ATLAS

of Industrial Wastewater Reuse Potential in South Africa

Authors: Steyn, M., Walters, C., Mathye, M., Ndlela, L., Thwala, M., Banoo, I., Tancu, Y and Genthe, B.

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1 INTRODUCTION

After agriculture, industry is the largest user of water for development, globally consuming 22% of water (UN Water, 2018). In Europe and North America, industrial water use accounted for half of their total water use in 2009, while in developing nations industrial water use ranged from 4-12% of national water use. With an increase in industrialisation in developing nations, industrial water use is likely to increase, adding to the pressure on already stressed water resources (WWAP, 2009).

The South African economy largely depends on mining and other large industries. According to the National Water Resources Strategy 2 (DWA, 2013a), the mining sector, with an estimated demand of about 5% of the country's available water, is a significant user of water. Coal and Platinum mining in particular is currently expanding into new areas with a projected increase in water demand. Many of these mines are located in water resource scarce catchments (e.g. the Lephalale and Steelpoort areas in the Limpopo province) where the availability of water can become a significant business risk. Water availability should however not be a limiting factor to growth in the country. Water resources management and development should prioritise availability of water to industry. Similarly, implementation of water conservation and water demand management (WC/WDM) measures within the mining sector is required in order to minimise this risk (DWS, 2016).

In face of the ever-growing demand for fresh water resources globally, there is a need for a paradigm shift in wastewater management from 'treatment and disposal' to 'reuse, recycle and resource recovery". Wastewater is increasingly viewed as a potentially sustainable source of water, from which many economic benefits could be derived.

The UN World Water Development Report (WWAP, 2017) suggests that improved wastewater management could facilitate the achievement of the UN's 2030 Sustainable Development Goals (SDGs). South Africa's National Water and Sanitation Master Plan (DWS, 2018) is aligned to the UN's Sustainable Development Goals' (SDGs) (UN, 2015) unique vision for a better future for all as set out in Goal 6 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). See Box 1.

Box 1: Alignment of South Africa's National Water and Sanitation Master Plan (DWS, 2018) to UN Sustainable Development Goals (UN, 2015).

Target 6.3: "By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally."

Target 6.A: "By 2030, expand international cooperation and capacity-building support to developing countries in water- and sanitation-related activities and programmes, including water harvesting, desalination, water efficiency, wastewater treatment, recycling and reuse technologies."

Wastewater reuse (Box 2) is therefore central to ensuring SDG6 is met. Reuse of wastewater presents an alternative water source for human activities (irrigation, gardening, toilet flushing, mining), thereby reducing the need for fresh water supplies and alleviating the pressures on groundwater and other natural water bodies. Another potentially positive aspect is the recycling of nutrients in wastewater, which might reduce the need for additional fertilizers. When the used water is eventually discharged back into natural water sources, it can still have benefits to ecosystems, by improving streamflow, nourishing plant life and recharging aquifers, as part of the natural water cycle.

Box 2: Water reuse objectives (US EPA, 2019)

Water Security

To ensure sustainable access to an adequate quantity or acceptable quality water for sustaining livelihoods, human well-being, and socioeconomic development

Water Sustainability

To warrant an adequate supply of clean water for humans and ecosystems now and in the future

Water Resilience

The ability of a water system or part thereof to adapt to or withstand the effects of rapid hydrologic change or a natural disaster

1.1 Defining Water Reuse

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 purposes such as agriculture and irrigation, potable water supplies, groundwater recharge, industrial processes, and environmental restoration. 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).

Water reuse can be classified as direct or indirect, planned or unplanned, as follows:

- **Unplanned water reuse** occurs when communities draw their water supplies from rivers, such as the Vaal River or the Crocodile River, that receive treated wastewater discharged from communities upstream.
- **Planned water reuse** refers to the explicit design, and development of water systems with the goal of beneficially reusing a recycled water supply. The Atlantis Managed Aquifer Recharge Scheme and the Beaufort West Direct Reuse Scheme are examples of planned water reuse in South Africa.
- **Direct reuse of wastewater** is when the water used for a given purpose can be reused with or without treatment for a different purpose for which the quality of wastewater is fit for purpose. Examples of direct reuse include wastewater reuse in industry or for irrigation. The direct wastewater reuse plant in Beaufort West reuses domestic wastewater effluent that is directly discharged to a drinking water treatment plant and augments drinking water supply to urban households in the area.
- **Indirect wastewater reuse** occurs when wastewater used for domestic or industrial purposes is treated to be available for another use. The George Indirect potable reuse plant is an example where treated wastewater effluent is discharged into the Garden Route Dam for dilution and storage before it is piped to the drinking water treatment plant for further treatment to subsequently replenish the surface water supply in the area.
- **Water recycling** involves reusing water for the same application for which it was originally used. Coca-Cola and South African Breweries as well as some fruit producing and packaging companies recycle some of their production or processing water to rinse bottles or for cleaning of package plants.

The types of wastewater reuse are further classified in four main categories (Asano et al., 2007): urban, industrial, agricultural, and groundwater recharge. Figure 1 is a schematic representation of water reuse, while Figure 2 depicts typical uses of recycled water.

