BULK SCALE INDUSTRIAL EFFLUENT REUSE POTENTIAL IN SOUTH AFRICA

Steyn, M[1], Walters, C[1], Mathye, M[2], Thwala, M[2], Banoo, I[3], Ndlela, L[1], Tancu, Y[1], Genthe, B[1]

1. CSIR, Jan Celliers Street, P.O. Box 320, Stellenbosch, 7599, South Africa
2. CSIR, Meiring Naude Road, P.O. Box 395, Pretoria, 0001, South Africa
3. CSIR, Mazisi Kunene Road, P. O. Box 59081, Durban, 4075, South Africa

ABSTRACT

Rationale: 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 m^3, 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 capitalise on the limited water we currently have. *Solution:* Bulk-scale reuse of industrial water effluent can play a significant role in water security in a water scarce country, such as South Africa, as it can augment or partially substitute freshwater resources needed for domestic purposes and future development. Water reuse in South Africa is however lagging. *Approach:* An Atlas for potential industrial bulk scale water reuse was produced from publicly available Natsurv and WARMS data. It highlights the urgent need for water reuse to form an integral part of an integrated water management supply approach in South Africa. While South Africa has progressive legislation to support the implementation of wastewater reuse, it can also be regarded as a barrier in implementing reuse projects, as often water reuse standards and guidelines are far too stringent to allow for cost-effective reuse options to be developed and implemented. *Findings:* Currently, very little to no data exists regarding wastewater reuse options, treatment options and capabilities, or costs, which can be used for decision making, and much more directed research and information is needed in order to identify wastewater and industrial effluent volume availability, quality and fitness for use in South Africa. A web-based Decision Support System (DSS) tool is being developed to enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use, and linking it with specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. The DSS can be particularly useful in wastewater reuse as it can provide assistance in the evaluation and selection of alternatives for a given reuse application. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

INTRODUCTION

Industrial water use is an estimated 22% of the global water demand. In heavily industrial and developed countries industry water demand can reach 50% of the country's water use, whereas in developing counterparts, which are not relatively industry intense, industry water demand accounts for 4 – 12% (UN Water, 2018). Considering rising global industrialization and urbanization, industrial water use is likely to increase in developing nations, adding to the pressure on already vulnerable water resources (WWAP, 2009).

South Africa's water supply is currently strained, and it is anticipated that the vulnerability extent will continue to rise in the near future due to population growth, climate change and increased pollution (DWS 2013a – NWRS II). A water deficit has been predicted by 2030 as water demand will reach 17.7 billion m^3/annum exceeding the available water supply of 15 billion m^3 (WWF, 2016). Commercial agriculture, mainly irrigation accounts for 61% of South Africa's water use followed by municipal (mainly domestic and some industry) (27%) and industry (7%) (DWS, 2018a,b)

South Africa’s economy is predominantly driven by mining, agriculture, and industrial manufacturing. Mining accounts for 5% of the country’s water use and is predominantly concentrated in water resource scarce catchments (e.g., upper Vaal, Olifants, Steelpoort, Lephalale) where water availability poses a significant business risk. Such a situation bears consequential implication for South Africa’s socio-economic development; hence water resources management should prioritise implementation of water conservation and water demand management (WC/WDM) measures across various sectors to avoid stunting socio-economic development (DWS, 2016).

The need for sustainable water use has fast become a reality for various users considering the current water supply vulnerability, hence solutions that enhance WC/WDM and widen water resources are a priority need. Wastewater reuse is amongst the measures to improve water sustainability as global demand for freshwater resources rises; requiring a paradigm shift in wastewater management from ‘treatment and disposal’ to ‘reuse, recycle and resource recovery”. Wastewater is a resource that can contribute to improving sustainability of water supply and enhance the achievement of the UN’s 2030 Sustainable Development Goals (SDGs) (WWAP, 2017) suggesting that improved wastewater management could facilitate the achievement of. South Africa’s National Water and Sanitation Master Plan (DWS, 2018a) is aligned to the SDGs, specifically SDG6 which stipulates: “to ensure the availability and sustainable management of water and sanitation for all”. SDG-6 specifically has a target to reduce the proportion of untreated wastewater by half by 2030, while sustainably increasing water recycling and safe reuse (WWAP, 2017).

Wastewater reclamation in South Africa is poorly utilized and is currently estimated to be below 14% (DWS 2011, – Water reuse strategy) and this is in spite of local examples which have earned global recognition (Durban Water Recycling Plant) (World Bank 2018) A review of current literature on wastewater reuse in South Africa is limited Most of the examples of reclaimed water are related to agriculture (Jiménez et al., 2010), with only a few exceptions (Eckart et al., 2011; Adewumi et al., 2010). Treated domestic wastewater has long since been reused for various purposes such as irrigation of sports fields and crops as well as for reclaimed drinking water (e.g. Atlantis managed aquifer recharge plant in the Western Cape). More recently wastewater has been treated and used directly for drinking (e.g., Beaufort West in the Western Cape). While there is still much more that can be done with domestic wastewater, the value of industrial effluent is yet to be optimally understood. This can be reflected in the Green Cape’s Market Intelligence Report (2018) where the total Gross Value Add (GVA) for moderate and highly water intense users in the Western Cape Province in 2016, excluding agriculture, was calculated to be R155 billion (Quantec, 2017). Water reclamation in industry is already practiced around the world, supported by advanced treatment technologies. Gulamussen et al. (2019) recently highlighted the need to identify industries with potential for use of reclaimed wastewater, and the evaluation of industrial water use locations and patterns. In addition, sewage flows available for reclamation should be identified to find links for incorporation of water reclamation in urban and industrial planning, within the framework of *green cities*.

