIATION IN SOUTH AFRICA

For wastewater re-use to be a viable practice in South Africa, it must be economically sustainable. Two funding mechanisms are considered here – wastewater charges and the Municipal Infrastructure Grant.

9.11.1 Implementation of effective wastewater charges

Regulations on wastewater charges are in line with international best practices, but implementation at municipal levels varies between municipalities. The cost of collection and treatment, treatment capacity, technology type, state of infrastructure, human capital, development costs, financial resources, existing infrastructure and water uses all affect the real cost of wastewater (Naidoo et al., 2016), and if these charges were implemented based on a scientific approach, this could produce incentives for water saving and wastewater re-use. Current difficulties with implementing wastewater charges are discussed in more detail in Section 10.5

9.11.2 CoGTA and the Municipal Infrastructure Grant

The Cooperative Governance and Traditional Affairs (CoGTA) Ministry comprises the Department of Cooperative Governance and the Department of Traditional Affairs. Their mission is to ensure that all municipalities perform their basic responsibilities and functions consistently by:

- putting people and their concerns first;
- supporting the delivery of municipal services to the right quality and standard;
- promoting good governance, transparency and accountability;
- ensuring sound financial management and accounting; and
- building institutional resilience and administrative capability.

The Municipal Infrastructure Grant (MIG) aims to eradicate municipal infrastructure backlogs in poor communities to ensure the provision of basic services such as water, sanitation, roads and community lighting. The Department of Cooperative Governance is responsible for managing and transferring the MIG and provides support to provinces and municipalities on implementing MIG projects. The MIG may be a useful mechanism for funding municipal initiatives in wastewater re-use, and should be fully investigated.

9.12 NEW AREAS OF RESEARCH

In addition to the opportunities and possibilities discussed in this section, research with a broader, strategic focus is required in South Africa, in the following areas:

- Research on the effects of climate change on water resources in the country, specifically the implications for waste and wastewater management.

- Comprehensive research on the use of water for sanitation systems vs. dry disposal methods:

  - Currently, nearly half of treated fresh water is used to move human waste away from settlements (where there are sewage networks) to be treated. The Sanitation Transformative Initiative (Saniti) aims to change this with approaches that use less or no water and are off the sewage grid, thus reducing freshwater consumption and producing useful products. Universal access to waterborne sanitation is not possible due to costs and the scarcity of water, and will not be sustainable in the future.

  - Saniti aims to create two new sanitation markets, the first in improved services to those who are already on off-grid basic sanitation, and secondly, to stimulate a new market of new and innovative off-grid/non-sewered sanitation technologies. Saniti has international partnerships with the Bill Gates Foundation and the Toilet Board Coalition, in addition to several academic centres, that are supporting and collaborating with government to realise this objective (Mail and Guardian Special report, 2018).

10. OBSTACLES TO USING WASTEWATER AS A RESOURCE

This section deals with real and perceived obstacles to the re-use and beneficiation of wastewater in South Africa. A critical element of future water management should be the full exploitation of the potential of wastewater for re-use and resource recovery. This section discusses the various institutional, social and technical barriers that exist that may slow or prevent this potential from being realised.

10.1 INSTITUTIONAL WEAKNESSES IN WATER GOVERNANCE

In November 2011, with the support of the Konrad Adenauer Foundation (KAS), the Centre for Environmental Rights (CER) hosted a gathering of civil society representatives and key experts in water governance, to critically examine how civil society can get water governance in South Africa back on track.

Some of the problems they identified included:

- A lack of capacity to manage the country's water resources effectively and sustainably, due partly to loss of expertise within the government, and partly to overly complex implementation strategies.

- Insufficient capacity, technical skills, experience, leadership and stability within DWA (now Department of Human Settlements, Water and Sanitation – DWS), resulted in poor leadership, low morale and severely depleted institutional memory; and poor financial management coupled with inadequate financing.

- Many of the tools for the protection and use of water in the National Water Act, 1998 (NWA) are overly complex and technical, causing significant delays in implementation as well as being too resource intensive to implement.

