From waste to resource: opportunities and challenges to combat water scarcity

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Abstract

Many parts of South Africa are still staggering on the back of severe droughts experienced over the past decade. Rapid urbanization has created a plethora of water-related challenges, including environmental degradation and water scarcity accentuated by climate change. Under the Intergovernmental Panel of Climate Change (IPCC) emissions scenarios, these challenges are projected to further affect both atmospheric and hydrological circulations. The livelihoods and food security of rural communities of a predominantly urban population are therefore at risk from water-related impacts linked primarily to climate variability. In this context, unconventional water resources can play a critical role to achieve water security. Water scarcity, increased pollution, unprecedented population growth, and climate change are collectively driving the need to reuse water with the aim to enhance water security, sustainability, and resilience. It is clear that South Africa's already strained water resources will become even more stressed in the near future. The Department of Water and Sanitation predicted that by 2030 water demand will reach 17.7 billion m3, far more than what is available to allocate. Globally, responsible and efficient water management is fast becoming a pressing reality for domestic users, agriculture, and industry alike. The challenge is therefore to capitalize on the limited water we currently have. Several response strategies are available that will provide both near-term relief and long-term benefits. This chapter examines the significant potential contribution available from water reuse opportunities. Reuse constraints and future water management strategies are also addressed.

Keywords

water reuse, agriculture, droughts, water security, decision support system, constraints

Introduction

Water scarcity is a glaring reality for many countries around the world. Unfortunately, the global climate change crisis is causing environmental changes and impacting natural resources such as agricultural production, energy production, water levels and more. Many South African cities have faced drought in the past few years (Muller, 2019), which significantly affected the above-mentioned production models. In addition, South Africa is facing a projected 17 % water deficit by 2030 (WWF, 2017).

Extreme weather conditions such as prolonged periods of drought represent new challenges for many industries, particularly agriculture. Agriculture is by far the largest user of available water globally (OECD, 2020). It is also likely to experience increasing pressure for water use efficiency as the competition for water increases. According to The World Bank Group (2020), it is likely that in future all sectors will be expected to have 25 – 40% of their water share reallocated to higher productivity and employment activities. More so for the agricultural sector in a water-scarce country. It is therefore critical to address water reuse and identify relevant technologies for enabling water reuse to make this a possible reality that improves water availability capacity for the country. Water reuse is a collective term used for planned and or unplanned potable or non-potable, reclamation (treatment of wastewater for reuse), or recycling (reuse of water without treatment, often within the same industry) of water for beneficial purposes. Sources of water for potential reuse can often include municipal wastewater, industrial process, and cooling water, as well as water produced during natural resource extraction activities. Reuse of these water sources often requires "fit-for-purpose" treatment, ensuring that treatment requirements for a specific use are met e.g., reuse of treated wastewater for irrigation of food crops, need to be of sufficient quality to prevent harm to plants and soils, maintain food safety, and protect the health of farm workers (US EPA, 2022).

The role of treated wastewater reuse as an alternative source of water is well embedded in international strategies including the Sustainable Development Goals (SDG) (specifically SDG 6). Among other aspects, SDG 6 considers the improvement of water quality by reducing by half the amount of wastewater that is not treated. SDG 6 also aims to increase recycling and safe reuse globally by 2030 (Tortajada, 2020). This will result in the availability of more clean water for all uses, and enormous progress in sanitation and wastewater management. Although water reuse is globally becoming a common strategy, South Africa is lagging far behind with only 14% of wastewater being reused according to estimates by the Department of Water and Sanitation (DWS), albeit South Africa's Water and Sanitation Master Plan (DWS, 2018) is aligned to this specific SDG.

The impact of climate change on agriculture

According to the Department of Water and Sanitation (DWS), the majority of water in South Africa is used in agriculture, with over 60% of all available water going into the sector for irrigation (DWS, 2018a,b; Figure 1).

As much as 30% of water is used for urban and rural use (including domestic use), while the remaining 10% is split among industrial, afforestation, and power generation. As such a large user, it is heavily impacted by the availability and reliability of freshwater resources. The agriculture sector is, therefore, arguably significantly vulnerable to climate risk.

Agriculture is a crucial sector and a driver for economic development (Zhane and Montmasson-Clair, 2016) and food security (Pawlak and Kolodziejczak, 2020).