A country level assessment of the industrial effluent reuse potential can assist in identifying opportunities to unlock “new water”. Industry is increasingly exploring the reuse of their effluent (wastewater) streams, some even achieving zero effluent status. A globally recognized local example is the DWR which receives treated domestic effluent from the eThekwini Southern Wastewater Treatment Works and supplies water to petroleum refining and paper manufacturing industries and this case has conservatively availed drinking water for approximately 300 000 residents in the Durban Metro area (eThekweni Municipality, 2011). Internationally, there is a general move towards zero liquid discharge, and several industries in South Africa already reclaim and reuse significant amounts of wastewater. In June 2018, Nestlé South Africa announced the launch of its R88-million zero-water dairy manufacturing facility in Mossel Bay, in the Western Cape. It was estimated that the facility would allow Nestlé to reduce the factory’s water consumption by more than 50% during the first year of implementation by reusing the water recovered from the milk evaporation process, saving 168-million litres of water per annum. Nestle will eventually reduce its municipal water consumption to zero (Engineering News, 2018).

Therefore, the aim of this research study was to develop a national Atlas for the potential bulk scale reuse of industrial effluent in South Africa. The Atlas is essentially a compilation of Geographic Information System (GIS) maps that have been created by digitising large volume (bulk) water users / consumers of water in South

Africa as well as the respective industry sectors producing and discharging bulk volumes of wastewater in South Africa. In that context, the Atlas has : 1) defined water reuse and discusses the drivers of industrial reuse in South Africa; 2) summarises the legislation underpinning industrial water reuse in the country; 3) provides examples of a few existing industrial reuse projects/activities currently taking place in South Africa; 4) describes “fitness for use” and the typical wastewater effluent quality for different industries; 5) identifies some of the current barriers to industrial effluent reuse; and 6) geographically maps the largest consumers of water and effluent producers in South Africa both at a national and provincial level. This paper provides an overview of the potential for bulk scale reuse of industrial effluent in South Africa.

Defining reuse of water

Reuse can be defined as “the beneficial use of reclaimed or treated wastewater”. Reclamation is “the treatment of wastewater for reuse, either directly or indirectly as potable or non-potable water” while recycling is “the reuse of wastewater, with or without treatment” (DWA, 2013b). Water reuse recovers water from a variety of sources from where it is then treated and reused for various purposes. The types of wastewater reuse are further classified in four main categories (Asano et al., 2007): urban, industrial, agricultural, and groundwater recharge. Water reuse can play an important role in water security in a water scarce country such as South Africa. Not only can it augment or partially substitute freshwater resources needed for domestic purposes and future development, it can also enhance sustainability and resilience (US EPA, 2020).

Drivers of industrial water reuse

An understanding of the drivers for and against water reuse can facilitate efforts to meet associated water reuse policy goals (Gulamussen et al., 2019). Global drivers of water reuse include multiple factors: pressure on water supply as a consequence of climate change (Nazari et al., 2012; Jiménez et al., 2010); water stress derived from population growth and, consequently, growth of cities that challenge the water resources and sanitation systems (Lautze et al., 2014); environmental and economic concerns that limit the use of other solutions to combat water scarcity, such as long-distance water transfer, construction of large dams and desalination (GWI, 2009); and increased confidence in and reduced costs treatment technologies, which provide assurance of the safety of reclaimed water blended into reservoirs or aquifers for potable uses (GWI, 2009).

Table 1 provides a summary of the general drivers for and main applications of water reclamation for industrial use in different regions of the world. Aside from water scarcity, water reclamation for industrial use in developed countries seem to be driven mainly by environmental concerns, with sewage treatment plant effluent typically utilized for purposes such as cooling, boiler feeds, condensing and steam production, firefighting, and dust mitigation. Water scarcity is however the main reason for water reclamation in developing countries (Gulamussen et al., 2019). Figure 1 provides a summary of driving forces impacting industrial water reuse in South Africa, based predominantly on water scarcity and costs.

Table 1: Drivers and industrial applications of reclaimed water globally

Region	Drivers	Main application	References
Northern Europe	• High industrial water demand in highly populated areas • Resource efficiency • Environmental concerns	Cooling	(Asano and Jimenez, 2008; USEPA, 1992; Ryan, 2016; Marecos do Monte, Angelakis and Gikas, 2014)
North America	• Water scarcity • Cost effectiveness of reclaimed water and resource efficiency • Environmental concerns	Process water, cooling, condensing and steam generation	(Asano and Jimenez, 2008; USEPA, 1992; Schaefer et al., 2004; Smith, 2015)
Asia	• Water scarcity • Political pressure	Cooling, washing and process water	(Asano and Jimenez, 2008; Indian Institutes of Technology, 2011; USEPA, 1992)
Australia	• Water scarcity • Environmental concerns	Cooling, boiler feed, firefighting and dust repression	(Asano and Jimenez, 2008; USEPA, 1992; Apostolidis et al., 2011)
Southern Africa	• Water scarcity	Cooling, mining and process water	(Indian Institute of Technology, 2011)

(Source: Adopted from Gulamussen et al., 2019).