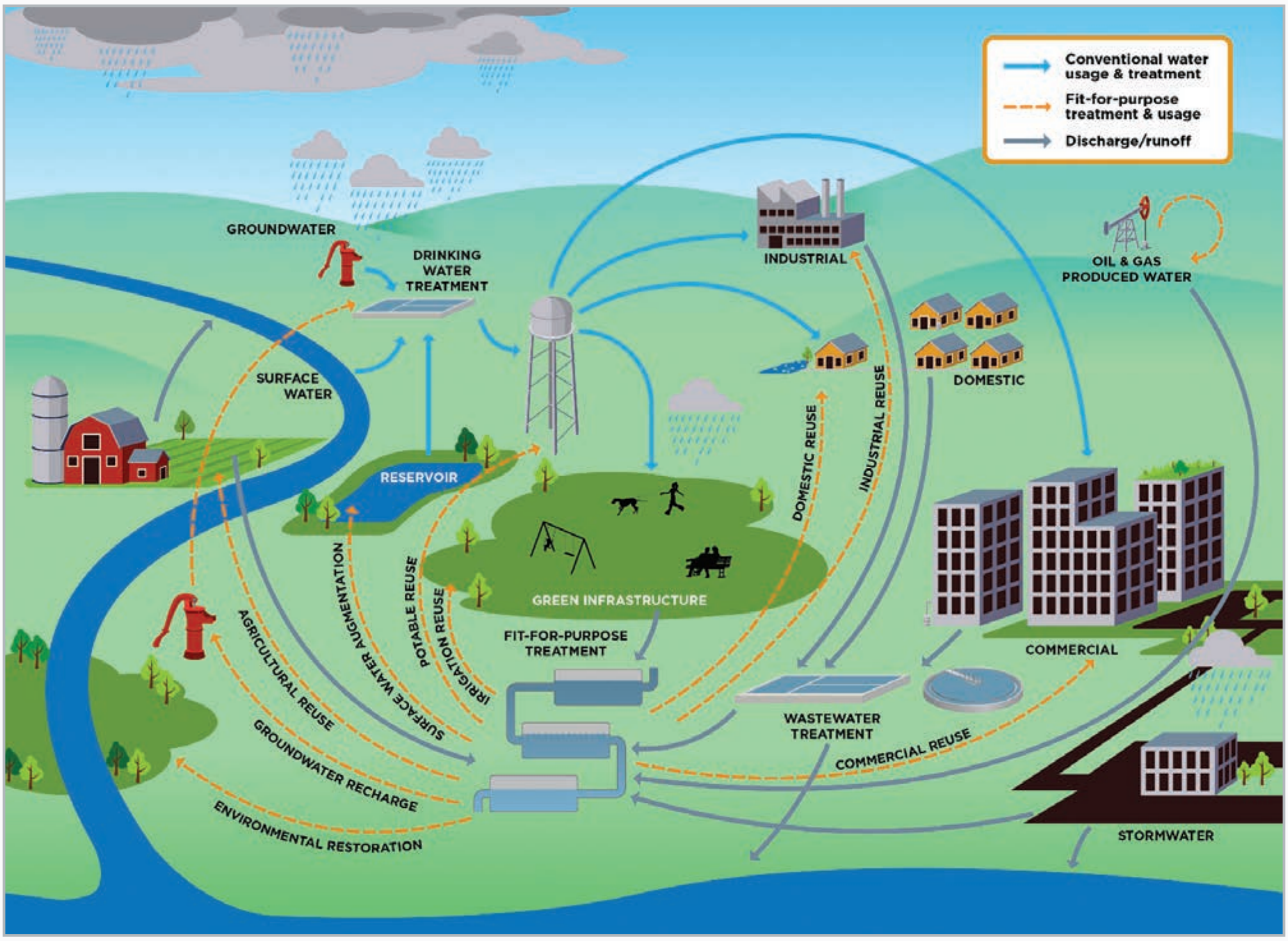


Figure 1: Water reuse flow chart (Source: USEPA, 2019)

Reclaimed water is still not extensively explored as an alternative reliable source of water supply in South Africa. Even in literature, information about water reuse in South Africa is scarce. Most of the examples of reclaimed water are related to agriculture (Jiménez et al., 2010), with a few exceptions (Eckart et al., 2011; Adewumi et al., 2010). Water reclamation in industry is already practiced around the world, supported by advanced treatment technologies.

Gulamussen et al. (2019) recognized 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. This Atlas therefore explicitly deals with the industrial water reuse potential in South Africa.

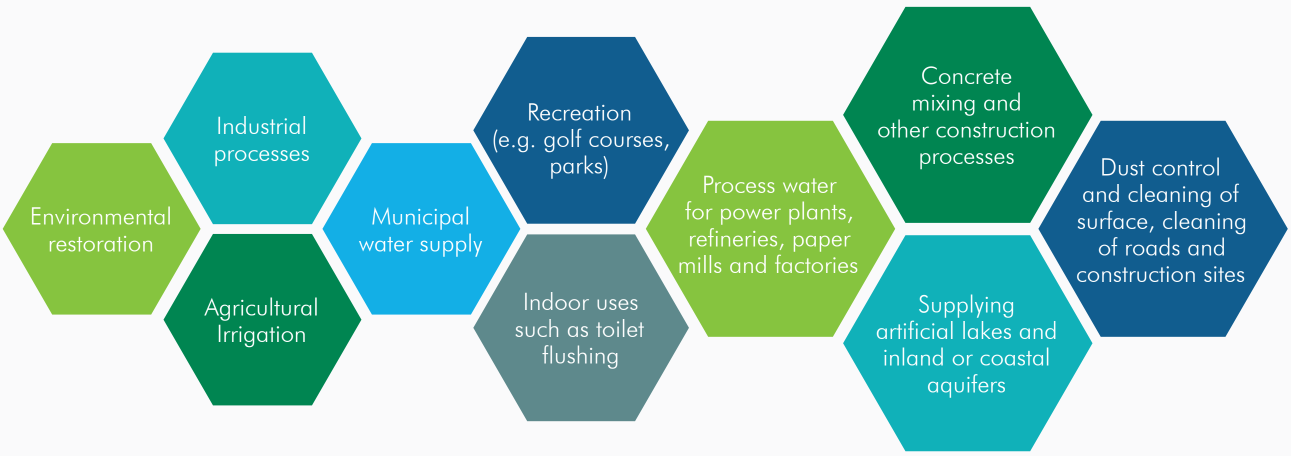


Figure 2: Typical uses of recycled water

1.2 Industrial Wastewater Reuse Potential – An Atlas

The Atlas is a product of a multi-phase programme aimed at unlocking and enhancing potential bulk wastewater reuse for industrial purposes in South Africa.

The information in the atlas was generated 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 using water for: irrigation, industrial use: including mining, power generation, recreational purposes and watering livestock for both surface and groundwater resources in the country.

This 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 sector industries producing and discharging bulk volumes of wastewater in South Africa.

In that context, the Atlas therefore aims to:

1) Define water reuse for purposes of the Atlas and discuss the drivers of industrial reuse in South Africa;
2) Summarise the regulations and legislation underpinning industrial water reuse in the country;
3) Provide examples of a few existing industrial reuse projects/activities currently taking place in South Africa;
4) Describe "fitness for use" and the typical wastewater effluent quality for different industries;
5) Identify some of the current barriers to industrial effluent reuse;
6) Geographically present the largest volume of water consumers and effluent producers in South Africa. These high-volume consumers and effluent producers were mapped at both a national and provincial level.

1.3 How the Maps were created

The data was plotted using proprietary ArcGIS® software (ArcMap™ 10.5.1). For the purpose of the atlas, standardised WGS84 reference spheroid was used for geographic coordinates. Shapefiles containing the relevant provincial boundaries were obtained. For practical reasons, effluent discharge and water use volumes per water use sector were plotted to create the provincial and national maps for water consumed and effluent produced.

It is important to highlight that it was not the aim, nor was it practical, to examine and map all the registered industrial water users in South Africa. 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, where consumption volumes exceeded 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, were volumes exceeding 100 000 m^3/annum. Bulk domestic wastewater effluent was also 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, as part of the CSIR's continued research investments into the bulk water reuse programme, 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.

2 LEGISLATION, POLICY FRAMEWORKS AND STRATEGIES PERTAINING TO IMPLEMENTATION AND MANAGEMENT OF INDUSTRIAL WATER REUSE IN SOUTH AFRICA

South Africa has extensive laws and guidelines regarding water use, reuse applications and effluent discharge. The Constitution, (Act 108 of 1996) (RSA, 1996) guarantees everyone the right to an environment that is not harmful to their health or wellbeing and guarantees the right to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures. It also guarantees all citizens the right of access to water.

Sustainable use of water resources builds on the principles of the National Water Policy Review (DWA, 2013c) which states that: "Water resources shall be developed, apportioned and managed in such a manner as to enable all user sectors to gain equitable water. Conservation and other measures to manage demand shall be actively promoted as preferred option to achieve this objective" (DWS, 2016).