Meister Consultants Group (2009) in their report on climate adaptation strategies, concluded that South Africa's development is highly dependent on two climate-sensitive industries namely agriculture and forestry. The Western Cape is the most important producers of agricultural goods in South Africa.

In 2015/16, this province experienced its worst drought in a century. Similarly, Nelson Mandela Bay Municipality (NMBM) in the Eastern Cape (another agricultural hotspot), is currently in the midst of its worst drought (BusinessTech, 2022). Climate change (through both increased temperature and decreased rainfall) can have fundamental negative impacts on agriculture and could contribute to the destabilization of the agricultural sector, with far-reaching impacts on food security and livelihoods. Climate change models have predicted even drier conditions by 2050 (DEA, 2013), which will have severe implications for the sector in multiple provinces.

South Africa is one of the 30 driest countries in the world, with three of the nine regions of South Africa

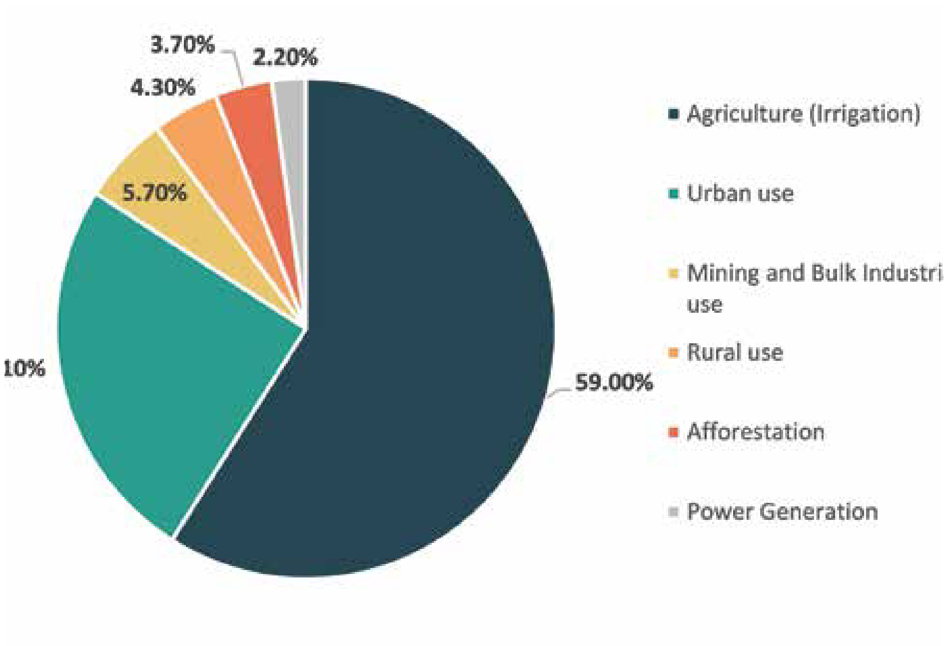

Figure 1. Water use per sector (DWS, 2018)

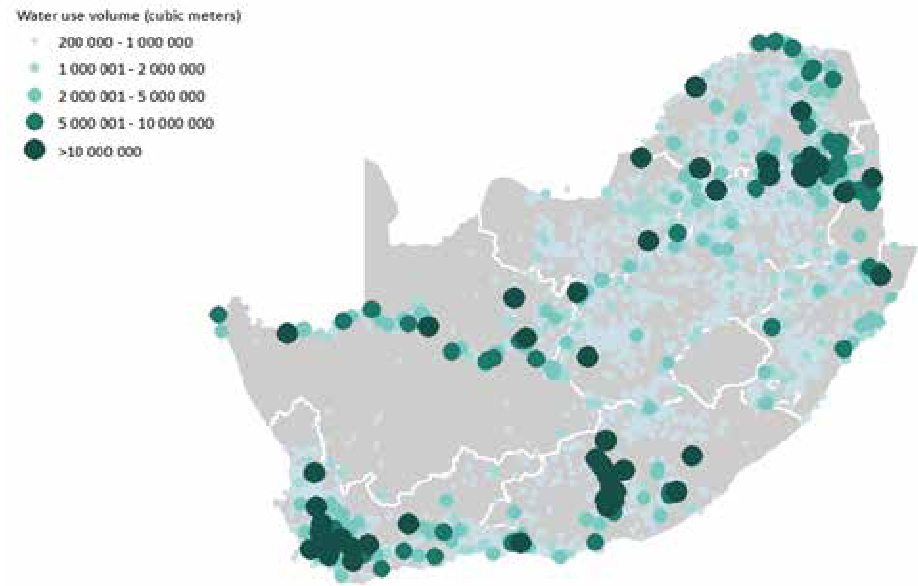

Figure 2. National agriculture water use volumes (Steyn et al., 2021)