Figure 1: Drivers for industrial reuse (adopted from Steyn et al., 2021).

Legislation guiding industrial reuse in South Africa

South Africa has extensive and comprehensive laws and guidelines regarding water use, reuse applications and effluent discharge. The Constitution, (Act 108 of 1996) (RSA, 1996) guarantees every person in the country the right of access to water and the right to an environment that is not harmful to their health or wellbeing now and in the future. Sustainable water reuse is further underpinned by the principles of the National Water Policy Review (DWA, 2013c) as follows: "Water resources shall be developed, apportioned and managed in such a manner as to enable all user sectors to gain equitable water. The main legislation that governs water use and the discharge thereof in South Africa is the National Water Act (Act 36 of 1998) (RSA, 1998a). This Act aims to ensure that the country's water resources are protected and managed to reduce and prevent pollution and degradation of water resources. Reuse of effluent in the country requires environmental authorization in terms of the National Environmental Management Act (Act 107 of 1998) (RSA, 1998b), and in some cases requires water use licenses (WULs) in terms of the NWA (36:1998) (RSA, 1998a). In terms of the NWA (36:1998), NEMA (107:1998), together with the Mineral and Petroleum Resources Development Act (Act No. 28 of 2002) (MPRDA) (RSA, 2002), all new and existing mines are required to optimize water reuse and reclamation (DWA, 2013b).

The Water Services Act (Act 108 of 1997) (RSA, 1997) relates more to the management of human drinking water and directs bulk water suppliers to the compulsory national standards in the form of SANS 241-1:2015. In line with the NWA and the WSA, water conservation (WC) and demand management (WDM) is an important step in promoting water use efficiency and viewed as a useful tool in achieving Integrated Water Resource Management (IWRM) (Gutterres and Aquim, 2013). Implementation of WC/ WDM programmes by all sectors is essential in ensuring economic efficiency. The National Water Reuse Strategy (DWA, 2013b) encourages wise decisions relating to water reuse at different scales and levels. The performance of existing wastewater treatment plants in terms of meeting discharge standards and reliability is critical to the successful integration of water reuse into reconciliation strategies and into water supply systems in South Africa (DWS, 2013, 2018). Other Acts, policies, frameworks and strategies which are also important include the Environment Conservation Act (Act 73 of 1989) (RSA, 1989), the National Environmental Management: Waste Act, (Act 59 of 2008) (RSA, 2008a), and the National Environmental Management: Integrated Coastal Management Act, (Act 24 of 2008) (RSA, 2008b), the Mine Water Management Policy (DWS, 2017) , the National Water Resource Strategy (DWA, 2013a; 2013b)) and the National Water and Sanitation Masterplan (DWS, 2018). In some instances, recent amendments to these acts and municipal bylaws may also be relevant.

Wastewater generation per industrial sector

The water consumption rates of industrial users are significantly higher than those of individual households. Provincial average values for individual water consumption range from 182 litres per capita per day (l/c/d) for Limpopo to 305 l/c/d for Gauteng, suggesting average consumption rates for a household of four persons in the order of one kilolitre per day, or 0.001 megalitres per day (Ml/d). By contrast, manufacturing plant/factory water consumption rates are three orders of magnitude higher in some industries. Paper and pulp use between 0.1 to 150 Ml/d, wet-cooled power stations (e.g., Matla and Lethabo) requires in the order of up to 100 Ml/d, while dry-cooled power stations (e.g., Kendal and Matimba) uses in the order of 10 Ml/d. Sugar mills consume between 0.6 to 6.8 Ml/d, while water consumption of between 5 and 10.5 Ml/d have been recorded for oil refineries.

Industrial water users return significant fractions of their water consumption to the municipal wastewater system or the environment as effluent, with the exception of wet-cooled power stations where water use is nearly entirely consumptive. Van der Merwe et al (2009) and Cloete et al (2010) studied water use by industry in South Africa and identified the paper and pulp industry as the biggest contributor to wastewater generation. Power generation, mining, and petroleum industries were also identified as major contributors. The food and beverage industry contributed greater than 5% in each case, however it encompasses many sub-industries. The textile industry contributes a small portion in each case. Classified as "Other", includes chemicals, pharmaceuticals, cement, metals processing, paint, plastics, tanneries, and waste management. Figure 2 provides a schematic breakdown of the main industrial water users and producers in South Africa (based on the Cloete et al., 2010 data).