- The slow processing of applications for water use licences (WULs), and water use authorisations that are plagued by procedural and substantive defects.

- The delay in rolling out water management institutions and the democratisation of water resource management (WRM) by the devolution to these institutions of WRM powers.

- The lack of political and institutional priority given to compliance, monitoring and enforcement (CME), and the limitations of criminal prosecution to punish and disincentivise non-compliance.

- A lack of progress in realisation of rights around access to water and sanitation that had reached crisis proportions in many parts of the country and was usually blamed on implementation failures by local government.

- Inadequate access to the Water Tribunal, which infringes the Constitutional right to access to courts, and the lack of management stability and organisational integrity within the Department of Water Affairs (DWA).

- There was limited information publicly available about the compliance and enforcement capacity and results within the DWA. The most regular information was obtained through questions posed to the Minister of Water Affairs or the DWA in Parliament.

A report on the status of sanitation services in South Africa (DWA, 2012b) identified challenges that included governance, institutional, social, technical, and operation and maintenance problems, as shown in Table 12.

Table 12. Challenges to the provision of sanitation services

Governance	The need for consolidated norms and standards
	Need for sanitation strategies to give better guidance on implementation of higher levels of service
Institutional	Inadequate technical capacity at municipal level
	Inadequate operation and maintenance capacity at local level
	Lack of management and expertise
Social	Inability of poor people to pay
Technical	Inadequate and uncoordinated management and regulation
	Effective service level choice and affordability
Operation and Maintenance	Inadequate maintenance of infrastructure
	Small municipalities do not operate effectively and maintain their waterborne sanitation schemes

(Adapted from Naidoo et al., 2016)

Since 2012, institutional problems at DWS have persisted. For example, there are still many vacant positions. Table 13 shows the large vacancy rates in departmental positions reported for 2017/18, and Table 14 shows vacancy rates for CME positions for 2016/17.

Table 13. Employment and vacancies in DWS by programme

Programme	Number of posts	Posts filled	Vacancy (%)
Water planning & info management	1 022	886	13.30
Water infrastructure development	499	413	17.20
Water sector regulation	454	367	19.50
Water resource management	3 133	2 895	7.60
Total	**7 946**	**6 911**	**13.00**

(Taken from DWS Annual Report 2017/2018)

Table 14. Posts dedicated to Compliance Monitoring and Enforcement

Office	Compliance Monitoring posts		Enforcement posts	
	Filled	Vacant	Filled	Vacant
National	**27**	**7**	**24**	**24**
Limpopo	1	0	4	0
North West	1	0	1	0
Northern Cape	2	1	0	0
Western Cape	0	2	2	2
Eastern Cape	7	3	5	4
Gauteng	11	2	2	0
KwaZulu-Natal	2	2	4	0
Mpumalanga	10	1	0	3
Free State	7	1	0	0
Total	**64**	**19**	**42**	**33**

(Taken from DWS Annual Report, Compliance Monitoring and Enforcement 2015/2016)

In 2011, the CER recommended the following steps to remedy the problems they had identified, including:

- Civil society coordination, empowerment and strategy development around water governance
- Strong civil society participation in reviews and amendment of key strategies and legislation
- The promotion of institutional stability within the DWA
- The improvement of cooperative governance affecting WRM by:
  - Support to local authorities; and
  - asserting the water mandate in decisions on mining and agriculture
- Improved access to information and oversight of water governance
- The roll-out, empowerment and resourcing of statutory and non-statutory participatory governance institutions like catchment management agencies (CMAs), water user associations (WUAs) and catchment management forums (CMFs)
- Implementation of key statutory WRM tools, appropriately simplified and prioritised
- Improvement of the quality of integrated WULs and a review of general authorisations
- Legislative amendments and law reform
- Strengthening CME through greater resourcing of the Blue Scorpions, and the incorporation of administrative penalties for non-compliance
- An overhaul of the composition and rules of the Water Tribunal (CER, 2012).

At the time of writing, it appears that many of the same problems persist and may have become more acute. Thus the CER's recommendations are still relevant to the water sector. As demonstrated by the case studies in Section 7, South Africa is facing a wastewater crisis. Much of our wastewater infrastructure is in a poor condition and poorly run.

