WATER RESEARCH COMMISSION

WORKING PAPER

The Future of Sustainable Wastewater Management

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Summary / Abstract

The view regarding wastewater as a 'nuisance' has been gradually changing to one of a 'resource'. This has globally resulted in a significant shift from end-of-pipe treatment to reuse and resource recovery. The need to change the view regarding wastewater as a 'nuisance' to one of a 'resource' is further underpinned by the 5R principle (Reduce, Reuse, Recycle, Recovery, and Restore) (Zvimba *et al*. 2021). In this regard, the future of wastewater management need to explore reuse and resource recovery opportunities available from integrated municipal, industrial and mine-impacted wastewater(s), and drive maximum benefits from utilisation of such resources through development of sustainable wastewater management practices and innovations in support of environmental protection and human health. This working paper provides perspectives on the research, development and innovation (RDI) promoting integration of municipal, industrial and mine-impacted wastewater(s) resource opportunities in support of sustainable future wastewater management. The paper addresses wastewater as a resource by encouraging reuse and volarisation/beneficiation across the domestic, industrial and mining sectors, by placing three critical elements at the centre of future of wastewater management, namely:

- Paradigm shift from current wastewater management practices driven by digital transformation and supported by the fourth industrial revolution (4IR)
- Wastewater as a resource catalysing achievement of sustainable development goals (SDGs) and beyond
- The need to support transitioning the water and sanitation sector to a circular economy

1. Introduction and background

Currently, approximately 4 billion people live in water-scarce and water-stressed regions, with nearly 1 billion people without access to safe drinking water and almost 1 million deaths per year from waterborne diseases (www.thesolutionsjournal.com). The World Economic Forum projects that under business-as-usual policy and technology practices, the world faces a 40 percent gap between water supply and demand by 2030 (WEF, 2012). In addition to water scarcity impacts, the world also faces negative effects from flooding and poor water quality to economic growth, business continuity, ecosystem health and social well-being. In particular, cities are vulnerable to the impacts of water scarcity and extreme weather events. These impacts are currently being realised in many cities and, as a result, various cities are looking to increase their resiliency to changing hydrologic conditions (www.thesolutionsjournal.com).

Current research indicates that cities most concerned about their water supply are in Asia and Oceania, Africa and Latin America, with 196 cities reporting risks of water stress and scarcity, 132 a risk of declining water quality, and 103 a risk of flooding. Furthermore, impacts from water scarcity on a regional and national scale as previously presented by the World Bank has indicated that water scarcity, exacerbated by climate change, could cost some regions up to 6 percent of their GDP, spur migration, and spark conflict. The combined effects of growing populations, rising incomes, and expanding cities will see demand for water rising exponentially, while supply becomes more erratic and uncertain (www.thesolutionsjournal.com).

As the global water security challenges continue to present themselves before the global community, South Africa remains a water scarce country, with 98% of its water resources already allocated, about 41% non-revenue water and a projected 17-20% supply deficit by 2030. From the total amount of water withdrawn in South Africa per annum 62% is used by the agricultural sector, 27% by the municipal sector and 11% by the industrial sector (DWAF, 2004). However, 89% and 86% is attributed to greywater of the water footprint in industry and in domestic supply respectively, while in agricultural production, this figure is only 6% (Table 1). Therefore, any strategy for mitigating the water footprint of industrial (including mining) and municipal sectors should focus on the polluting effect of effluent rather than the supply of freshwater. However, sole focus on polluting effect of effluent is not that attractive for both industry and municipalities from a cost point of view. Thus, consideration for other beneficial aspects such as volarisation and beneficiation of wastewater(s) in support of offsetting the cost is required as part of future wastewater management.