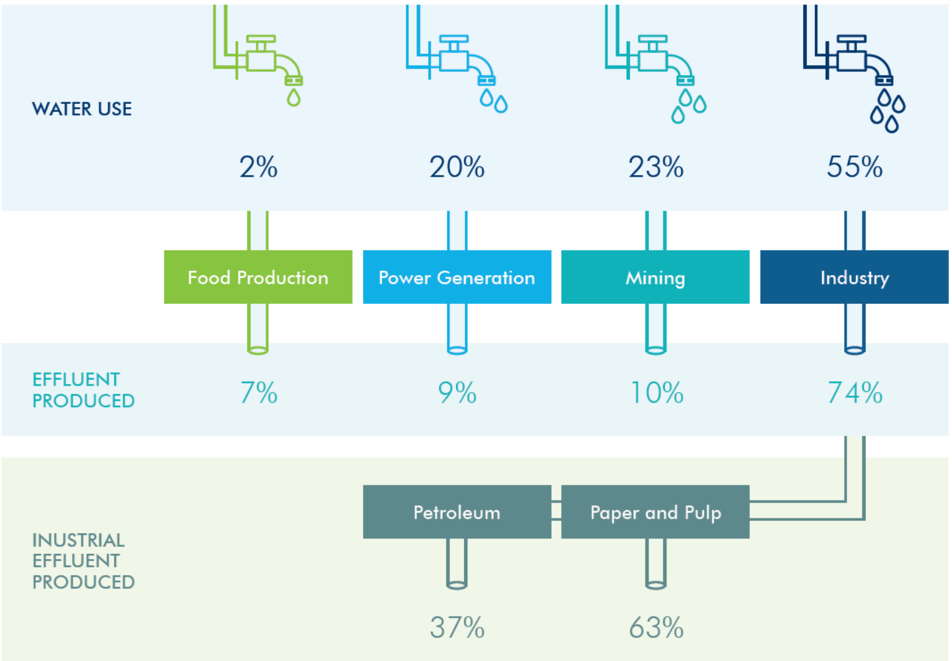

Figure 2: Industrial water use and effluent produced in South Africa (adopted from Cloete et al., 2010).

Managing water for potential reuse and fitness for use

A number of novel technologies are readily available to treat industrial wastewaters, and judicious decision making is therefore required before selecting appropriate technologies. The technology selection depends on the quantity and quality of waste impurities, and desired quality goal for subsequent treatment. Furthermore, the choice of technology is influenced by wastewater re-use goals: e.g., recovery of valuable materials from wastewater, possible water recycling and reuse, complying with the statuary norms for discharge into water bodies and/or the economics of the treatment process itself (Need a Ref for this?). The quality of the effluent makes the task of technology selection, oftentimes, rather complex. However, for the majority of wastewater qualities, appropriate remediation technologies already exist.

Therefore, the concept of "fitness for use" is central tenet to water quality management in South Africa as it is embedded in the development and use of our national water quality guidelines (DWS, 1996). In the current context; wastewater aimed for re-use will be managed and/or treated to be fit for the intended use. The concept of "fit-for-purpose" specifications are to meet treatment requirements to bring the water from a particular source to the quality needed, to ensure public health, environmental protection, or specific user needs. For example, reclaimed water for crop irrigation would need to be of sufficient quality to prevent harm to plants and soils, maintain food safety, and protect the health of farm workers. In uses where there is a greater risk to human health, the water may require additional treatment (US EPA, 2020).

Industrial water demand and wastewater production are sector-specific. The concentration and composition of the industrial effluent (mass/time) can vary significantly depending on the industrial process (Mhlanga and Brouckaert, 2013; Iloms et al., 2020). Wastewater is typically characterized by biological, physical and chemical characteristics.

Water quality parameters specified in the South African Water Quality Guidelines for Industrial use (DWS, 1996) are limited in comparison to other water uses. A review of available literature in South Africa, however revealed, that only four commonly listed parameters are used to measure wastewater quality. These were pH, total suspended solids (TSS), chemical oxygen demand (COD) and biochemical oxygen demand (BOD). Mining and power generation did not list BOD but placed importance on total dissolved solids (TDS) and ion concentrations (Harding et al., 2020). The guidelines further describe four categories of water for use in different industrial processes. Wastewater, because it must often meet stringent discharge regulations, may unnecessarily be of higher quality than required for other uses, such as for recycling applications.

METHODOLOGY

The information in the Atlas was developed using open-source data obtained from the Department of Water Sanitations, Water use Authorization and Registration Management System (WARMS), QA Data Reports for water consumption and effluents produced. The WARMS database (DWS, 2019) is the official national register of water use in South Africa as defined in terms of section 139(2)(d) of the National Water Act 1998 (RSA, 1998a), viz, to store and produce accurate water use information to advance economic growth, development, and democracy. The DWS WARMS database contain detailed information and reports on South Africa water users who use water for: irrigation, industrial use: including mining, power generation, recreational purposes and watering livestock for both surface and groundwater resources in the country.

The data was plotted using proprietary ArcGIS® software (ArcMap™ 10.5.1). For the purpose of the Atlas, standardized WGS84 reference spheroid was used for geographic coordinates. The GIS data used to generate the map products of the Atlas are supplied in ArcGIS native formats (e.g., Shapefiles containing the relevant provincial boundaries). The Atlas presents maps at both national and provincial context and provides a visual account of both the volumes of water used and effluent produced per industry sector. In order to achieve optimum robustness and comprehensiveness, lower volume limits were set low to accommodate the majority of entries in the database, whilst maintaining practical information. Additionally, the authors acknowledge and recognize that the water use applications are commonly pitched at high registered volumes rather than actual volumes (consumed or produced) in order to factor in future forecast scenarios. Hence real water use and effluent discharges can be significantly lower compared to licensed volumes. For water consumption, the data was sorted to include those bulk water consumers, with the minimum consumption volumes set at 200 000 m^3/ annum. For effluent discharges, the data was analysed to include bulk industrial effluent producers, which for the purposes of this Atlas, the minimum effluent volumes were set at 100 000 m^3/annum. Bulk domestic wastewater effluent was mapped as this can provide industries or municipal decision makers with an indication where large volumes of wastewater effluent is available and in close proximity to industries for potential reuse. The difference in volumes for consumption compared to effluent discharge volumes used in the Atlas is based on the fact that water is lost as a result of industrial processes. Loss of water volumes of up to 50% of the consumption volume was therefore standardised and used throughout. Future research will entail more detailed data analysis at higher resolution, for example at municipal level. This will allow more scenario-specific opportunities to be identified using detailed criterion such as area specific water billing data.