Before the treated wastewater from a plant can be re-used, the plant has first to become fully operational once again, so as to generate wastewater of suitable discharge standard, and to do so consistently. In many cases, this is going to require investment in infrastructure and in people, but the costs of inaction are increasing dramatically, as highlighted in the case studies.

Access to potable water is a priority, but there needs to be more political and institutional focus on solving our wastewater problems, which are extremely serious. Apart from the weaknesses of the sewered wastewater system and WWTPs, informal settlements also need attention. Here, the poorest, most vulnerable people have access to potable water but very limited access to wastewater disposal systems. Whenever access to water is given, wastewater is generated, thus access to potable water must be coupled with access to safe, hygienic wastewater disposal.

With regard to industrial wastewater, industries are required to treat effluent discharged to sewers to meet standards set by National Government and local municipal by-laws. Compliance, enforcement and monitoring are not always consistent or effective. Most monitoring by the municipality of industrial effluent is ad-hoc and results of sample testing may only be available a few weeks after the sampling date. If the composition of effluent does not meet the standards, the company is fined by the municipality. Fines are generally low enough that such that there is no incentive for the company to invest in treating its wastewater to a better quality. Thus the same kinds of systemic weaknesses exists with industrial wastewater charges and fines as described in Section 10.5 for municipal wastewater charges.

10.2 MONITORING AND REVIEW

As mentioned in Section 3, DWS admits that there has been a decline in the frequency and quality of monitoring in the water sector (ASSAf, 2019 and DWS, 2019), which is almost certainly due to the institutional problems discussed in Section 10.1. Effective monitoring, data gathering, and review processes are key to the 2030 Agenda. These are also central to the management of wastewater at a national level, and to implementing the kinds of changes proposed in this report.

According to the UN (2018), monitoring national implementation of the SDGs requires the collection, processing, analysis and dissemination of reliable, timely, accessible and sufficiently detailed data. This includes the global SDG indicator framework, for the follow-up and review of progress, which was adopted in 2017 (UN-Water, 2017) and contains 232 indicators.

The UN recognises that countries have different institutions for monitoring progress towards the SDGs, and these may need to be strengthened. Some questions to be considered with regard to national monitoring efforts include:

- What efforts are being made to strengthen national statistical systems and the availability of quality data? Are there any institutional innovations to support the collection of data?
- What efforts are being made to disaggregate data? What constraints do countries have in this regard?
- What challenges are being faced with data collection and management?
- What data gaps have been identified and what steps are being taken to address these gaps?
- What efforts are being made to monitor the indicators and ensure transparency and accountability?
- What efforts are being made to follow up on and review implementation of the 2030 Agenda, including multi-stakeholder participation and mobilizing support through partnerships?
- Are monitoring efforts presented in a way that allows for sufficient review and dialogue by all stakeholders?

Insufficient monitoring capacity highlighted by reviews such as this should be addressed, and if the state has insufficient resources, partnerships with civil society and the private sector should be strengthened to improve monitoring capacity (United Nations, 2018; WHO and UNICEF, 2017).

10.3 NEGATIVE PERCEPTIONS ABOUT WASTEWATER RE-USE

At present, the benefits of reusing wastewater are not immediately obvious, and the general public, government, policy makers and businesses should be educated about them. Typical objections which may be posed include:

- Wastewater is “polluted” – such perceptions may include health, cultural and religious concerns.
- Large upfront capital investments for municipalities and industry may be required to implement wastewater re-use.
- Policy and regulation changes may be needed.
- For industry, there may limited incentives to invest in additional water treatment and re-use, or to use recycled wastewater.

With regard to the perception of wastewater as inherently polluted and unsafe, education and, critically, good control of the quality of recycled water are necessary to allay users’ concerns. Scientific studies showing that wastewater is safe to use are important components of the education efforts. For example, the United States’ National Research Council found that “the risk of exposure to certain microbial and chemical contaminants from drinking reclaimed water does not appear to be any higher than the risk experienced in at least some current drinking water treatment systems, and may be orders of magnitude lower” (National Research Council, 2012).