The National Water Act (Act 36 of 1998) (RSA, 1998a), is the primary legislation governing the use and discharge of water and 'wastewater' in South Africa. This Act aims to ensure that the nation's water resources are protected and managed to reduce and prevent pollution and degradation of water resources. The NWA promotes the 'polluter pays' principle. The stringent Wastewater Discharge Standards proposed herein forces industries to develop their own "cleaner" production systems. The NWA further requires that any person using wastewater for irrigation purposes, discharge, or disposal must register with the responsible authority as a registered water user and must ensure that the wastewater does not impact other water sources, property, or land and that the wastewater is not detrimental to the health of the public.

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. The SANS 241 standard is specifically designed with bulk water suppliers in mind and is aimed at safe water provision for domestic drinking purposes, and as a result focuses primarily on life-long safety for all types of users and aesthetic acceptability of water (RSA, 1997).

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.

Currently the reuse of effluent streams requires environmental authorization in terms of the National Environmental Management Act (Act 107 of 1998) (DWS, 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 Department of Water and Sanitation developed a National Strategy for Water Reuse (DWA, 2013b). The intent of the water reuse strategy is to encourage 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.

3 DRIVERS FOR INDUSTRIAL WATER REUSE

Gelasmusssen et al (2019) state that understanding the drivers for and against water reclamation can facilitate efforts to meet associated water reuse policy goals.

Worldwide, water reuse and reclamation has been driven by multiple factors: pressure on water resources 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 of membrane and disinfection 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 3 provides a summary of driving forces impacting industrial water reuse in South Africa, based predominantly on water scarcity and costs.

Table 1: Global Variation in water reclamation for industrial application

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).

Industrial and population growth
South Africa's population is growing exponentially, and together with urbanisation, there is an increased need for power generation.

Freshwater costs
The cost of clean, fresh water is continually increasing, and is impacting all provinces of South Africa.

Regulatory requirements
All water use and discharge in South Africa needs to be registered and users need to obtain a water use license. Discharge regulations are in place that include volume and quality restrictions.

Social responsibility
Industry and the general public has a social responsibility to protect the environment. Negative publicity around industry's water use will have an impact on a company's sales/growth.

Discharge costs
Sewer and wastewater costs have increased at a higher rate than fresh water costs.

Water scarcity
South Africa is a water scarce country and many regions are susceptible to drought. Additionally, some industrial plants have limited access to clean/fresh water.

Wastewater processing limitations
On-site industrial wastewater treatment capacities have not increased proportionally with production. Industry strive to meet higher flows with limited operational resources.

Sustainability efforts
Industry strive towards sustainability by implementing economically sound programs and procedures to minimize a plant's negative environmental impact while conserving energy and natural resources.

Figure 3: Drivers for industrial water use

4 INDUSTRIAL WATER USE AND REUSE IN SOUTH AFRICA

4.1 Potential for Industrial Reuse

Globally, the reuse of water has become more acceptable and feasible because of increasing water scarcity/ shortages, improved treatment technologies and decreasing treatment costs. More recently, improvements in membrane technologies and their affordability have made a significant contribution.

However, the implementation of water reclamation in sub-Saharan Africa in general, is lagging behind. In South Africa, approximately only 14% of wastewater is reused according to estimates by the Department of Water and Sanitation (2018). It is estimated that for in-land areas such as Gauteng in the Vaal and Crocodile catchments, water is reused indirectly as the return flows from the wastewater plants forms part of a downstream raw water abstraction from the same river. The reuse of return flows could however be significantly increased, particularly in coastal cities where wastewater ordinarily drains into the sea (DWS, 2018).

Resource recovery, e.g., through water reclamation programs, is essential for wastewater management in sub-Saharan Africa (Nansubuga et al., 2016). In this way, water reclamation for industries will begin to play an important role in addressing water scarcity, giving industries the responsibility of not competing with the available fresh water resources for domestic use and, in many cases, resulting in financial benefits (Grobicki, 2008). By using reclaimed water in industry, additional water will be made available for drinking and other domestic applications and purposes.

4.2 Wastewater Generation by 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/. 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 waste water 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 4 provides a schematic breakdown of the main industrial water users and producers in South Africa (based on the Cloete et al., 2010 data).

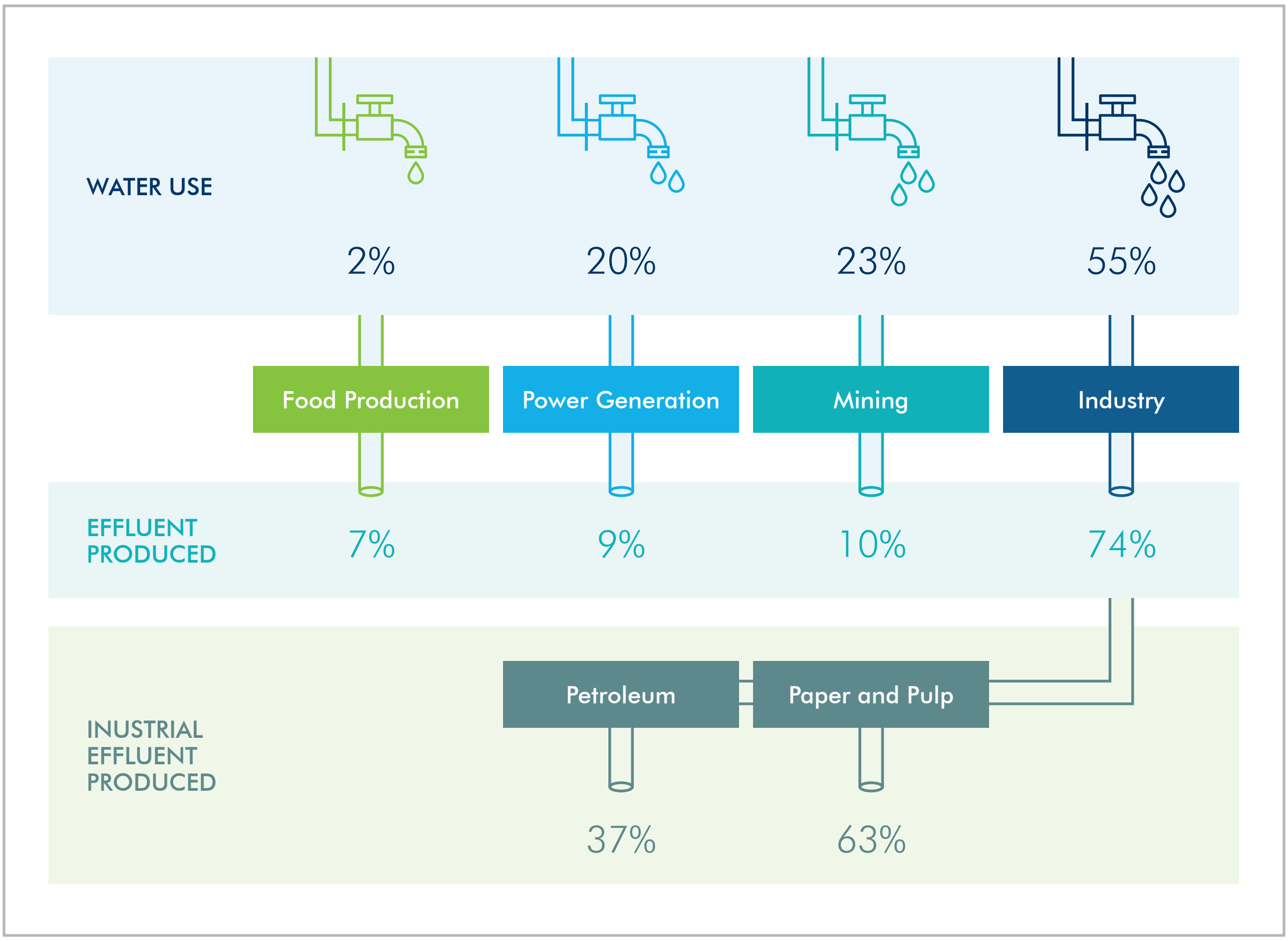


Figure 4: Industrial water use and effluent production in South Africa (Adapted from Cloete et al., 2010)

4.3 Existing Industrial Wastewater Reuse Examples

Wastewater reuse in industry can take place within a business or between businesses and has the potential to reduce costs for businesses both on their water bills as well as wastewater treatment. Depending on the contaminants present in wastewater and its future reuse, it can either be directly reused, or treated and reused (recycled). Table 2 summarises a few examples where treated domestic wastewater effluent is used in industry or where industrial effluent is treated and used for irrigation or other industrial processes in South Africa.