RESULTS AND DISCUSSION

Bulk water use

From a national perspective, water use intensive industries were largely represented by the agriculture sector, mostly through irrigation. Second to agriculture was water supply services, urban industry, mining and non-urban industry. Water use for mining was the highest in Mpumalanga, followed by Gauteng, North West, Northern Cape and Limpopo. Mpumalanga had the highest water withdrawals, followed by the Free State, Eastern Cape and Gauteng provinces. In all provinces, the largest water use was for agricultural irrigation, except in Gauteng, where industrial water use was the highest. The second highest industrial water use was the Western Cape. In the Western Cape, the highest water withdrawals per sector were for agricultural irrigation, followed by urban industry and water supply services. A large portion of non-urban industrial water use was identified in Kwa Zulu Natal and Mpumalanga. The Northern Cape province had the lowest registered water withdrawal of all provinces. Figure 3 depicts examples of national maps. The map on the left is a national bulk scale water consumption map for the Agriculture sector. The map on the right depicts bulk scale domestic wastewater effluent at national level.

Bulk effluent production

Effluent reuse (treating the final effluent to potable standards for onsite reuse, typically for non-product contact purposes) with or without energy recovery (biogas), represents the largest opportunity for water savings in the sector. From a national perspective, the highest effluent produced was registered by urban/domestic (sewage treatment works), followed by mining. Mining effluent was recorded in all provinces except the Western Cape.

Gauteng was the highest ranked province in terms of wastewater discharge, followed by Mpumalanga and the Eastern Cape provinces, respectively. Discharging wastewater effluent was associated with urban areas and industry. Large-scale irrigation with wastewater is largely limited to the Breede-Gouritz catchment in the Western Cape. The provinces that registered the lowest effluent volumes included Limpopo and Northern Cape provinces. Figure 4 depicts examples of provincial maps (Gauteng) of bulk scale water consumption and bulk effluent production (all sectors).

Examples of national maps

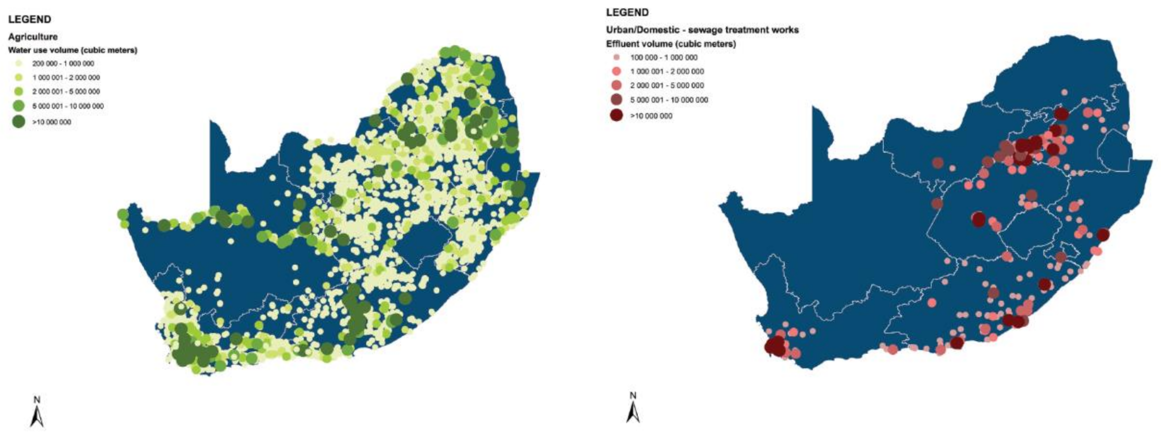

Figure 3: National bulk water consumption (Agriculture) (left) and national bulk effluent production (domestic wastewater effluent) (right).

Examples of provincial maps

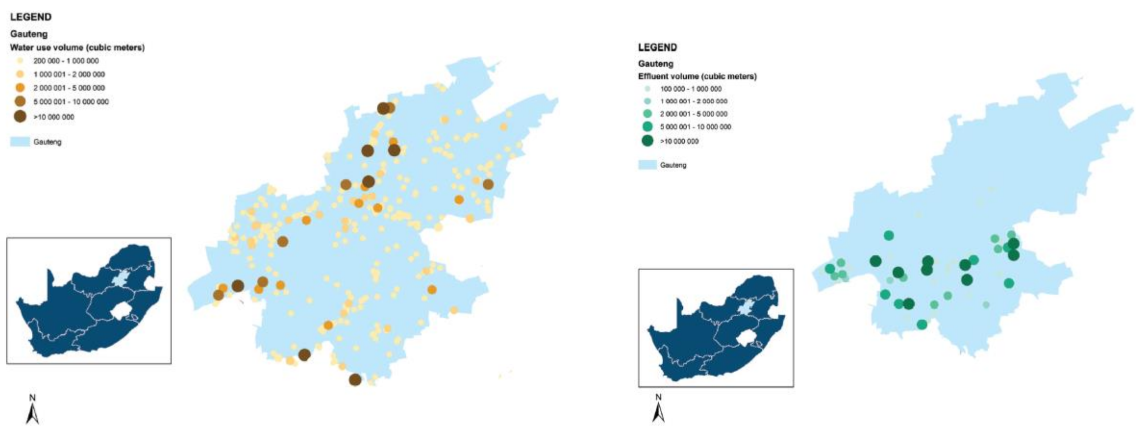

Figure 4: Industrial bulk water consumption and effluent produced in Gauteng Province.