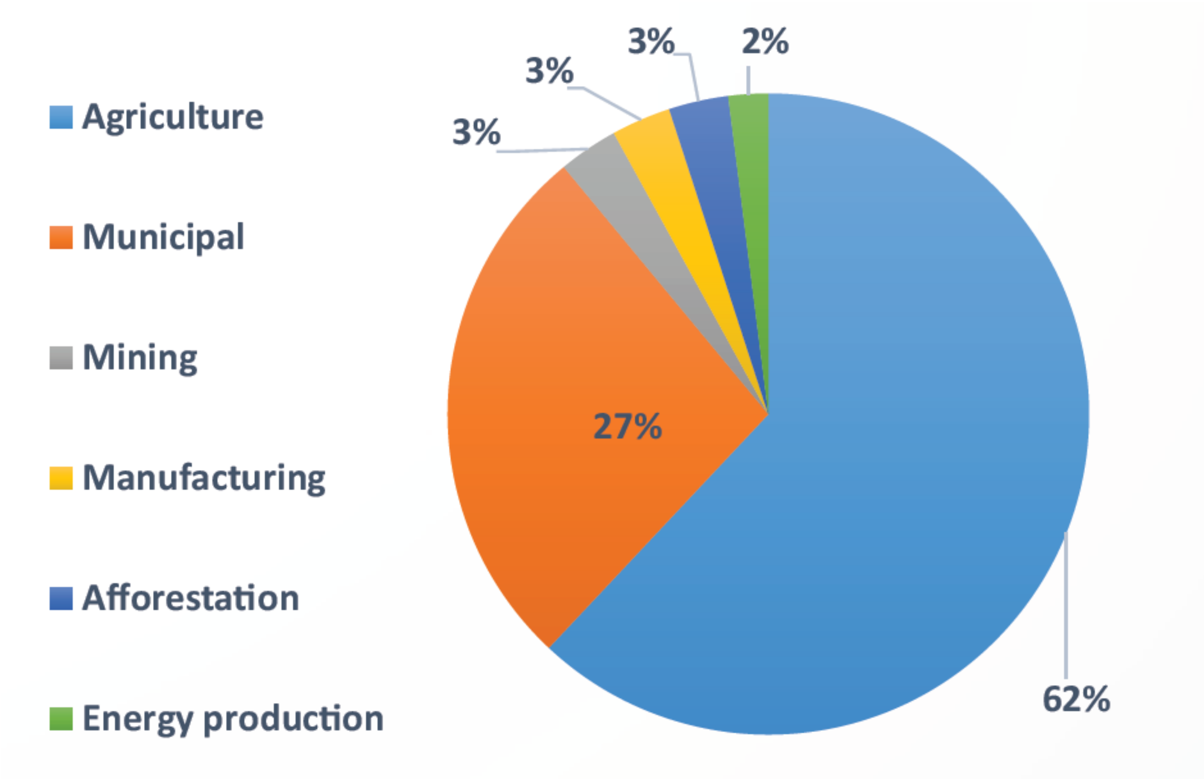

Figure 1: National water footprint for different sectors in South Africa (DWAF, 2004)

Table 1: Greywater footprint for industry, domestic supply and agriculture

Water Footprints (million m^3)						
Agricultural Production			**Industry**		**Domestic Supply**	
Green	**Blue**	**Grey**	**Blue**	**Grey**	**Blue**	**Grey**
45 928	6694	3126	38	309	390	2368
55 748			347		2758	

It is on this basis that wastewater resource management of the future will entail practising a more sustainable way of managing wastewater resources that will prioritise aspects such as reuse and resource recovery. Additionally, future wastewater management approaches should be designed to go beyond addressing sustainability issues and begin to address restoration and regeneration of the planet (Jazbec et *el*., 2020).

In this regard, designing for sustainability requires to design for human and planetary health; to maintain the planet in a condition where life as a whole can flourish (Jazbec et *el*., 2020). Sustainable actions are generally at the energy neutral point of not doing any further damage, and are considered as resource efficiency initiatives that can be implemented within the control of the water sector business. However, as we push the planet beyond the planetary boundaries, aiming for sustainability only is no longer adequate, as we need to consider restoring the material balance and actively go beyond with restorative actions that will ensure the planet's health, resilience and ability to adapt (Jazbec *et al*., 2020).

Restorative solutions focus more on resource recovery with a broader material flow influence which may require new business models (Jazbec *et al*., 2020). Moving towards the regenerative state where actions are designed in line with nature, solutions seek to integrate a wider influence on social and environmental systems, with the aim of doing more rather than just doing less harm. However, for this to be successful, thinking, designing and doing things differently are required, including disruptive technologies and governance approaches that enhance our natural, urban and social environments. This might mean considering the problem from an entirely different perspective, such as considering waste products (including wastewaters) as resources, moving away from end-of-pipe solutions, or starting with the outcome in mind and planning services around them (Jazbec *et al*., 2020).

For the South African context, wastewater resource management of the future should broadly aspire to address current water sector challenges in support of achieving sustainability, restoration and regeneration of the water resources. This will entail a significant consideration of the following three critical elements by the water sector as pillars for achieving sustainable wastewater resource management of the future:

- Paradigm shift from current wastewater management practices driven by digital transformation and supported by the 4IR
- Wastewater as a resource catalysing sustainable development goals (SDGs) achievement and beyond
- The need to support transitioning the water and sanitation sector to a circular economy

Therefore, the purpose of this working paper is to articulate the position and rationale of the Water Research Commission and sector partners regarding the future of wastewater management within the South African water industry.