declared as disaster areas due to drought in 2018 (DEA, 2019). South Africa's annual precipitation is highly variable. The average annual rainfall between 1900-2009 was recorded at 450 mm compared to the average annual rainfall of ~990 mm globally (US AID, 2015). Rainfall was average in the 1970s, late 1980s and mid to late 1990s; and below average in the 1960s and early 2000s before reverting back to average in 2010 (US AID, 2015).

An atlas for potential industrial bulk scale water reuse was produced by the CSIR in 2021. Data was obtained from the publicly available National Industrial Water and Wastewater Survey (NATSURV) and Water use Authorisation & Registration Management System (WARMS). Maps produced in the atlas indicated that from a national perspective, water-intensive industries were largely represented by the agriculture sector, mostly through irrigation (Figure 1). In all provinces, the highest water withdrawals per sector was for agriculture, except in Gauteng.

The atlas also illustrated that the Western Cape region is characterized by intensive agricultural activity and high irrigation requirements (Steyn et al., 2021).

The challenge

Figure 3 depicts the current water supply vulnerability (i.e., demand versus supply) in eight1 of the nine metropolitan areas of South Africa (i.e. Cities of Johannesburg (COJ), City of Ekurhuleni (CoE), and City of Tshwane (CoT) in the Gauteng Province, eThekwini Metropolitan Municipality (EMM) in KwaZulu-Natal, Mangaung Metropolitan Municipality (MM) in Free State, Nelson Mandela Bay Municipality (NMBM) and Buffalo City Metropolitan Municipality (BCMM) in the Eastern Cape, and City of Cape Town (CoCT) in the Western Cape) (CSIR, 2019). A vulnerability index of [1] implies that the water demand and supply of the municipality are equal, <1 indicates that there is surplus water supply, while an index of >1 indicates that either the water demand is too high, the water supply is too low, or both. The water demands, supply and vulnerability index for each of the major municipalities are presented in Figure 3.

Since the vulnerability exceeded 1 in at least two municipalities (i.e. EMM at 1.07 and NMBM at 1.04), it stands to reason that additional (more pronounced) water reuse activities should be concentrated in these municipalities. The current climatic condition

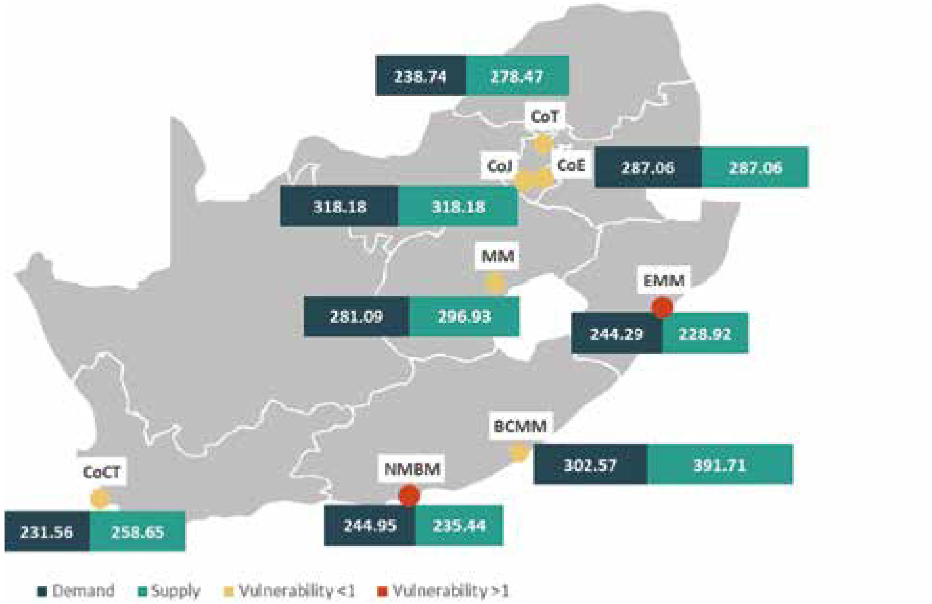

Figure 3: Water demand, supply and vulnerability for each major municipality. Yellow circle denotes a vulnerability index <1, while red circle denotes a vulnerability index >1

in South Africa is predicted to worsen (IPCC, 2022). Furthermore, drought conditions could worsen the projections for the national water deficit.