Even though country and municipality specific information on industrial reuse options, water quality and quantity (volumes), are not widely accessible, this study was able to present a "current point in time" reflection which highlighted the largest water consumers in each province and at a national scale (a critical first step towards unlocking industrial waste water reuse potential. Similarly, high volume industrial effluent producers for each of the different industrial sectors were highlighted per province and at a national level, which provided a good geographical overview of industrial effluent production.

From the above examples, there are a clear need for water reuse to become an integral part of an integrated water management supply approach in South Africa. The authors realized that this Atlas provided only a one dimensional and geographical overview of industrial reuse effluent volumes (based on water use license registrations). As a result, an Excel-based decision support system (DSS) for bulk scale reuse of industrial effluent was developed (a web-based and mobile application in the process of being developed). This DSS (Figure 5) will enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use and linking it to specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

The underlying systemic approach of the tool makes it intuitive also for users with limited prior knowledge in the field to identify most adequate solutions based on multi-parameter inputs. This will promote water reuse and spearhead initiatives for more detailed feasibility and design commissioning for implementation of water reuse schemes.

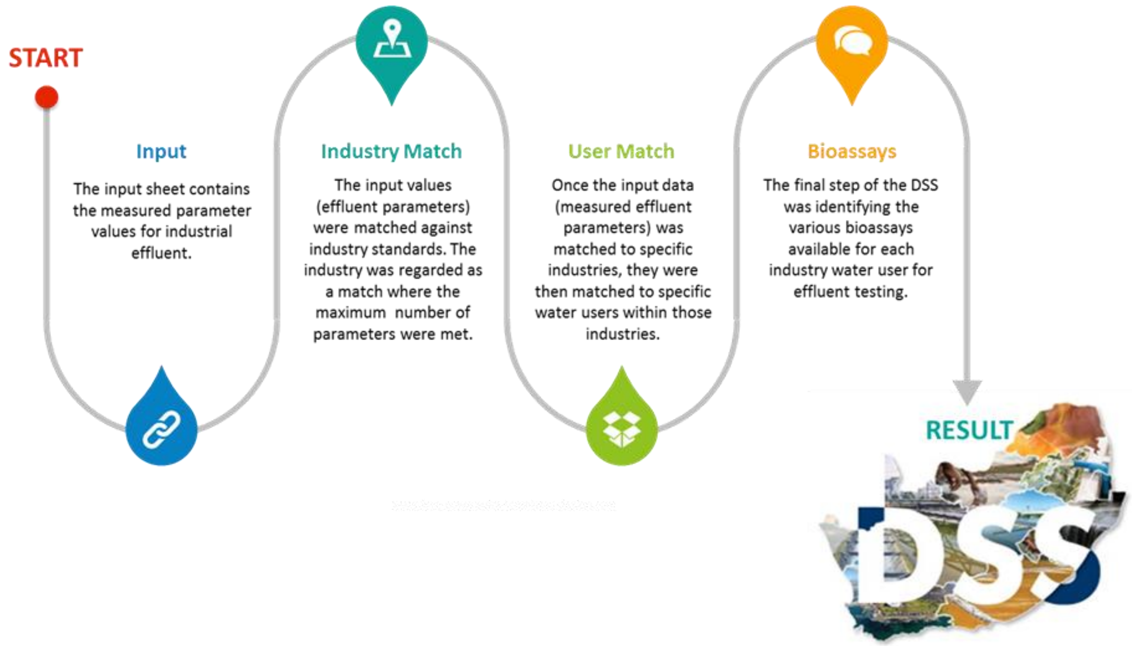

Figure 5: Flow diagram of the current steps in the DSS.

CONCLUSION

Water reuse in South Africa is lagging behind the rest of the world. The Atlas produced from publicly available Natsurv and WARMS data, shows huge potential for the reuse of bulk industrial effluent. A limiting factor to date is the fact that this data does not give a true reflection of actual volumes available for reuse. The Atlas as well as the Decision Support System (demonstration model) needs to be updated with real-time data from municipalities and industries. Similarly, actual effluent quality requirements are not known. While South Africa has progressive legislation to support the implementation of wastewater reuse, it can also be regarded as a barrier in implementing reuse projects, as often water reuse standards and guidelines are far too stringent to allow for cost-effective reuse options to be developed and implemented. Currently, very little to no data exists regarding wastewater reuse options, treatment options and capabilities, or costs which can be used for decision making, and much more directed research and information is needed in order to identify wastewater and industrial effluent volume availability, quality and fitness for use in South Africa. A web-based Decision Support System (DSS) tool is being developed to enable municipal and industry partners, and water quality managers to make informed decisions for possible reuse options. The tool aims to directly assist by linking industrial effluent volumes and quality to fitness for use, and linking it with specific industries in the geographical vicinity based on industry specific water quality and quantity requirements. In addition, the tool will enable engineers and industry partners to collaborate to identify and employ treatment technologies and capabilities to link industrial effluent quality and volumes available to that of potential user requirements in a geographical area.