Table 2: Examples of water reuse in industry.

Name of Plant	Description	References
Durban Water Recycling (Pty) Ltd, eThekwini Municipality	The plant uses Veolia water technologies to treat 47.5 million litres of domestic and industrial wastewater to a near potable standard for direct reuse in industrial processes. At the plant, 98% of the wastewater is recycled for reuse, reducing the city's water consumption by 7%. Currently the two largest customers for its high-quality but lower-cost water are Mondi Paper who uses 85% of the recycled water directly for production of fine paper. The rest of the treated 47ML/d is used by the SAPREF Refinery owned by Shell and BP.	Ethekwini Municipality and Veolia Fact sheet 7: Durban Water Recycling Plant. http://prg.ukzn.ac.za/docs/default-source/projects/fact-sheet-7_durban-water-recycling-plant.pdf?sfvrsn=2 2018 International Bank for Reconstruction and Development. The World Bank Naidoo D. The Water Wheel May/June 2015 Volume 14 No 3 Ethekwini Municipality. Services. Projects. http://www.durban.gov.za/City_Services/water_sanitation/Services/Pages/durban-recyling.aspx;

Name of Plant	Description	References
Nestle, South Africa – Project ZerEau, Mossel Bay Municipality	In 2018, Nestle South Africa implemented zero water discharge technology at its Mossel Bay dairy factory. Nestle uses milk which normally contains 88% of water to make milk products (powdered milk, condensed milk, etc) through an evaporation process. The technology captures the evaporated water, treats it and uses it for other applications within the facility. The water is reused for various purposes such as such as cooling, garden watering and cleaning. This zero-water technology eliminates the need for municipal water intake and the reduction of wastewater from the factory (reuse of recovered water) thereby freeing up capacity at the municipality's wastewater treatment plant. Nestle has estimated that it will reduce its water consumption by more than 50% in the first year on the technology implementation by reusing the recovered water.	Nestle South Africa Media release. https://www.nestle-esar.com/media/pressreleases/nestle-launches-zero-water-technologies-site-mossel-bay Kilian, A. 2018. Nestlé launches 'zero water' manufacturing facility in Western Cape. https://www.engineeringnews.co.za/article/nestl-launches-zero-water-manufacturing-facility-in-western-cape-2018-06-05
Coca-Cola Beverages, South Africa (CCBSA),	Coca-Cola Beverages South Africa (CCBSA), had set a target to reduce the amount of water used in soft drink production by 20% by 2020. The company implemented a number of advanced technologies such as electrochemically activated (ECA)-, membrane- technology and anaerobic digesters. Both ECA- and membrane technologies uses scientific reactions to clean and disinfect equipment. This cleaning processes uses significantly less water and chemicals. On the other hand, anaerobic digesters are used to recycle waste water more efficiently, resulting in more clean, potable water being made available for other uses. By 2016, the company had already exceeded their target realising a 30% reduction saving almost 726 million litres of water over six years. In 2010 the company used 2.13 litres of water to produce 1litre of soft-drink and by 2016, only 1.7 litres were required to produce the same volume.	Coca-Cola Sustainability Commitments https://www.ccbsaco.com/sustainability/; Africa, T. 2017. Coca-Cola Beverages SA announces 726 million litres of water savings https://www.iol.co.za/business-report/companies/coca-cola-beverages-sa-announces-726-million-litres-of-water-savings-9341663
Optimum Water Reclamation Plant	The Optimum Water Reclamation Plant (OWRP), located near Hendrina in Mpumalanga was initiated in 2008. Optimum Water Reclamation Plant is owned and operated by Glencore Optimum Coal Holdings. The plant which employs advanced treatment technology and disinfection, is designed to treats 15ML/day with peak capacity of 18Ml/day. The treats water with a 98% water recovery. About 95 % of the treated water would be available for the surrounding communities (local Hendrina Municipality), while the remaining five percent is discharged into the Klein Olifants river to sustain the aquatic reserve, as required by department of water and environmental affairs.	Van Niekerk A.M. and Schneider B., (2013). Implementation Plan for Direct and Indirect Water Re-use for Domestic Purposes – Sector Discussion Document. WRC Report No KV 320/13. Nafasi Water (2019). Available from: https://nafasiwater.com/projects/ [Accessed on 21 May 2020]. Cogho V.E., (2012).Optimum Coal Mine: striving towards a 'zero effluent' mine. The Journal of the Southern African Institute of Mining and Metallurgy, 112, pp 109-112
Middelburg Water Reclamation Plant	The Middelburg Water Reclamation Plant (MWRP) was designed to treat mine-impacted water from the Hartebeesfontein, Goedehoop and Klipfontein sections of 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. It treats 20Ml/day with a peak capacity of 25Ml/day with 99.7% water recovery.	Nafasi Water (2019). Available from: https://nafasiwater.com/projects/ [Accessed on 21 May 2020]. Aurecon. Middelburg Water Reclamation Project, South Africa. Available from: https://www.aurecongroup.com/projects/water/middleburg-water-reclamation-project [Accessed on 21 May 2020].