Figure 3. Water demand, supply and vulnerability for each major municipality. Yellow circle denotes a vulnerability index <1, while red circle denotes a vulnerability index >1 .

As shown in Figure 4, the anticipated (2050) climate and population growth projections for the major municipalities indicate that five of the eight metros would see a reduction in the mean annual precipitation, while all (except one) would see a drastic increase in population growth (CSIR, 2019). These anticipated future changes in precipitation and

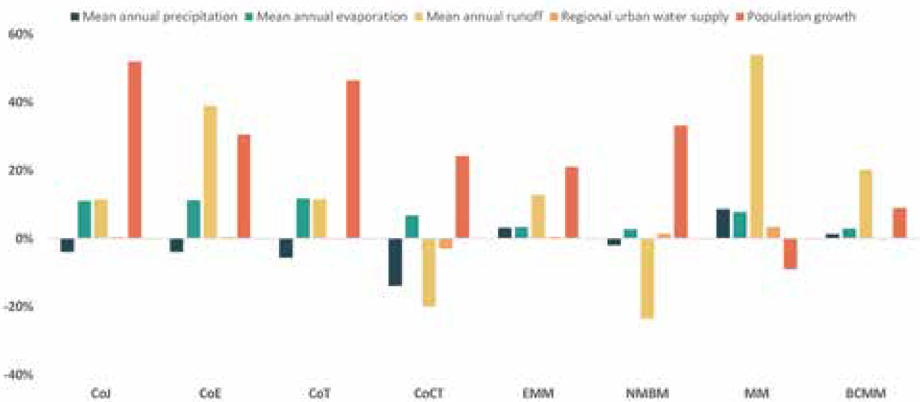

Figure 4: Projected (2050) climate and population growth for the major municipalities

temperature collectively will result in an increase in the irrigation demands across the country.

Figure 4. Projected (2050) climate and population growth for the major municipalities

It is therefore important that water reuse forms part of the drought risk management strategy of the country.

Water reuse - a potential solution

Water reuse is a reliable, local water supply that reduces vulnerability to droughts, population growth, and water-supply constraints. It can play an important role in water security in a water-scarce country such as South Africa (Toze, 2006; Tortajada, 2021). Reuse of treated domestic wastewater is not a new phenomenon and has been practiced all over the world. For example, the City of San Jose (California, USA) uses reclaimed water for city offices and a public fountain. Also Israel and Singapore reuses more than 80% and 30% of its wastewater, respectively. Australia replenishes their groundwater through wastewater reuse. Both South Africa and Namibia reclaim potable drinking water from treated wastewater (USEPA, 2019). Formal water reuse projects/schemes are however severely lacking in South Africa. The projected water reuse volumes depicted in Figure 5 presents additional potential to expand current reuse volumes (derived from CSIR, 2019).

Recent droughts in the country have triggered several water reuse projects and programmes, highlighting the immense potential of the South African water sector in combating water shortages. Selected water reuse schemes have been implemented to date, withsome still planned for the future. A few examples of water reuse schemes in industry are summarized below:

- **City of Cape Town**

  Cape Town narrowly avoided "Day Zero" in 2018, during the worst drought on record. Following public comment, Cape Town's Water Strategy was adopted in 2019, with the aim to ensure that water can continue to support the life of the city – even during period of low rainfall. Cape Town's advanced purification demonstration plant at Zandvliet Wastewater Treatment Works was commissioned in 2019. The plant produces up to 10 m

- **Atlantis Water Resource Management Scheme (AWRMS)**

  Atlantis Water Resource Management Scheme (AWRMS) has been in operation for over 40 years. The scheme consists of stormwater collection ponds, recharge basins, coastal recharge basins, treatment plants, and two wellfields (Witzands and Silwerstroom), and uses treated wastewater and stormwater, which is diverted to the recharge basins, where it infiltrates into the sandy aquifer. The current yield from the existing wellfield varies between 5 - 13Ml/day. The refurbishment plan, which is expected to bring in an additional 12 Ml/day, as well as the introduction of a new wellfield which is expected to bring in an additional 10 Ml/day. The eventual total capacity from the combined Atlantis wellfield will therefore be in the order of 35 Ml/day.