REFERENCES

Adewumi, J.R., Ilemobade, A.A., and van Zyl, J.E. 2010. Treated wastewater reuse in South Africa: overview, potential and challenges. Resources, Conservation & Recycling. 55(2). Pp 221-231

Asano, T., Burton, F. L., Leverenz, H. L., Tsuchihashi, R., and Tchobanoglous, G. 2007. Water Reuse: Issues, Technologies and Applications. New York, NY: McGraw-Hill.

Cloete, T., Gerber, A., and Maritz, L. 2010. A first order inventory of water use and wastewater production by SA industrial, mining and electricity generation sectors. WRC Report No. 1547/1/10. Water Research Commission, Pretoria, DEA (Department of Environmental Affairs, South Africa) (2017) National Environmental Impact Assessment and Management Strategy (EIAMS). URL: https://www.environment.gov.za/documents/ strategies/eiams_environmentalimpact_ assessmentmanagement (Accessed 10 April 2017).

DWA (Department of Water Affairs). 2013a. National Water Resource Strategy. 2nd Edition. Water for and Equitable and Sustainable Future. June 2013. https://cer.org.za/wp-content/uploads/2013/07/NWRS2-Final-email-version.pdf

DWS (Department of Water and Sanitation). 2013b. National Strategy for Water Re-use (NSWR). Appendix D of National Water Resource Strategy Version 2. 2013.

DWA (Department of Water Affairs). 2013c. National water policy review. Department of Water Affairs, Pretoria, South Africa.

DWAF (Department of Water Affairs and Forestry)., 1996. South African Water Quality Guidelines. Volume 3: Industrial Water Use. 2nd Edition, 1996. Pretoria, South Africa.

DWS (Department of Water and Sanitation). 2016: Guideline for the Development and Implementation of Water Conservation and Water Demand Management Plans for the Mining Sector.

DWS (Department of Water and Sanitation). 2017. Mine Water Management Policy. Government Gazette, 7 July 2017.

DWS (Department of Water and Sanitation), 2017.Strategic overview of the water sector in South Africa 2017. Pretoria, South African Government.

DWS (Department of Water and Sanitation). 2018a. South Africa's National Water and Sanitation Master Plan. Volume 1: Call to Action. Version 10.1. Ready for the Future and Ahead of the Curve. https://www.gov.za/sites/default/files/gcis_document/201911/national-water-and-sanitation-master-plandf.pdf

DWS (Department of Water and Sanitation), 2018b. National water and Sanitation Master Plan. Volume 2: Plan to Action. Final Draft. Version3.3. 31 March 2018. Pretoria, South African Government.

DWS (Department of Water and Sanitation). 2019. Water use Authorization & Registration Management System (WARMS) QA Data Reports. https://www.dws.gov.za/Projects/WARMS/default.aspx

Eckart, J., Ghebremichael, K., Khatri, K., Mutikanga, H., Sempewo, J., Tsegaye, S., and Vairavamoorthy, K. 2011. Integrated Urban Water Management in Africa. Patel School of Global Sustainability, University of South Florida.

Engineering News, 2018. Nestlé launches 'zero water' manufacturing facility in Western Cape. 5 June 2018. https://m.engineeringnews.co.za/article/nestl-launches-zero-water-manufacturing-facility-in-western-cape-2018-06-05/rep_id:4433 eThekwini Municipality, 2011. The Durban Water Recycling Project. http://www.durban.gov.za/City_Services/water_sanitation/Services/Pages/durban-recyling.aspx

Green Cape, 2018. Water: Market Intelligence Report. GreenCape, Cape Town; www.greencape.co.za

Grobicki, A. 2008. The Future of Water Use in Industry, World Water, available from: https://sswm.info/sites/default/files/reference_attachments/GROBICKInyTheFutureofWaterUseinIndustry.pdf ; (last accessed 12 September 2019).

Gulamussen, N., Arsénio, A., Matsinhe, N., and Rietveld, L. 2019. Water reclamation for industrial use in sub-Saharan Africa – a critical review. Drinking Water Engineering and Science. 12. 45-58. 10.5194/dwes-12-45-2019.)

Gutterres, M., and Aquim, P.M., 2013. Wastewater reuse focused on industrial applications. In S.K. Sharma and R. Singh (eds). Wastewater Reuse and Management Springer Science. Dordrecht, The Netherlands. Pp. 127 – 140.

GWI (Global Water Intelligence). 2009. Municipal water reuse markets 2010. Analysis, Forecasts and Inventory. Oxford Media Analytics.