2. Elements of future sustainable wastewater management

According to the World Bank, across the globe, about 1.3 billion metric tons of waste is generated every year and this is expected to continue increasing in future because of rapid urbanisation and industrialisation across regions (THE WORLD BANK, 2018). Driven by rapid urbanization and growing populations, global annual waste generation is expected to jump to 3.4 billion tons over the next 30 years from the current 2.01 billion tons. Furthermore, the smart waste management market has been valued at USD 1.77 billion in 2020 and is expected to reach USD 6.52 billion by 2026, registering a compound annual growth rate of 25.7%, during the forecast period of 2021 – 2026 (GLOBAL SMART WASTE MANAGEMENT MARKET, 2020).

Currently, almost 90% of waste generated in South Africa continues to be sent to landfill for disposal, with waste management approaches in South Africa generally structured as follows (Godfrey, L., & Oelofse, S., 2017):

- 82% Landfills
- 11% Wastewater treatment plants
- 7% Recovery centres

This practice is considered as economically and environmentally unsustainable as it fails to recognize the benefits of waste volarization and the need to protect the environment.

2.1 Paradigm shift from current wastewater management

Despite the challenges associated with waste management in South Africa, the waste economy currently has a financial potential of R15 billion and provides 29 833 jobs, with implementation of 100% recycling able to unlock R17 billion worth of resources/ products (Waste Economy: Market Intelligence Report 2017). In this regard, more opportunities are available within the South African industrial operations (including mining) and wastewater services. For instance, wastewater services currently host more than 1 000 municipal wastewater treatment works (WWTW), treating about 7 500 ML/d at an operational cost of about R4.5 billion/year. On the other hand, the abandoned gold mines within the Witwatersrand basin have the potential to supply 145 – 240 ML/day of mine-impacted water, with opportunities for valuable recovery existing from the implemented three neutralisation plants. Currently the neutralised mine-impacted water is discharged into the Vaal Barrage where the water is diluted using freshwater from the Vaal Dam to ensure compliance before discharge into the Vaal River. With the Lesotho highlands water projects phase 2 scheduled to be commissioned by 2025, until then, the water availability in the Vaal River System (VRS) will remain at risk, with dam levels in the VRS declining. There is therefore need for the DWS to implement various initiatives to mitigate against future water security risks in the integrated VRS.

The capacity distribution of municipal treatment works and schematic for the mine-impacted water treatment works within the Witwatersrand basin is given in Figure 2 below.

(a) (b)

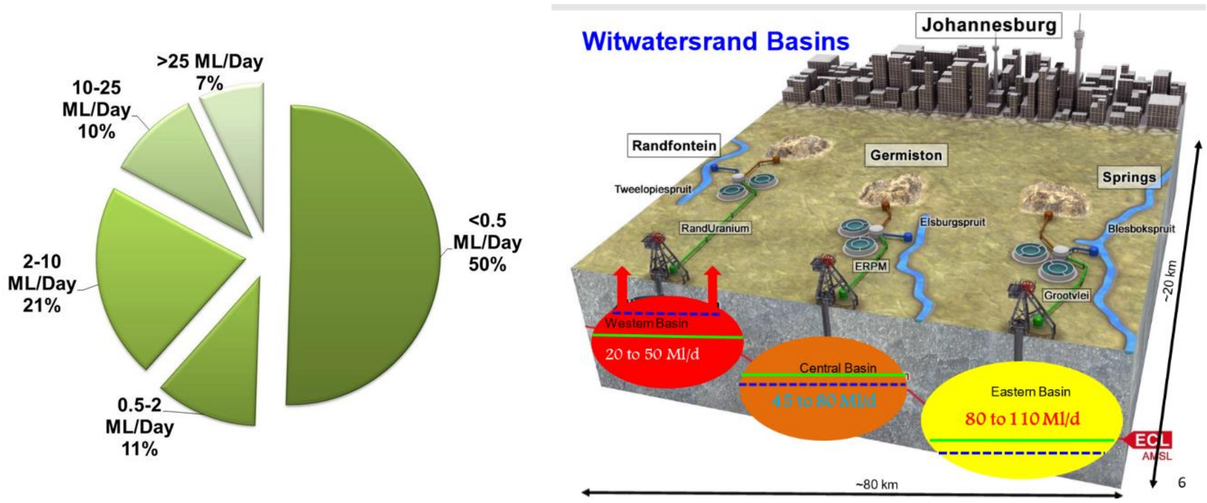

Figure 2: Distribution of the (a) WWTW capacity within the South African wastewater sector and (b) schematic for the mine -impacted water treatment works within the Witwatersrand basin.

Other water resource recovery and reuse opportunities exist within current coal mining locations, particularly in Mpumalanga where most mines are due for closure within the next 10 – 20 years. As an example, the eMalahleni water reclamation plant currently purifies 30 Ml/d of mine-impacted water to potable quality and covers almost 20% of the total potable water demand in eMalahleni.