Name of Plant	Description	References
The eMmalahleni Water Reclamation Plant	The eMalahleni water reclamation (EWRP) plant is situated in the Witbank coalfields of South Africa's Mpumalanga province. The plant is Anglo American's flagship project that started in late 2005 and was first commissioned in 2007. The process involves pumping excess mine water from the Kleinkopje Colliery, the Navigation Section of the Landau Colliery, the Greenside Colliery and the BHP Billiton Energy Coal South Africa to EWRP, where it is treated 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. Extra water is sent to other Anglo American operations; Greenside, Kleinkopje and Landau collieries as well as various nearby Anglo American service departments for domestic use and for mining activities, such as dust suppression thus reducing serious supply problems of the municipality. The plant also supplies eight megalitres of potable water per day to Zondagsfontein, an Anglo Inyosi Coal greenfield project, BECSA's Klipspruit mine and the Phola coal washing plant, a joint venture between the two mining houses.	Sergienko N. (2015). The eMalahleni Water Reclamation Plant in South Africa. Available from: http://www.iwa-network.org/filemanager-uploads/WQ_Compendium/Cases/The%20eMalahleni%20Water.pdf/. [Accessed 19 May 2020]. World Coal Association Case Study (2014). South Africa Anglo American eMalahleni Water Reclamation Plant –Winner of WCA Award for Excellence in Environmental Practice 2013. March 2014. Van Niekerk A.M. and Schneider B., (2013). Implementation Plan for Direct and Indirect Water Re-use for Domestic Purposes – Sector Discussion Document. WRC Report No KV 320/13. Mathews C. African Decisions. Available from: https://www.africandecisions.com/resources/water-and-mining/ [Accessed on May 2020].
Rustenburg Local Municipality Wastewater Treatment Plant	Rustenburg local municipality's (RLM) wastewater treatment plants are managed by Rustenburg Water Services Trust and operated by Magalies Water. The treated effluent mainly from Rustenburg wastewater treatment is used for mining and irrigation and small portion is reserved for the city's use. In 2006, Platinum's mines signed an agreement with the Rustenburg Water Services Trust to use 15 ML per day of treated effluent from its sewage treatment plant. Due to inconsistent water quality and supply which limited the optimal use of the treated water, the mine commissioned water-treatment plant at its Rustenburg operations in 2011 to improve the quality of the treated sewage water introduced into its water-reticulation system. Additional pipelines were installed in 2014 to promote the use of additional 3 ML/day of treated sewage water and simultaneously offset the use of the same volume of potable water.	Anglo American (2011). Anglo American in South Africa: Transformation Report 2011. Joshi S., Cui A., Victor C., Lauwa L., Xiaocheng F., and Edwin Y. (2014). Visioning and programming report: Integrated Master Plan for RLM. November 2014. Anglo American Platinum Limited (2011). Sustainable Development Report 2014
Sasol One	Sasol uses large amounts of fresh water and runs a very large complex water system that employs a high degree of reuse and recycling. One example of water reuse is the use of stripped gas liquor (SGL) as cooling water. Previously, SGL was treated together with industrial and domestic wastewater in Sasol One WWTW using trickling filter technology and the final effluent from treatment plant was used to transport ash in the Sasol One ash transport system. But in 1998, Sasol implemented a project to use SGL as a make-up in cooling system, rather than direct treatment in WWTW. The cooling system improved the quality of water discharged into Vaal River by reducing COD, ammonia and phenol concentration and also reducing the final volume discharged. Abstraction of water from Vaal River as cooling water make-up was also reduced. Raw water intake was reduced by about 9Ml/d and the discharge was reduced by about 6Ml/d.	Schutte, F. Chapter 8. Water reuse in Central and Southern Regions of Africa. In Jemenez, B., and Asano, T. Water reuse: an international survey of current practice, issues and needs. 2008 IWA publishing. https://iwaponline.com/ebooks/book/26/Water-Reuse-An-International-Survey-of-current?redirectedFrom=PDF

5 MANAGING WASTEWATER FOR POTENTIAL INDUSTRIAL REUSE IN SOUTH AFRICA

Historically, industrial effluent has been viewed as an unwanted by-product of manufacturing processes. Occasionally however, industrial effluents contain useful resources that can be viably recovered and re-used.

In South Africa, all effluent discharge is regulated by the Department of Water Affairs and Sanitation (DWS). Industry effluents within Municipal boundaries are commonly handled through the Municipal sewage systems. Municipalities impose minimum discharge standards in order to protect the sewage network. For example, limits against low pH which can be corrosive, and high suspended solids to prevent clogging of pipes. Flammable liquids are not permitted for discharge into the sewer networks to avoid fire risks. Due to public and increasing environmental pressures, DWS has become stricter with Municipalities that do not meet minimum discharge criteria.

As a consequence of this, many SA Municipalities have had to re-examine the capacities of their treatment plants, sewage networks and customers. By-laws are in place to ensure that Municipalities can recover treatment and piping costs from individual polluters. Once again, the Municipal by-laws are lately becoming far stricter with South African industries, who are now facing unprecedented discharge fees for their effluent.

5.1 Treatment And Fitness For Use

Process water discharged from operations/processes (wastewater/effluent) can be reused for multiple purposes if appropriate treatment systems are implemented and collective management of wastewater treatment plants (from various dischargers) can lower costs for all participants in a wastewater re-use scheme.

Industrial wastewater treatment, recycling, and reuse is an important theme in today's context, not just to protect the environment from pollution, but also to conserve water resources so that water stress is reduced. 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 waste impurities, and desired quality goal for treatment. Furthermore, technology choice can be 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. The quality of the effluent makes the task of technology selection, oftentimes, rather complex. However, for the majority of wastewater qualities, appropriate remediation technologies exist. Given these challenges, the overview presented below is intended to be a useful guide in identifying key issues and facilitating the selection of appropriate processes for treating wastewater (Ranade and Bhandari, 2014).

Broadly, there are two major categories for wastewater reuse: (a) potable uses and (b) non-potable uses, such as: irrigation in agriculture; industrial reuse (e.g., water cooling); aquifer recharge and other urban reuses such as toilet flushing, train washing, washing of taxis and buses, ground cooling, or building construction (Schellenberg et al., 2020).

Therefore, the concept of "fitness for use" is central 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. "Fit-for-purpose" specifications are the treatment requirements to bring 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).

5.2 Typical Industrial Wastewater Effluent Quality

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. Table 3 summarises the typical broad spectrum of pollutants in typical industrial wastewater effluent streams.

Table 3: Typical industrial wastewater effluent quality and content (WWAP, 2017)

Industry	Typical content of effluent
Paper and Pulp	Chlorinated lignosulphonic acids, chlorinated resin acids, chlorinated phenols and chlorinated hydrocarbons – about 500 different chlorinated organic compounds identified
	Coloured compounds and absorbable organic halogens (AOX)
Iron and steel	Pollutants characterized by BOD, COD, suspended solids (SS), toxicity and colour
	Cooling water containing ammonia and cyanide
	Gasification products – benzene, naphthalene, anthracene, cyanide, ammonia, phenols, cresols and polycyclic aromatic hydrocarbons
	Hydraulic oils, tallow and particulate solids
	Acidic rinse water and waste acid (hydrochloric and sulphuric)
Mines and quarries	Slurries of rock particles
	Surfactants
	Oils and hydraulic oils
	Undesirable minerals, i.e. arsenic
	Slimes with very fine particulates
Food industry	High levels of BOD and SS concentrations
	Variable BOD and pH depending on vegetable, fruit or meat and season
	Vegetable processing – high particulates, some dissolved organics, surfactants
	Meat – strong organics, antibiotics, growth hormones, pesticides and insecticides
	Cooking – plant organic material, salt, flavourings, colouring material, acids, alkalis, oil and fat
Brewing	BOD, COD, SS, nitrogen, phosphorus - variable by individual processes • pH variable due to acid and alkaline cleaning agents • High temperature
Dairy	Dissolved sugars, proteins, fats and additive residues • BOD, COD, SS, nitrogen and phosphorus
Organic chemicals	Pesticides, pharmaceuticals, paints and dyes, petro-chemicals, detergents, plastics, etc. • Feed-stock materials, by-products, product material in soluble or particulate form, washing and
	cleaning agents, solvents and added-value products such as plasticizers
Textiles	BOD, COD, metals, suspended solids, urea, salt, sulphide, H2O2, NaOH • Disinfectants, biocides, insecticide residues, detergents, oils, knitting lubricants, spin finishes, spent solvents, anti-static compounds, stabilizers, surfactants, organic processing assistants, cationic materials, colour • High acidity or alkalinity
Energy	Production of fossil fuels – contamination from oil and gas wells and fracking • Hot cooling water

Water quality parameters specified in the South African Water Quality Guidelines for Industrial use (DWS, 1996) are limited in comparison to other water uses and are summarised in Table 4. 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).