Economic and institutional barriers are discussed in separate subsections.

10.4 ECONOMIC BARRIERS TO RE-USE

Faced with increasing water scarcity, policy makers are increasingly interested in tapping non-conventional water resources, such as recycled wastewater, to meet demands for water. Yet despite the apparent advantages, few countries have succeeded in developing extensive, successful, and safe re-use programmes. One problem is that users of water often have little economic reason to opt for recycled water. If governments wish to stimulate wastewater re-use, they need to ensure that it makes economic sense to users (Jeuland, 2015).

As mentioned in Section 10.3, there are reasonable concerns that the up-front investment needed to implement wastewater re-use is a significant barrier to adoption. However, the economic feasibility of proposed re-use projects should be addressed on a case-by-case basis, taking into account future water demands and the fit for purpose water quality concept. As shown in the example of the Potsdam WWTP in Cape Town (Section 9.5.2), investment was required for new infrastructure to expand wastewater re-use. However, the main purpose of the Potsdam expansion was to increase treatment capacity to meet the needs of a growing population, and it was possible to incorporate additional re-use potential into the design, within the project budget. This has made it possible to provide users with fit for purpose water at a fraction of the cost of providing potable quality water.

It should also be noted, as mentioned in Section 9.5, and elsewhere, that a secondary level of wastewater treatment makes possible a variety of re-use options, including industrial use and urban green space and forestry irrigation. Most WWTPs in South Africa, when operating as designed, would achieve at least secondary treatment level, and are, in fact, required to do so, in terms of their effluent discharge permits. This means that if WWTPs run as designed and permitted, their effluent quality would be good enough for many re-use options. Fixing our dysfunctional WWTPs would immediately produce treated effluent that could be re-used, and the only additional investment might be in the distribution infrastructure needed to get it to users.

10.5 WASTEWATER CHARGES

The current wastewater charge system needs review, as there is an under-recovery of costs for wastewater treatment in municipalities. Calculating the correct charge that users should be pay for wastewater disposal is a highly technical process, and municipalities may not have the technical skills to do it.

At present, Water Service Authorities (WSA) may stipulate a wastewater treatment charge for households based on:

- A volumetric charge (which is often considered best practice).
- A flat fee across all households, which is common for small homogenous communities and cannot differentiate between indigent, high water consumption or high household size.
- A fee related to the size of the erf - simple to implement and allows for differentiation based on socio-economic circumstances.
- A fee relative to the rateable property value, with consideration for indigent households.

However, despite the availability of such legal frameworks, these charge structures are not being applied at the municipal level, especially in municipalities that struggled to achieve Green Drop certification. This suggests that the reason for the lack of implementation of wastewater charges within municipalities is a lack of capacity, and of understanding of the law (Naidoo, 2016).

Thus, a lack of political will and inadequate skills are seen as the main barriers to the setting and implementation of effective wastewater charges. With regard to human resources, skills availability is one of the biggest constraints in the wastewater sector. Many municipalities have many unfilled positions and staff with inadequate qualifications. These problems disproportionately affect smaller municipalities, where it may be difficult to attract staff with relevant skills, there is insufficient training due to financial constraints and there may be the potential for nepotism.

To set effective wastewater charges, municipalities must have a good understanding of the cost components of wastewater treatment. This can be complex, because costs of operating and maintaining WWTPs differ. Older plants generally incur more maintenance and repair costs, while smaller plants have higher administrative costs per unit of treatment capacity. Also, if additional treatment is needed before wastewater can be re-used, the added costs would have to be considered in the wastewater charge (Naidoo, 2016).

10.6 NEW AND EMERGING CONTAMINANTS IN WASTEWATER

There is a range of treatment options available to mitigate water quality issues in reclaimed water. However, most municipal wastewater treatment plants are not designed to deal with emerging contaminants, such as pharmaceutical residues, that are present in wastewater. Many of these compounds may pass through conventional wastewater treatment systems without removal. There is limited information regarding the environmental fate, and eco-toxicological behaviour of these compounds in the environment, and justified concern about the risks to human health they pose if wastewater is re-used, especially for potable use (Swartz et al*.,* 2018).