Furthermore, the 18 major industrial operations in South Africa currently documented as part of the national survey on industrial water and wastewater management are well known to use significant quantities of water and energy while generating huge amounts of wastewater posing challenges for the water sector (SP 125/21). The currently available updated national survey documents providing a snapshot of current water use and wastewater generation and management within the specific industries are given in table 2:

Table 2: The national survey reports on current industrial water and wastewater management.

No.	Title	Year	Report number
1	Water and wastewater management in the malt brewing industry	2016	TT 676/16
2	… metal finishing…..	2016	TT 644/15
3	… soft drink……	2016	TT 640/15
4	… dairy…..	2015	TBC
5	… sorghum malt & beer industry	2016	TT 692/16
6	… edible oil	2016	TT 702/16
7	… red meat abattoir	2016	TT 701/16
8	… laundry	2016	TT 703/16
9	… poultry abattoir	2017	TT730/17
10	… tanning and leather finishing	2017	TT 713/17
11	… sugar	2017	TT 721/17
12	… paper and pulp	2016	TT 704/16
13	… textile	2017	TT724/17
14	… fruit and vegetable processing	2021	TT 863/21
15	…oil refining and re-refining industry	**Outstanding**	TBC
16	….power generating	2021	TT 853/21
17	… iron and steel	2017	TT 705/16
18	… pelagic fish	2021	TT 839/20

Despite the challenges associated with poor wastewater management in the sector, there exist opportunities to address these challenges and improve current wastewater management practices, thereby promoting a shift from current wastewater management practices to sustainable future wastewater management. For instance, the majority of municipal treatment systems have serious overload challenges resulting in poor operations and maintenance and non-compliance. On the other hand, industry's continuous failure to comply with municipal bylaws places a huge burden on treatment systems, while ability to manage mine-impacted water is compromised by ingress challenges, resulting in less cost effective management of wastewater.

In this regard, a shift from the current less cost-effective, end-of-pipe treatment and disposal is required, and this can be achieved by catalysing conversion of current treatment systems into future water resource recovery facilities (WRRFs) across industrial (including mining) and municipal operations. Figure 3 shows an envisaged mapping of such WRRFs, whereby such a facility would use energy-efficient operations, supported by smart systems to monitor operations, recover water, energy and materials such as nutrients, as well as produce clean water and other valuable products in an integrated manner.