- **Beaufort West**

  The Beaufort West water reclamation plant, commissioned in 2010 when the town's main water supply, the Gamka Dam, dried up during a severe drought, in 2011. The plant uses secondary treated wastewater via an advanced water treatment facility for further treatment to drinking water quality standards.

- **Durban Water Recycling plant**

  Durban Water Recycling plant was commissioned in May 2001. The plant uses water technologies to treat 47.5 million litres of domestic and industrial wastewater to a near potable standard for direct reuse in industrial processes. In addition, 98% of the wastewater is recycled for reuse, reducing the city's water consumption by 7%.

- **Optimum Water Reclamation Plant**

  Located near Hendrina in Mpumalanga, the Optimum Water Reclamation Plant was initiated in 2008. The plant uses advanced treatment technology and disinfection, is designed to treats 15ML/day with peak capacity of 18Ml/day. Approximately 95 % of the treated water is available for use by the surrounding communities (local Hendrina Municipality), while the remaining 5% is discharged into the Klein Olifants river to sustain the aquatic reserve (Nafasi Water, 2019).

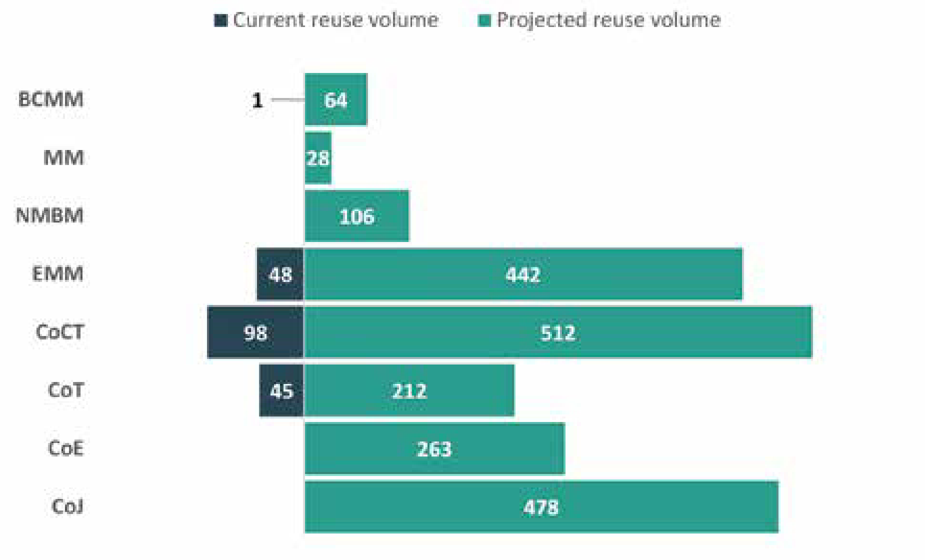

Figure 5: Current and projected water reuse volumes (ML/d) for each major municipality (CSIR, 2019)

- **Middelburg Water Reclamation Plant**
  The Middelburg Water Reclamation Plant was completed in 2015. The plant treats 20Ml/day with a peak capacity of 25Ml/day with 99.7% water recovery. It was designed to treat mine-impacted water from the Middelburg Colliery in Mpumalanga to a standard suitable for reuse by the colliery, and for discharge of surplus water into the Spookspruit, a tributary of the Upper Olifants River (Nafasi Water, 2019).

- **The eMalahleni Water Reclamation Plant**
  The eMalahleni Water Reclamation Plant was commissioned in 2007. The plant treats mine water by desalination to potable water standards. The plant currently has the capacity to treat 30 Ml/day to potable quality, the bulk of which is piped directly to the eMalahleni Local Municipality's reservoirs supplying 12% of the city's daily water needs (Nafasi Water, 2019).