Table 4: South African water quality parameters for industrial water use

Alkalinity	Iron	Silica	Total Dissolved Solids
Chemical Oxygen Demand	Manganese	Sulphate	Total Hardness
Chloride	pH	Suspended Solids	

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.

Table 5: Categories of processes defined according to required water quality (DWAF, 1996)

Category 1	Processes that require a high quality water with relatively tight to stringent specifications of limits for most or all the relevant water quality constituents. Standard or specialised technology is essential to provide water conforming to the required quality specifications Consequently, costs of inhouse treatment to provide such water are a major consideration in the economy of the process.
Category 2	Processes that require water of a quality intermediate between the high quality required for Category 1 processes and domestic water quality (Category 3 processes). Specifications for some water quality constituents are somewhat tighter or more stringent than required for domestic water quality. Standard technology is usually sufficient to reach the required water quality criteria. Cost for such additional water treatment begins to be significant in the economy of the process.
Category 3	Processes for which domestic water quality is the baseline minimum standard. Water of this quality may be used in the process without further treatment, or minimum treatment using low to standard technology may be necessary to reach the specifications laid down for a desired water quality. Costs of further inhouse treatment are not significant in the economy of the process.
Category 4	Processes that within certain limitations can use water of more or less any quality for their purposes without creating any problems. No additional treatment is usually required and there is therefore no further cost.

Based on the varying water requirements for different sectors and industries, different qualities are needed for different industrial processes. For example, category 3 quality water can be used for more purposes compared to category 1, in terms of acceptability from reuse (DWS, 1996), from a water quality perspective (Table 5).

Table 6: Examples of industrial processes and water quality fitness for use categories

Category 1 Industrial Processes			
Cooling Water	Steam Generation	Process Water	Wash Water
Evaporative cooling (high recycle)	High pressure boilers (demineralisation – plant feed water)	• Phase separation • Petrochemicals • Pharmaceuticals (demineralisation – feed water)	Washing with no residuals (electronic parts) (demineralisation – feed water)

Category 3 Industrial Processes				
Cooling Water	Steam Generation	Process Water	Product Water	Utility Water
• Evaporative cooling (once through) • Bearing cooling • Mould cooling	Low pressure boilers: softening process feed water	• Solvent • Dilution agent • Transport agent • Glad seal • Vacuum seal • Lubrication • Desealing (iron and steel industry) • Gas scrubbing	• Beverages • Food products • Baking and confectionery • Chemicals	• Surface washing (table tops, walls) • Domestic use • Fire fighting

6 FINANCIAL BENEFITS AND COSTS OF INDUSTRIAL WATER REUSE

The cost of re-using water relative to other alternatives is one of the main factors that will impact future water reuse decision making processes. It is therefore essential to unpack and further understand some of the key factors that will affect costs and how these will vary between different applications of reuse, and how these are likely to change over time, relative to other water supply alternatives. It is also important to understand how these costs might be reduced to make water reuse more economically attractive. The key determinants of cost are location, water quality, treatment technology and volume (scale) (DWA, 2013b).

Considering a wastewater treatment system as a source of water rather than merely a location for disposal of water, the analyses of benefits can change substantially. In general, the water quality required for reclaimed water for irrigation or industrial use is not much different to that of typical secondary or tertiary treated wastewater effluent.

Distribution system costs are usually the most significant component of costs for non-potable reuse systems. Consequently, projects that minimize those costs and use effluent from existing wastewater treatment plants are frequently cost-effective, due to the minimal additional treatment needed for most non-potable applications beyond typical wastewater disposal requirements. When large non-potable reuse customers are located far from the water reclamation plant, the total costs of non-potable projects can be significantly greater than potable reuse projects, which do not involve separate distribution lines.

Whether reclaimed water is used for non-potable or potable uses, there are several factors that affect the costs of a water reuse program. These include the location of the wastewater, customer use requirements, transmission and pumping, timing and storage needs, energy requirements, concentrate disposal, permitting, and financing costs. In most cases, reclaimed water systems originate at a municipal wastewater treatment plant which are typically constructed at lower elevations within close proximity to a point of discharge such as a river, lake, or ocean. As a result, there are pumping costs to transport reclaimed water to the customers or to the water treatment plant, which is typically sited at higher elevations.

7 BARRIERS TO INDUSTRIAL WATER REUSE

One of the main complications to the adoption of wastewater reuse in industry, is the high capital costs. The capitals costs required for reuse projects differ significantly, depending on factors such as the quality of the wastewater and the required level of treatment. Treatment of organic wastewater to potable standards is estimated to be in the order of R 20 – R200 million per project, while an estimated R10 – R15 million is needed to treat inorganic effluent to potable water standards. Project sizes can range between 0.2 – 1 million litres per day.

A significant barrier to industrial reuse in South Africa is the low fresh water abstraction tariffs. Recent drought conditions throughout South Africa resulted in significant hikes in municipal tariffs. However, no information is currently available on the future trajectory of these tariffs nor the post-drought municipal tariffs. Should even, more expensive treatment technologies, such as desalination, be included into municipal water network grids, there is a potential for municipal tariffs to increase significantly in the short to medium term in South Africa.

Some industries, depending on the level and type of water reuse and treatment (e.g., acid mine drainage in the mining industry) often result in a saline brine waste stream after recovery of the water. The direct discharge of brine into the sewerage lines is not permitted, and presents a challenge for many reuse projects. Such industries will be required to make use of more expensive treatment options (e.g., eutectic freeze).

Legislative requirements in terms of water quality and strict treatment and testing standards to prevent human health impacts, further add to the ongoing project costs and can be a deterrent to uptake of reuse.

While wastewater reuse is more widely practiced and increasingly accepted, industrial companies and municipalities are often wary of negative public perception related to effluent reuse. Lack of knowledge with regards to water reuse options and treatment technologies may also act as a barrier to adopt such technologies.

For inland municipalities, information regarding the downstream allocations to the ecological reserve and determining the volumes of water available for reuse within a specific municipal area or catchment is critical. Coastal municipalities are slightly advantaged in that they able to reuse the total volume of wastewater effluent generated and return the final effluent to sea.

8 MAPS: NATIONAL AND PROVINCIAL REGISTERED BULK WATER USE

From a national perspective (Figure 5), water intensive industries are largely represented by the agriculture sector, most of which is used in irrigation. Second to agriculture is water supply services, urban industry, mining and non-urban industry. Water use for mining is the highest in Mpumalanga, followed by Gauteng, North West, Northern Cape and Limpopo. Figures 7 – 15 presents provincial water consumption volumes for various water sectors as per the registered water uses on the DWS WARMS database.