There are significant eco-toxicological concerns associated with exposure of aquatic organisms to emerging contaminants. Exposed aquatic animals have been found to have low sperm counts, a high incidence of certain cancers, and an unusual prevalence of intersex fish. However, the human health effects associated with exposure to emerging contaminants have yet to be clearly established for many compounds.

The risks posed by these compounds should be considered on a case-by-case basis for wastewater re-use, and if additional treatment is deemed necessary, the following techniques may be applicable, although each has its disadvantages:

- Membrane technologies, which show a reduction in the concentration of oestrogenic hormones in wastewater but produce a concentrated brine stream with high concentrations of the contaminants.
- Chlorination, which has the disadvantage of producing reaction products with persistent characteristics.
- Ozonation, which is effective but expensive (Swartz et al., 2018).

11. CONCLUSIONS

This study has reviewed the present state of wastewater management in South Africa in the context of the UN Sustainable Development Goals, the numerous serious challenges facing the water sector and the clear imperative to view wastewater as resource, not a liability.

South Africa adopted the UN's 2030 Agenda for Sustainable Development, which includes the Sustainable Development Goal (SDG) 6 "Clean Water and Sanitation". Within **SDG 6, Target 6.3** aims ***to improve water quality, wastewater and safe re-use, and by 2030 a country should have improved water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe re-use***. Within Target 6.3, there are two Indicators, 6.3.1., which is the ***proportion of wastewater safely treated*** and 6.3.2, the ***proportion of bodies of water with good ambient water quality.***

The study has aimed to:

- map out the challenges South Africa faces in achieving sustainable wastewater management, including associated public health and environmental concerns;

- review and consolidate research results dealing with sustainable wastewater management and the country's progress, or lack of it, towards Target 6.3; and

- identify and analyse the opportunities that exist to make wastewater management more sustainable.

DWS reports that South Africa is working towards SDG 6 and that there has been good progress toward Target 6.3. A total of 52% of wastewater is treated and discharged safely and 59% of surface water bodies have good quality water (47% of rivers have good water quality). However, the country is unlikely to achieved SDG 6 by 2030.

With regard to surface water quality, other studies show a different picture: as discussed in Section 6, a 2014 study showed that 62% of 50 major water bodies were hypertrophic - having very high nutrient concentrations - and more than 50% suffered from cyanobacterial blooms, while the Vaal, Crocodile and Olifants river catchments suffer from on-going increases in salinity and sulphate levels.

South Africa has a comprehensive legal framework for managing water and wastewater. DWS recognises the need for an integrated water management approach to "improve the water mix" and move away from the current over-reliance on surface water through recycling and re-use. However, the government has also been criticised for the lack of progress in realising constitutional rights of access to clean water and sanitation, due, in essence, to an institutional incapacity to fully implement the letter and spirit of the law. As shown in Section 7, these failings have resulted in numerous, and on-going, cases of untreated sewage spilling into the environment and causing major public health and environmental emergencies.

Section 8 is a highly topical side note on recent research from the Netherlands and USA, indicating that sampling influent wastewater at wastewater treatment plants may be a useful indicator of levels of coronavirus infection in communities.

In spite of the manifold problems in the South African wastewater sector, there has been on-going, and encouraging, research into the opportunities revealed by viewing wastewater as a resource, rather than a burden. It will also be valuable to start taking an integrated or life-cycle approach, such as that exemplified in the Cleaner Production framework, first established for the chemical industry, which is based on simple reduce-reuse-recycle concepts: use the lowest quantity of input needed (use the appropriate quality of input, not one that is too high); do not mix waste streams; identify opportunities for, and implement, re-use and recycling of waste and by-products.

Section 9 reviews a wide array of opportunities and case studies of beneficial wastewater re-use, and the recovery of nutrients and energy from wastewater. There are important and immediate opportunities for the beneficial re-use of treated wastewater, and this can be achieved without significant additional expenditure.