There is however a large difference between the volume of water resources available and the volume that can be reused. Until recently, water supply, sanitation, and water resources management and investments have been managed as separate entities. An integrated approach that encompasses the whole water cycle (the water resources available and water supply, treatment, and reuse options) is however needed to turn wastewater into an asset (GWP, 2009; DWA, 2013; DWS, 2018). The need for such an integrated water supply approach in South Africa was also highlighted in the CSIR-produced atlas (Steyn et al., 2021).

Such an integrated approach requires that water reuse underpins water management. Water reuse implementation requires active water management and policy implementation with the value of wastewater reuse underpinning all future water management approaches in South Africa. It calls for integration in how water demand and conservation planning is done and how water use licenses are issued. It further unscores wastewater treatment and new treatment infrastructure planning together with housing and industrial development in the country. To this effect, Kalabaile et al (not dated) reported that water supply authorities in South Africa are increasingly becoming aware that water reuse are no longer only an emergency supply option, but rather water reuse must be considered as part of a long-term water supply mix strategy in water resources planning. Within the long term planning, a circular economy approach provides

an important opportunity to recover water, energy, nutrients and other precious materials embedded in wastewater (IWA, 2018). Besides benefits associated to increased water availability for irrigation, Arena et al (2020) describes the multiplier effects of wastewater reuse of urban water. While reuse avails additional potable water of good quality for drinking and urban development, wastewater reuse projects can result in positive environmental impacts, as they contribute to improve water quality of the receiving bodies by diverting wastewater from their outlet. This further represents a typical win-win situation where significant synergies can be achieved between urban and agricultural sector, and the environment.

These favorable conditions, however, do not necessarily imply that water reuse is feasible. Reuse might not be feasible form an economic perspective or due to fitness-for-use. Social acceptability is also key to public buy-in for wastewater reuse project implementation.

A water reuse decision support system

In this context of reducing water demand and increasing water supply, within the context of sustainable development and a circular economy, the CSIR has embarked on the development of a web-based decision support system (DSS) tool, to allow water users (in various industries including agriculture) to implement more robust and sound decisions with regards to effluent reuse options.

The current demonstration version of the CSIR's DSS tool aims to allow complex decision-making with regards to bulk scale water reuse in South Africa. The DSS includes a geographical information system interface with a distance calculator in order for decision-makers to match compatible water users within a specific area. The current version of the DSS tool (Figure 6) incorporates bulk water use volume data (demand), as well as bulk scale water effluent volume data (reuse supply potential) obtained from all water users registered on the DWS WARMS database. In addition, the tool allows for aspects of fitness of use and water quality, as well as the different treatment technology.

Figure 7 depicts a screenshot of the summary dashboard of the demonstration version of the DSS for a user match, allowing decision-makers the opportunity to make informed water reuse decisions within an area, e.g., metropolitan area or within a specific province. However, a challenge exists in that success of the tool requires data sharing and a collaborative effort between industry stakeholders and government to improve current and future versions of the tool.

While the DSS could allow for complex decision-making and potentially guide the prioritisation of water reuse potential in a specific geographical area or between different industries, there are multiple constraints that hamper the water reuse potential.

Reuse constraints

The use of recycled water (e.g., for the irrigation of crops) has benefits in using a resource that would otherwise be discarded and wasted. The use of recycled water

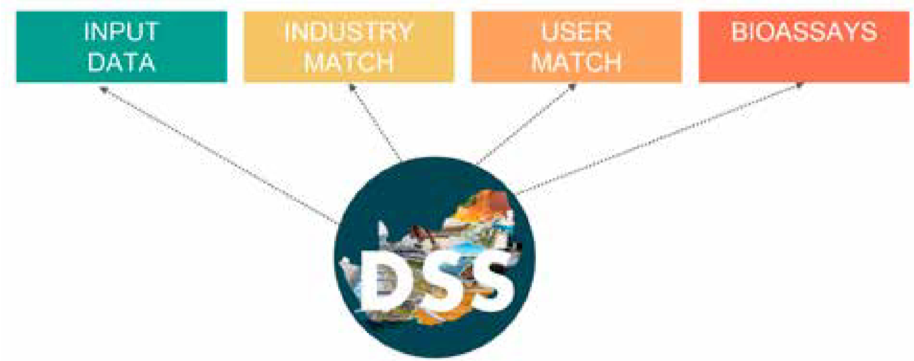

Figure 6: The DSS Framework

also reduces the pressures on the environment by reducing the use of environmental waters (UN, 2021). Morris et al. (2021) did a comprehensive review and analysis and found 56 barriers for implementing water reuse in agriculture.