Mpumalanga has the highest water withdrawals, followed by the Free State, Eastern Cape and Gauteng provinces. In all provinces, the largest water use is for agricultural irrigation, except in Gauteng. While nationally the largest water user is the agricultural sector, in Gauteng; industrial water use is the highest. The second highest industrial water use is 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 KwaZulu-Natal and Mpumalanga. The highest water withdrawals per sector in Mpumalanga province were noted for agricultural irrigation, mining, water supply services and urban industry.

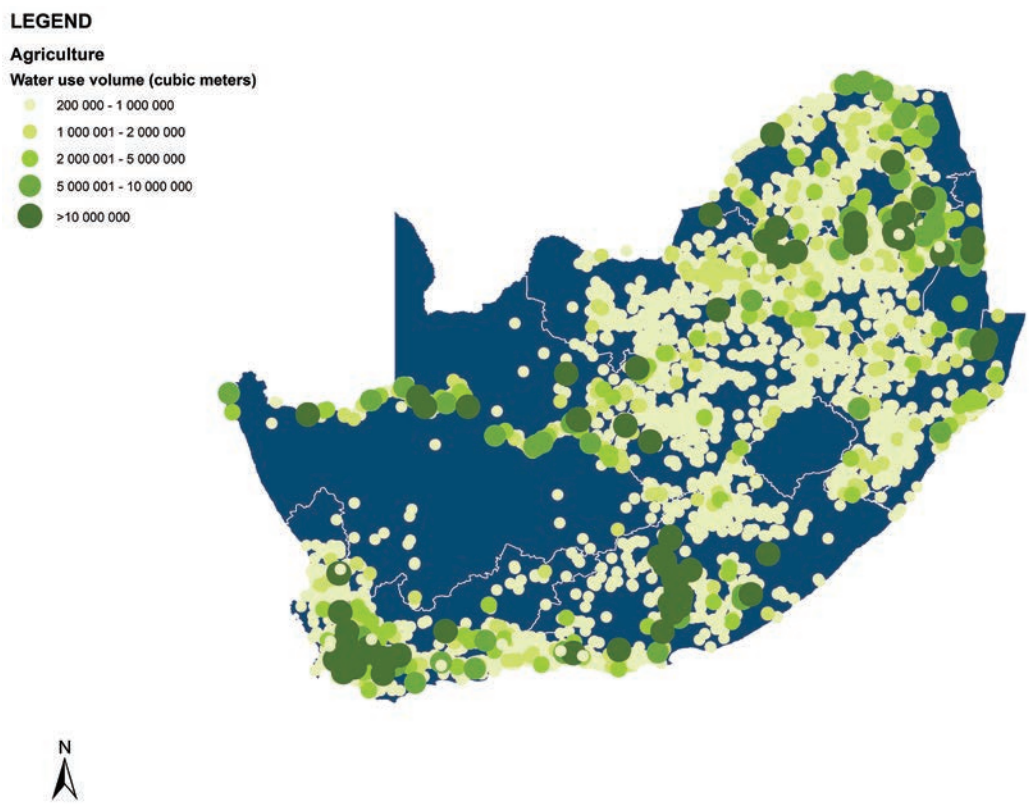
For KwaZulu-Natal, the highest water withdrawals per sector were recorded for agricultural irrigation, water supply services and non-urban industry.

For the Eastern Cape, the highest water withdrawals per sector were recorded for agricultural irrigation and water supply services.

For the Free State province, the highest water withdrawals per sector were recorded for agricultural irrigation, water supply services, mining and industry (urban). The Free State province does not have water use volumes registered for power generation, recreation, schedule 1 and urban (excluding industrial and/or domestic).

The Limpopo province had the highest withdrawals for agricultural irrigation, water supply services, mining, power generation and schedule 1.

The Northern Cape province had the lowest registered water withdrawal of all provinces. Per sector, for North West province, the second highest volumes were registered for the mining sector.



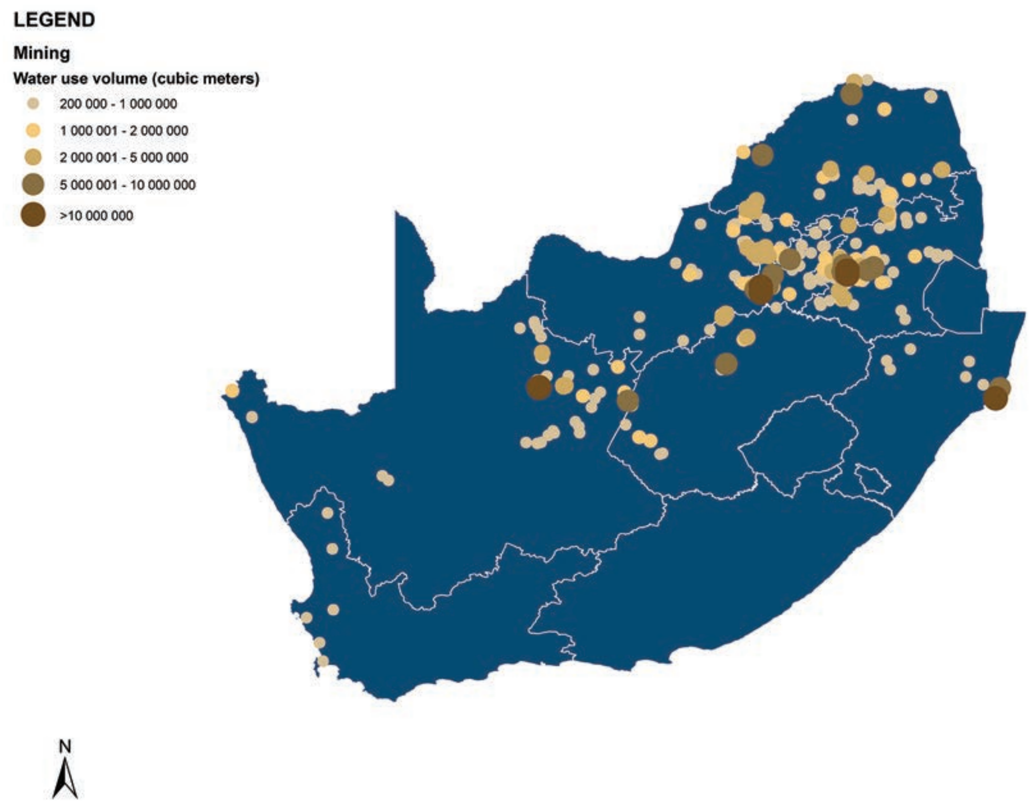
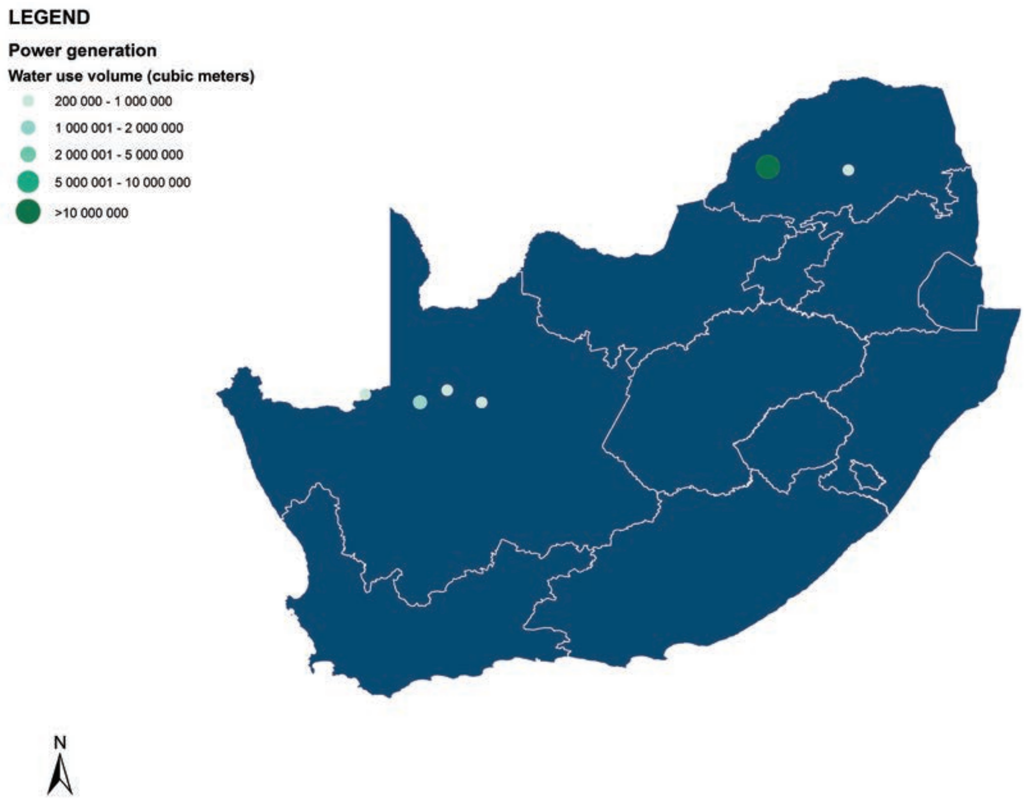