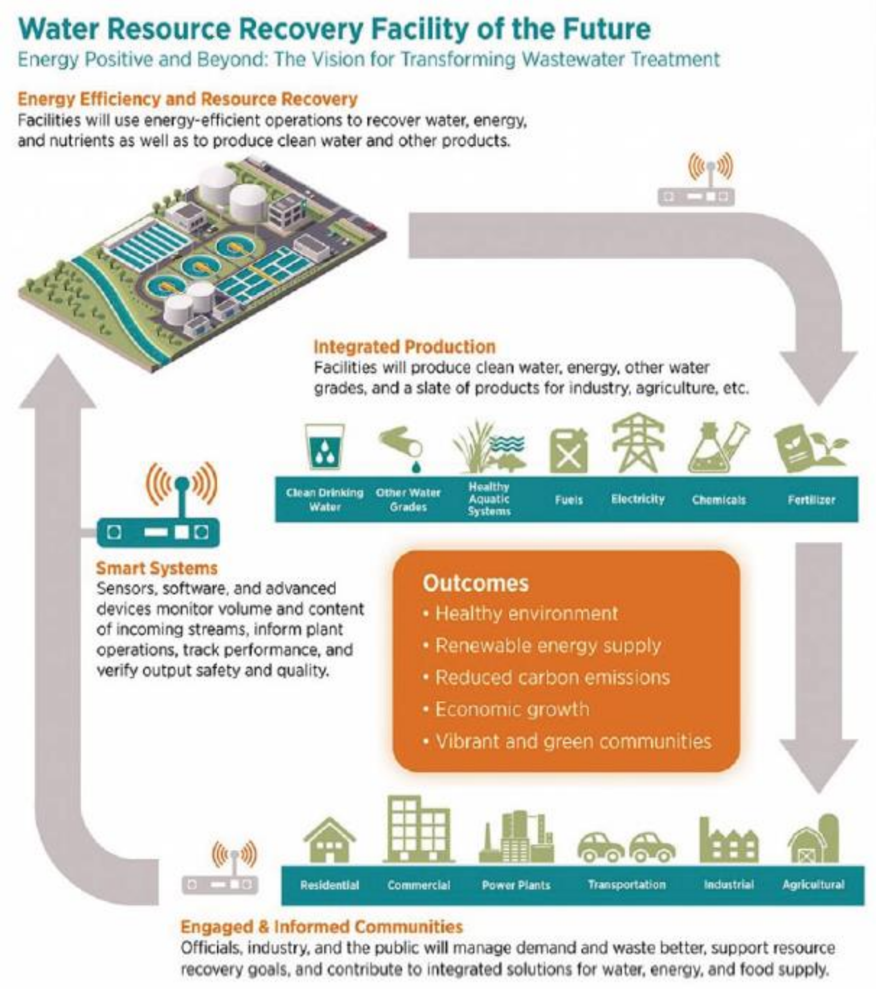

Figure 3: Water Resources Recovery Facilities of the future (Courtesy of The Bioenergy Technologies Office: Advancing a Thriving and Sustainable Bioeconomy Fuelled by Innovative Technologies, November 3, 2015).

The efficient operation of such WRRFs will be further supported by well engaged and informed waterwise communities. On this basis, officials, industry and the public will manage the water demand and waste better, support resource recovery goals, and contribute to integrated solutions for water, energy and food supply.

The envisaged benefits and outcomes of transitioning current treatment systems to future WRRFs within wastewater services include the following:

- Health environment
- Renewable energy supply
- Reduced carbon emissions
- Economic growth and
- Vibrant and green communities

2.1.1 *The Role of the fourth industrial revolution*

Currently, our relationship with water is undergoing a transformation in response to increased demand for water, the impacts of climate change and poor water quality. Digital technologies such as information communication technologies (ICT) are leading this transformation through the emergence of technologies such as remote sensing, inexpensive sensors, smart devices, machine learning, artificial intelligence, virtual reality, augmented reality and blockchain (www.thesolutionsjournal.com).