The following key constraints were highlighted:

1. ***Social and economic constraints*** – a general lack of knowledge and public understanding, leads to negative perceptions towards reusing wastewater in terms of human health impacts, environmental impacts and cost implications. Long-term financial burdens and short-term financial barriers were a prominent feature amongst stakeholders. Kirchherr et al (2018) found that economic feasibility aspects of technological solutions were one of the main barriers in wastewater reuse (Kalebaila et al., not dated).
2. ***Governance and Policy*** – A general lack of regulatory barriers at local or regional levels delay investment in wastewater solutions. According to Sharma (2000) local water specifications often do not recognize the use of recycled water. Lack of political will and a regulatory framework that support reuse further impacts integrated wastewater management in cities. (Kalebaila et al., not dated).
3. ***Technological aspects*** –Technological advances and infrastructure needs to treat complex mixture of polluted wastewaters are often expensive and not economically viable (Morris et al., 2021). Fit-for-purpose treatment could solve the problem without excessive implementation costs as not all practices for reuse requires the same water quality requirements. Often tertiary treatment of wastewater could be a viable option where freshwater availability is declining. In some cases, simple green and low technologies could be effective in allowing reuse while closing the loop on nutrient recycling (e.g., phycoremediation of domestic wastewater) (Steyn and Oberholster, 2021).
4. ***Environmental aspects*** – Water reuse within a circular economy approach could pose significant risks to the environment (Hamilton, 2006; Toze, 2006; Voulvoulis, 2018). Nutrient and salinity aspects could cause real concern in agricultural areas (De Langet et al., 2008) while pathogens, or the accumulation of metals from insufficiently treated wastewater could hamper human health[2] (DWS, 2022).

Future of water management

Water reuse is on the rise globally – and not just in developing nations. In 2018, the IWA Wastewater Report (IWA, 2018) found that the global market for Wastewater reuse and recycling reached almost $12.2 billion in 2016 and expressed a predicted increase against the backdrop of climate variability, population growth and urbanisation to $22,3 billion by 2021. A paradigm shift is needed where used water is no longer seen as a waste that one needs to get rid of, but a valuable resource that forms an integral part of water budgeting and planning in urban areas, industry and agriculture alike (GWP, 2009; Rodriguez et al., 2020; UN, 2021). Several key areas for effective integrated water management should include the following:

1. ***Planning for integration*** – Wastewater treatment should be incorporated into economic development agendas and planning of cities. The location of treatment (either centralized or decentralized) should be planned close to reuse sites e.g., peri-urban farmers or industrial users. The treatment and disposal of wastewater of a city / town should be seen as part of the water management. Planning should consider the risks e.g., pathogens, build-up of contaminants (Hamilton et al., 2006; Van Koppen and Schreiner, 2014; Van Niekerk and Schreider, 2013).
2. ***Sanitation opportunities*** – a portfolio of sanitation options and alternative solutions will enable communities and decision-makers to select the best possible option. Technical, environmental, economic, and institutional criteria will inform such decisions. In some cases, decentralized systems would best protect the environment, and avoid transfer of water over long distances (Brault et al., 2022).
3. ***Define fit-for purpose and cost-effective treatment options*** – Treatment options are often based on the effluent regulatory standards or guidelines instead of managing the performance criteria based on reducing human health risks, lessen the environmental impact or potential for reuse (which could be more effective). Planning for reuse (planning of treatment plant design) will have optimal results (Capodaglio, 2021).
4. ***Source of supply approach*** – Both centralized and decentralized water treatment options should be considered. A shift is needed where for example industrial pollutants are removed at the source instead of after it has joined the municipal sewer system. This is much more complicated, and in some cases even not technically or economically feasible. Within a circular economy approach, nutrients or pollutants should be considered within a closed-loop approach and retained within the same industry for example (Voulvoulis, 2018; Kesari et al., 2021).
5. ***Agriculture within an urban water treatment cycle*** – To take advantage of the water and nutrient recycling opportunities, agriculture should be considered as the land treatment option for closing the nutrient loop, e.g., domestic wastewater and the irrigation of fodder crops, or forest trees (Rosemarin et al., 2020).
6. ***Enabling environment*** – Paramount to the above, a complete wastewater discharge, treatment and reuse system requires an enabling environment e.g., an integrated view and adapted legislation and institutional structures (IWRM approach) (Van Koppen and Shreiner, 2014; Van Niekerk and Schneider, 2013; Kalebaila, not dated). Political will should be strengthened and collective pro-active action from all sectors e.g., tourism, trade, agriculture should be communicated together with the impact on poverty reduction. Water rights must be defined and clearly communicated to all users. Economic incentives for the reuse of wastewater should be defined. In-plant recycling and pre-treatment should be pro-actively financed as part of future water supply strategies. Realistic guidelines or standards should be developed for treatment and reuse that are both enforceable and affordable. These guidelines should consider local conditions (e., socio-cultural, environmental, epidemiological). Public awareness and training