Greywater recycling, especially in un-sewered communities, must be a key area of attention. There are significant strategic opportunities for WWTPs to generate and use biogas to generate electricity on site to make them more resilient against the vagaries of the Eskom grid. The useful use of sewage sludge, either for its nutrient or soil-structuring benefits, or its energy content, is another key area where relatively simple interventions can result in net gains.

Lastly in this section, we have mentioned that as a matter of overarching urgency, it is necessary to attempt to integrate the expected impacts of climate change on wastewater systems, and, fundamentally to challenge the entire paradigm of using water as medium to transport human waste, as exemplified in the Sanitation Transformation Initiative (Saniti).

Section 10 reviews the institutional and social barriers to widespread beneficiation of wastewater. These include the institutional problems related to infrastructure and governance, data gathering and monitoring, the complexity and lack of implementation of wastewater charges and other economic barriers such as implementation costs. There are also social barriers related to the perception of wastewater as "pollution" and public health concerns, including concerns about emerging contaminants such as pharmaceuticals and endocrine disruptors.

In Section 12 we have compiled a short list of recommendations for (1) required actions to achieve SDG Target 6.3, and (2) directions for future research.

12. RECOMMENDATIONS

This section presents a list of recommendations for (1) actions to improve South Africa's rate of progress towards SDG Target 6.3 and (2) research priorities in the wastewater sector.

Improving progress towards SDG Target 6.3

In general, an overhaul of the municipal wastewater system is needed, ranging from a renewed political vision, upskilling of personnel, preventative maintenance, fixing ageing and failing infrastructure and providing additional capacity.

Specific actions to improve performance should include:

a) Setting clear and published targets for SDG 6, reporting progress and resourcing the effort accordingly, in partnership with civil society and researchers.

b) Investing in re-use infrastructure and operational effectiveness to ensure consistent good quality treated effluent, suitable for re-use.

c) Increased institutional and political priority for compliance, monitoring and enforcement of wastewater management, which could include:

    i. Reintroduction of the Green Drop certification for municipalities.
    ii. Independent monitoring of effluent quality.
    iii. Effective enforcement actions for non-compliance, including individual administrative sanctions (e.g., suspension of benefits, unpaid leave) and criminal prosecutions against public officials who do not meet their responsibilities with respect to sanitation.
    iv. The establishment of an effective enforcement body for water and sanitation law, which may be best constituted as a joint effort of the National Prosecutions Authority, DWS, and the departments of Environment and Health.

d) Review and implement wastewater charges, and all other economic and financial instruments allowed in the water and municipal legal framework, including the Municipal Infrastructure Grant, to help fund wastewater beneficiation efforts.

e) Education of policy makers and the public about the benefits of re-using and recycling wastewater, to address negative perceptions.

f) Develop guidelines and issue regulations for greywater, including health regulations and by-laws, covering greywater use in both sewered and non-sewered areas.

a) Plan new WWTP, as well as upgrades to existing plants, to include biogas-based energy recovery and on-site power generation.

Research priorities

In the light of the findings of this report, the following topics are considered to be important focus areas for future research:

a) Dry-disposal sanitation vs. water-based sanitation: the end of water-borne sewage?
    i. Implications for the net quality and volume of wastewater produced, and how a move away from water-borne sewage would influence existing systems.
    ii. Management and potential for beneficiation of solid waste from dry systems.

b) Decentralised wastewater treatment systems for rapidly-growing cities.
    i. Current and potential applications for industries, large buildings and local areas.
    ii. Beneficial use of effluent and solid waste from decentralised systems.

c) Long term effects of using greywater for irrigation on soil, crops and health.

i. Minimising potential risks to health from greywater use for landscaping and crop irrigation.
ii. Effects of sustained greywater use on groundwater.
iii. Guidelines for landscaping and crop irrigation with greywater, including a review of plant varieties most suited to greywater irrigation.

d) Emerging contaminants in wastewater.
i. The fate of emerging contaminants, such as prescription and non-prescription pharmaceuticals in wastewater.
ii. The efficacy of current wastewater treatment processes to treat emerging contaminants to safe levels.

e) The implications of climate change for wastewater management in South Africa.

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