Harding, G., Chivavava, J. and Lewis, A.E. 2020. Challenges and shortcomings in current South African industrial wastewater quality characterisation. Water SA 46(2) 267–277 / Apr 2020 https://doi.org/10.17159/wsa/2020.v46.i2.8242

Iloms, E., Ololade, O.O., Ogola, H.J.O. and Svarajan, R. 2020. Investigating Industrial Effluent Impact on Municipal Wastewater Treatment Plant in Vaal, South Africa. Int. J. Environ. Res. Public Health 2020, 17, 1096; doi:10.3390/ijerph17031096

Jiménez, B., Drechsel, P., Koné, D., Bahri, A., Raschid-Sally, L., and Qadir, M.: Wastewater, Sludge and Excreta Use in Developing Countries: An Overview, in: Wastewater irrigation and health: assessing and mitigating risk in low-income countries, edited by: Drechsel, P., Scott, C. A., Raschid-Sally, L., Redwood, M., and Bahri, A., 3–27, International Development Research Centre (IDRC), International Water Management Institute (IWMI), London, Ottawa, Colombo, Sri Lanka, 2010.

Lautze, J., Stander, E., Drechsel, P., da Silva, A. K. and Keraita, B.: Global Experiences in Water Reuse., 2014. Colombo, Sri Lanka: International Water Management Institute (IWMI). CGIAR Research Program on Water, Land and Ecosystems (WLE). 31p. (Resource Recovery and Reuse Series 4). http://www.iwmi.cgiar.org/Publications/wle/rrr/resource_recovery_and_reuse-series_4.pdf ; DOI: https://doi.org/10.5337/2014.209

Mhlanga, F.T., Brouckaert, C.J., 2013. Characterisation of wastewater for modelling of wastewater treatment plants receiving industrial effluent. Water SA. Water SA Vol. 39 No 3 WISA 2012 Special Edition 2013. DOI: 10.4314/wsa.v39i3.9

Nansubuga, I., Banadda, N., Verstraete, W., and Rabaey, K. 2016. A review of sustainable sanitation systems in Africa, Rev. Environ. Sci. Bio, https://doi.org/10.1007/s11157-016-9400-3.

Nazari, R., Eslamian, S., and Khanbilvardi, R. 2012. Water Reuse and Sustainability. Ecological Water Quality - Water Treatment and Reuse, Kostas Voudouris, IntechOpen, DOI: 10.5772/34428. Available from: https://www.intechopen.com/books/ecological-water-quality-water-treatment-and-reuse/water-reuse-and-sustainablity

Nestle South Africa Media release. https://www.nestle-esar.com/media/pressreleases/nestle-launches-zero-water-technologies-site-mossel-bay

Quantec 2017. Regional Output and GVA at basic prices by industry and 2011 local municipal/ward-based metro region level 1993-2016 (v2 18Aug17), Online: Quantec.co.za. in Green Cape; Water: Market Intelligence Report, 2018.

RSA (Republic of South Africa). 1996. Constitution of the Republic of South Africa, No. 108 of 1996. 18 December. Government Printer, Cape Town.

RSA (Republic of South Africa). 1997. Water Services Act: Act No. 108 of 1997. Government Gazette 18522. Government Printer, Cape Town.

RSA (Republic of South Africa). 1998a. National Water Act, No. 36 of 1998. 20 August. Government Printer, Cape Town.

RSA (Republic of South Africa). 1998b. National Environmental Management Act, No. 107 of 1998. Government Gazette 401 (19519). 27 November. Government notice no. 1540. Government Printer, Cape Town.

RSA (Republic of South Africa). 2002. Mineral and Petroleum Resources Development Act (Act No. 28 of 2002). 10 October. Government Printer, Cape Town.

RSA (Republic of South Africa). 1989. Environment Conservation Act (Act 73 of 1989). 9 June. Government Printer, Cape Town.

RSA (Republic of South Africa). 2008a. National Environmental Management: Waste Act, (Act 59 of 2008). 10 March. Government Printer, Cape Town.

RSA (Republic of South Africa). 2008b. National Environmental Management: Integrated Coastal Management Act, (Act 24 of 2008). 11 February. Government Printer, Cape Town.

SANS (South African National Standards). 2015. Drinking water (SANS 241:2015). https://www.mwa.co.th/download/prd01/iDW_standard/South_African_Water_Standard_SANS_241-2015.pdf

UN, 2015. United Nations General Assembly (2015). Transforming our world: The 2030 agenda for sustainable development. Retrieved from undocs.org/A/RES/70/1.

UN Water. 2018. Water Quality and Wastewater. Factsheet. file:///C:/Users/MSteyn/Downloads/WaterFacts_water_and_watewater_sep2018%20(1).pdf

US EPA (United States Environmental Protection Agency). 2020. Water Reuse. Basic Information about Water Reuse. https://www.epa.gov/waterreuse/basic-information-about-water-reuse#basics.

Van der Merwe, I.W., Lourens, A., Waygood, C., 2009. An Investigation of Innovative Approaches to Brine Handling: Report to the Water Research Commission. WRC Report No. 1669/1/09. Water Research Commission, Pretoria.

WWAP (World Water Assessment Programme). 2009. The United Nations World Water Development Report 3: Water in a Changing World. Paris: UNESCO, and London: Earthscan. https://unesdoc.unesco.org/ark:/48223/pf0000181993/PDF/181993eng.pdf.multi

WWAP (World Water Assessment Programme, United Nations) (2017) The United Nations World Water Development Report 2017. Wastewater: The Untapped Resource. UNESCO, Paris. http://www.unesco.org/new/typo3temp/pics/0d623deb50.jpg

WWF (World Wildlife Fund). 2016. Water: Facts and Futures. Rethinking South Africa’s Water Future. http://awsassets.wwf.org.za/downloads/wwf009_waterfactsandfutures_report_web__lowres_.pdf