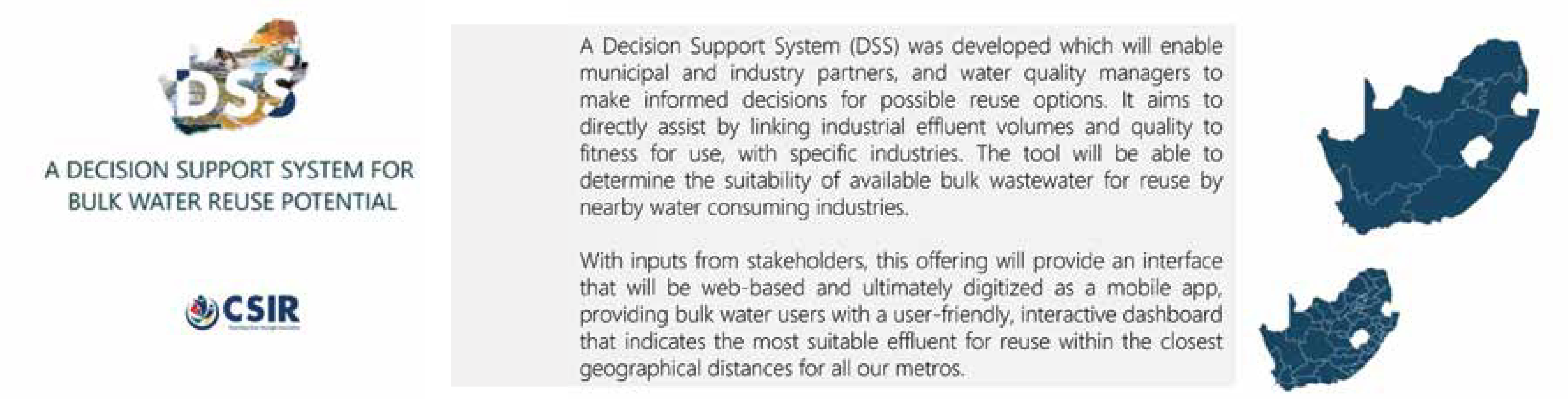

Figure 7: DSS screenshots

and stakeholder engagement should be integrated, and water quality data should be freely available and shared with customers and the general public.

Conclusions

There is tremendous unexploited potential to improve water efficiency and augment or partially substitute freshwater supplies in South Africa. Reuse of treated wastewater to augment water supplies and improve water security as a result of climate change and drought, will allow more water to be available for potable uses. Decision support systems are valuable tools that strive to assist decision-makers in metropolitan areas with complex and important drought risk management decisions. Decisions for reuse are not linear and depend on various factors – such as stormwater management, aquifer protection, and industrial development. Integrated management of water resources is in line with sustainable development and the recent drive to a circular economy. This calls for targeted collaborative effort form all parties involved within and enabling environment to improve water reuse and decrease water security issues, while managing risks.

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- [1] Data was only available for eight of the nine provinces of South Africa and projections therefore only available for eight metropolitan areas.
- [2] Of the 995 municiapl wastewater treatment works in South Africa, 334 (39%) was found to be in a critical state, and therefore potentially not treating domestic wastewater effluent sufficiently before releasing it into the environment (DWS, 2022).