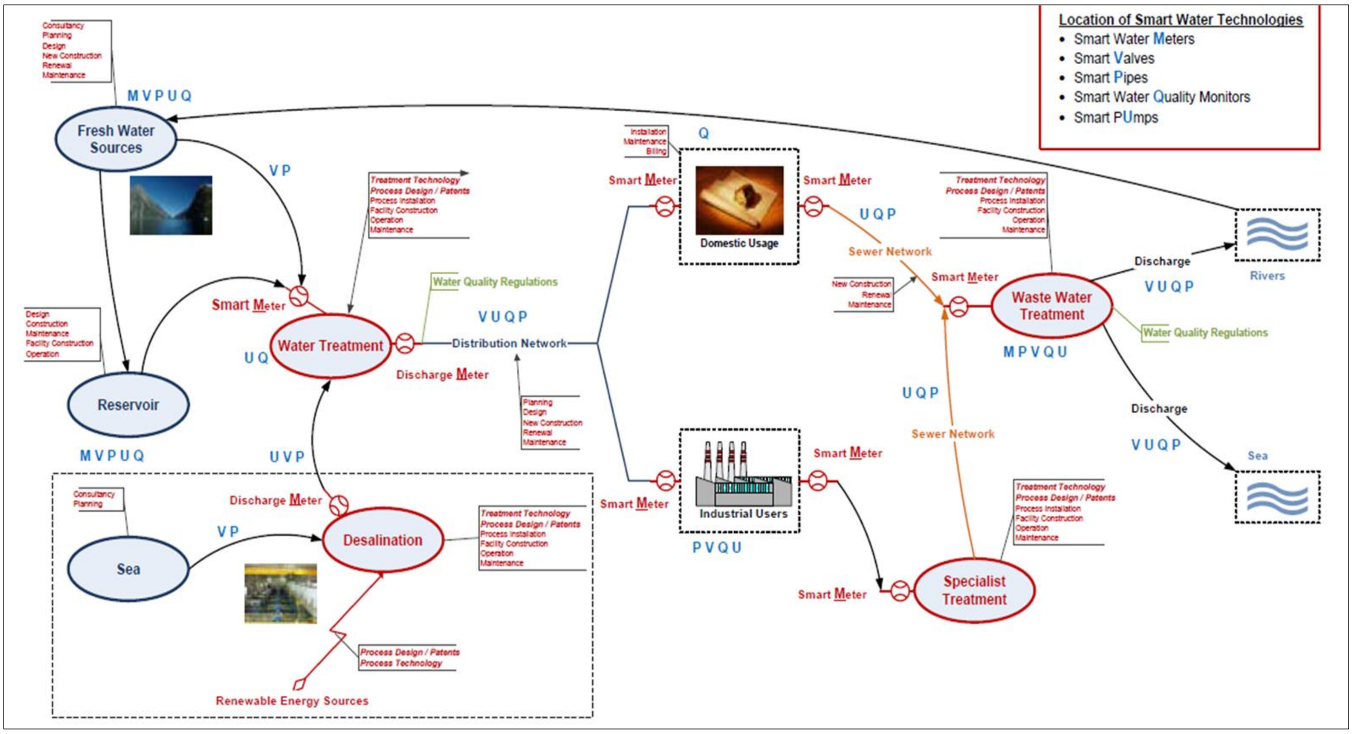

Figure 4: Rethinking the Water Value Chain – Smart Utilities

This digital transformation of water is currently enabling real-time water quantity and quality monitoring, vastly improved management of infrastructure assets, direct consumer engagement and facilitating the adoption of off-grid and localised infrastructure technologies (www.thesolutionsjournal.com). Not only will water utilities be transformed by digital technologies, but the public sector will benefit through improved knowledge of water supply, demand and quality to better inform public policy and investments. The private sector will also be positioned to ensure the efficient and effective use of water in their supply chains and operations (www.thesolutionsjournal.com).

Several organisations have already acknowledged the potential of digital water technologies (www.thesolutionsjournal.com). The World Economic Forum frames the adoption of digital technologies in all industrial sectors as the Fourth Industrial Revolution (4IR). In this regard, digital technologies have the potential to democratise access to water data, actionable information and, in turn, to safe drinking water in support of improved service delivery.

Achieving SDG 6 may be within reach through digital technologies and their ability to facilitate the adoption of other innovative water technologies (www.thesolutionsjournal.com). By 2030 we will therefore see digital water technologies as commonplace just as we have seen digital technologies become integrated into the energy and transportation sectors (www.thesolutionsjournal.com). Moreover, digital technologies will enable leapfrogging of traditional infrastructure such as centralised systems to hybrid and new systems by providing real time access to water/wastewater quantity and quality data for consumers, technology providers and regulators (www.thesolutionsjournal.com).

Therefore, digital technologies will be transformational in positioning the water industry, other commercial sectors and governments for expanded resilience from increased demand for water and the impacts of climate change. The water/ wastewater industry has therefore the opportunity to take the lead in addressing 21st century water risks through the adoption of digital water technologies (www.thesolutionsjournal.com).

2.2 Wastewater as a resource catalysing SDGs achievement

The United Nations' Sustainable Developmental Goal 12 (SDG 12) with Target 12.5, "Responsible consumption and production" promotes the substantial reduction of waste generation through prevention, reduction, recycling, and reuse. In the same manner, Target 12.4 recommends significantly reducing the release of chemicals and contaminants to air, water, and soil to minimize their influence on the environment and human health, creating sustainable circular economies. To achieve these goals, biowastes use in agricultural lands recently experienced a sizeable increase both locally and globally, to improve yields, and supplement or replace inorganic fertilizer crop requirements in agricultural lands (Wang et al., 2018).

Agricultural production requires huge inputs of nutrients for optimal production. Solid stream wastewater can therefore be utilised as a source of nutrients, restoration of degraded land and as carbon sink in support of climate change mitigation. The liquid stream wastewater is also useful as source of water and nutrients, referred to as fertigation. In this regard, the use of solid stream wastewater as a source of nutrients contributes to increased food production in support of zero hunger (SDG 1). This further contributes to good health and wellbeing (SDG 3) as solid stream wastewater is a good source of micronutrients, thus fortifying the nutrient composition in support of food production and security.

On the other hand, the use of liquid stream wastewater as a source of water contributes to SDG 6 as this reduces possible contamination of water resources through irresponsible discharge and disposal. Similarly, use of both solid and liquid stream wastewaters in support of food production contributes to responsible consumption and production (SDG 12) as well as supporting life on land (SDG 15). Furthermore, the use of both solid and liquid stream wastewaters in agricultural facilitate sequestration of carbon in support of climate change mitigation (SDG 13).

Figure 5 shows the role of wastewater generated from integrated municipal, industrial and mine-impacted water as a resource catalysing SDGs achievement.

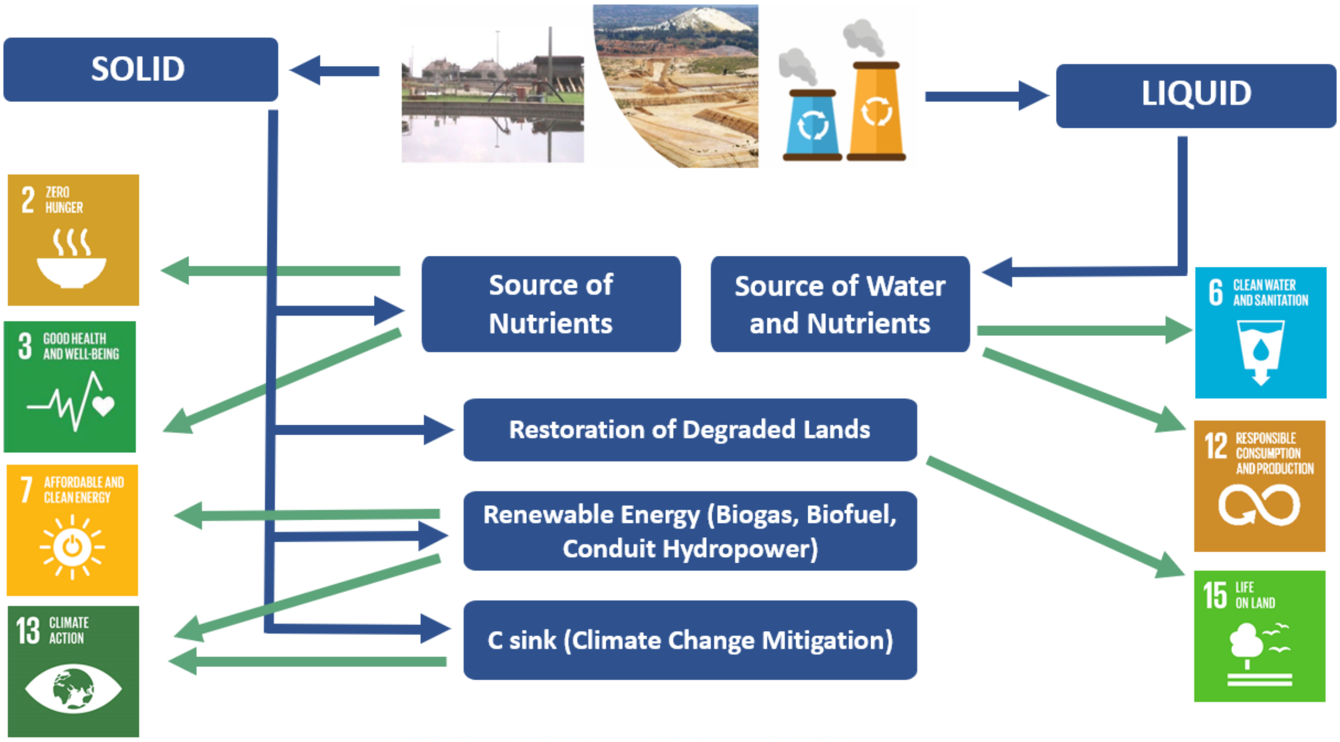

Figure 5: Wastewater as a resource catalysing SDGs achievement

Based on previous research (Libala *et al*. 2021) the SDGs are generally considered interlinked suggesting that achieving one goal is highly dependent on the other goals.

2.3 Transitioning the water sector to a circular economy

A circular economy model (Figure 6a) is an alternative to a traditional linear economy (Figure 6b; make, use, dispose) in which resources are kept in use for as long as possible, extracting the maximum value from them whilst in use, then recover and regenerate products and materials at the end of each service life. Figure 6 shows the conceptual framework of both circular and linear economy for the water sector.

Currently, many utilities globally are considering the benefits of unlocking the circular economy to better manage water and wastewater resources, make and use products to regenerate natural systems. To define a clear role for water utilities in transitioning to a circular economy, the International Water Association (IWA) developed framework has identified three key interrelated pathways to achieving circular economy principles in the water sector as water, material and energy (IWA, 2016). The water pathway needs to be developed as a closed loop, with diversified resource options, efficient conveyance systems and optimal reuse as three key factors. Under the materials pathway resource recovery from wastewater operations must be able to compete with other products on the market for successful incorporation into the circular economy. On the other hand, the objective of the energy pathway includes reduction of carbon-based energy consumption and increased renewable energy production and consumption, thereby contributing to the zero-carbon emissions initiative (www.bizcommunity.com).

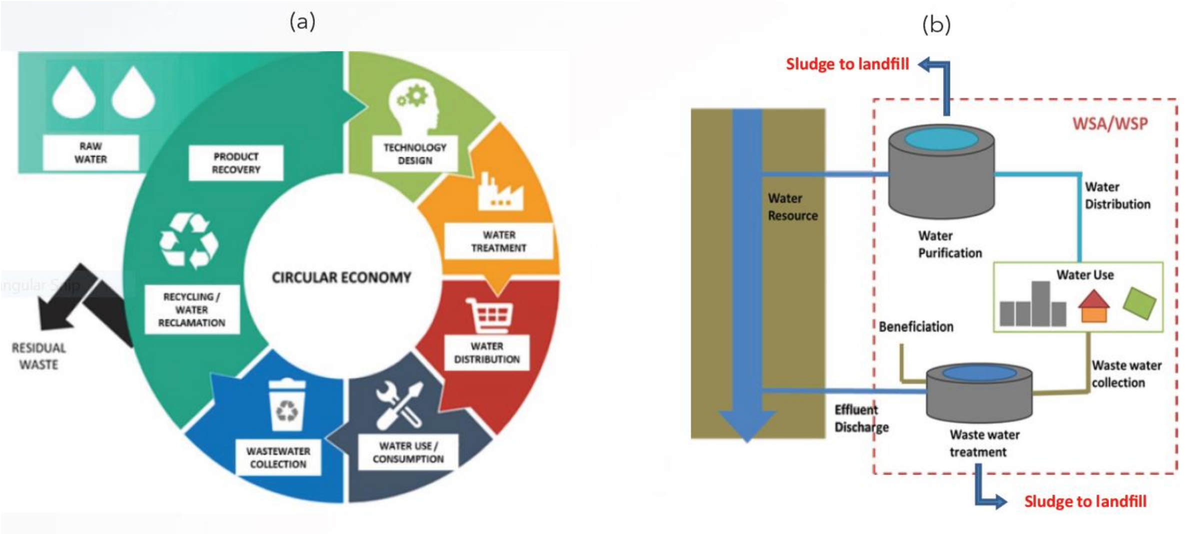

Figure 6: Conceptual framework of (a) circular economy and (b) linear economy for the water sector.

Throughout the pathways, there are critical junctions where water, energy, or materials intersect and opportunities arise to transition to a CE. By analyzing these junctions, utilities can gain insights and take actions and create partnerships for transitioning to the CE. These junctions include (IWA,2016):

- **Water-Wise Communities**: Engaging citizens as consumers and professionals so that they can realize their instrumental role in supporting the integration of water across sectors through their personal and professional choices and decisions
- **Industry:** As large water users, water polluters and potential customers for materials, industry can help bring CE solutions to scale
- **Wastewater Treatment Plants:** Shifting the traditional paradigm and viewing, designing and operating wastewater treatment plants as resource factories, energy generators and used water refineries
- **Drinking Water Treatment Plants:** Promoting circularity through designing plants to operate more efficiently, treating water from multiple sources to produce different water quality for different purposes and keeping production costs low
- **Agriculture:** Being the largest water user and a significant water polluter, the agricultural sector is a vital partner to support a CE through creating business opportunities as well as improved efficiencies and value-added, competitive products and services
- **Natural Environment:** Increased understanding of the natural environment's value as a provider of water services and unlocking its significant potential in providing

treatment, storage, buffer and recreational solutions will give rise to multiple benefits and cost-savings

- **Energy Generation:** Co-operating with the energy sector to create energy independence using less carbon-based energy and contributing renewable energy to the grid

The main factors that drive and enable the transition of the water sector to a circular economy are consumers, industry, regulation, infrastructure and urban and basin economies (IWA, 2016). Water utilities need to anticipate, respond to and influence these factors in order to accelerate the pathways to achieving a circular economy. The challenge for utilities is to shift these factors from traditionally enabling a conventional linear economy model to a circular economy model. In transitioning to a circular economy, water utilities also need to change their current way of operation and seek new management approaches, partnerships and business opportunities (www.bizcommunity.com).

The transitioning to a circular economy within the South African water sector is in line with the United Nations SDGs. Water has a dedicated goal in SDG 6 (ensure availability and sustainable management of water and sanitation for all) and its attainment will be reliant upon contributing to and benefiting from the attainment of other SDGs, most notably in the context of the circular economy, SDG 12 (ensure sustainable consumption and production patterns). This interdependence across goals manifests at a national level in highlighting the need for greater cooperation amongst sectors, incentivised innovation and enabling meaningful engagement with citizens. Moreover, the shift from a linear to a circular economy has multiple economic, social and environmental benefits. It allows the sector to create more value while reducing their dependence on scarce and costly resources. Furthermore, a circular industrial system that is regenerative by design, which restores material, energy, and labour inputs, can only be good for both society and business.

3. Conclusion

In conclusion, wastewater resource management of the future within the South African wastewater services should broadly aspire to view wastewater as a resource, with significant shift from end-of-pipe treatment to reuse and resource recovery. This will entail a significant consideration of three critical elements by the water sector as pillars for achieving sustainable wastewater resource management of the future, namely, (i) paradigm shift from current wastewater management practices driven by digital transformation and supported by the 4IR, (ii) wastewater as a resource catalysing sustainable development goals (SDGs) achievement and (iii) the need to support transitioning the water and sanitation sector to a circular economy. Thus, development of novel and innovative knowledge solutions to improve the sector’s ability to tap the strength of wastewater(s) and restore environmental health, sector competitiveness, stimulate enterprise development, and contribute towards economic growth and prosperity is critical in support of future sustainable wastewater management.

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