Figure 5: National bulk water use map



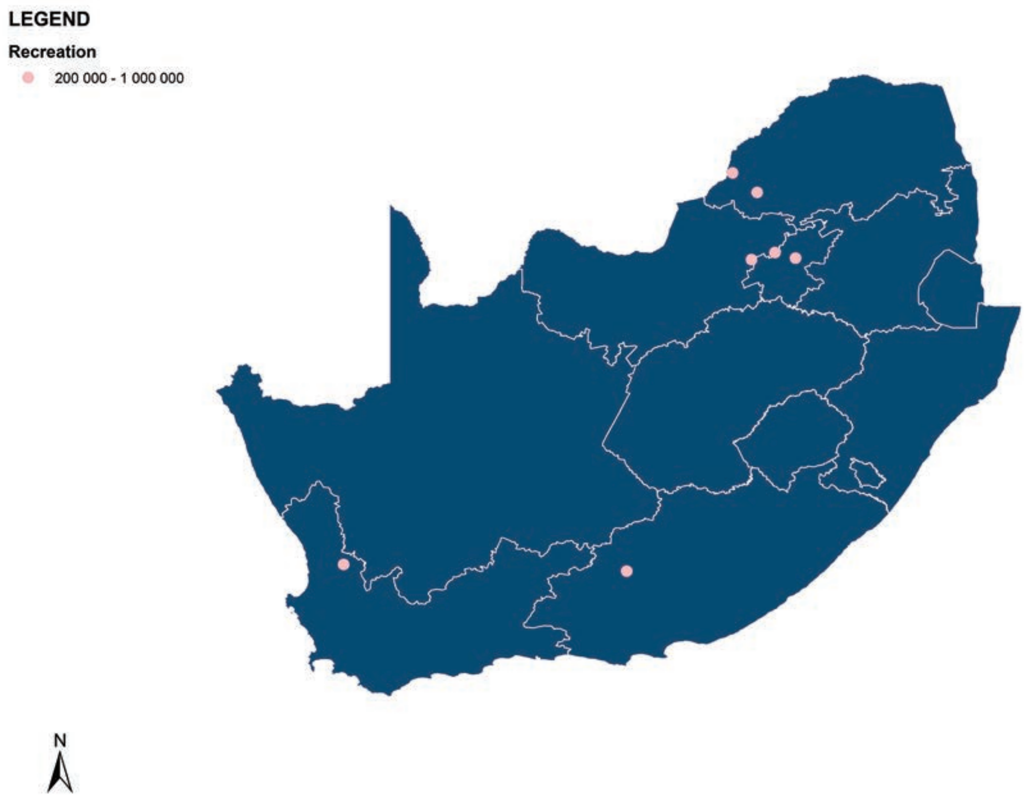
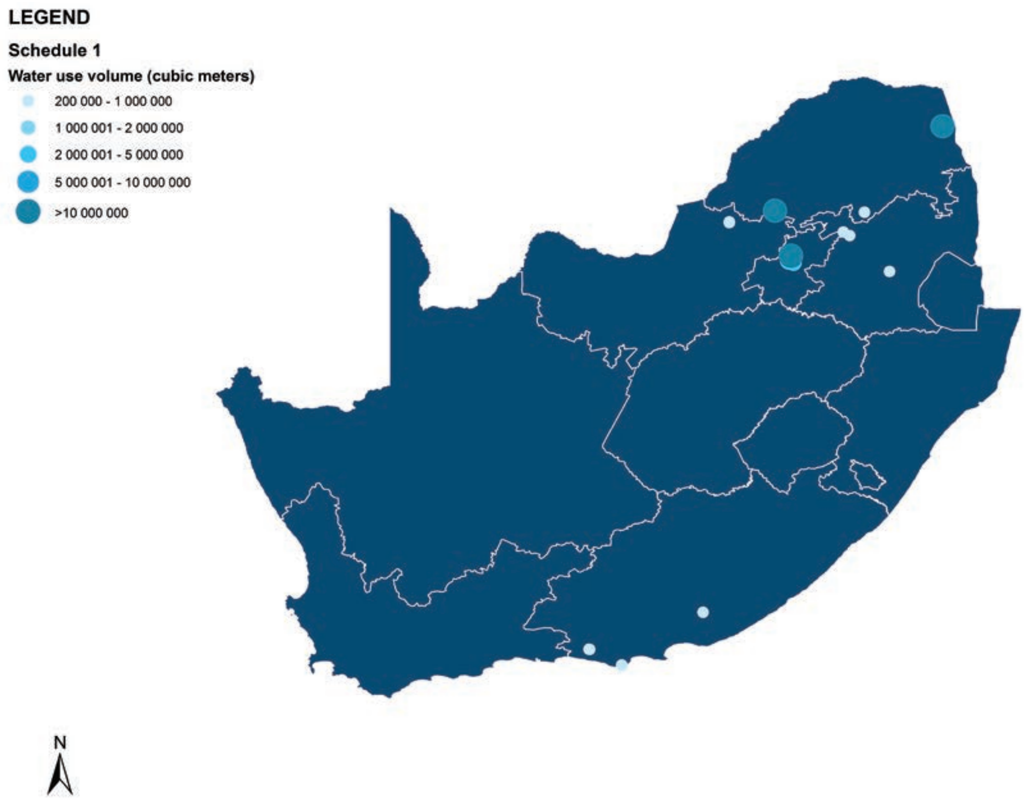


Figure 5: National bulk water use map



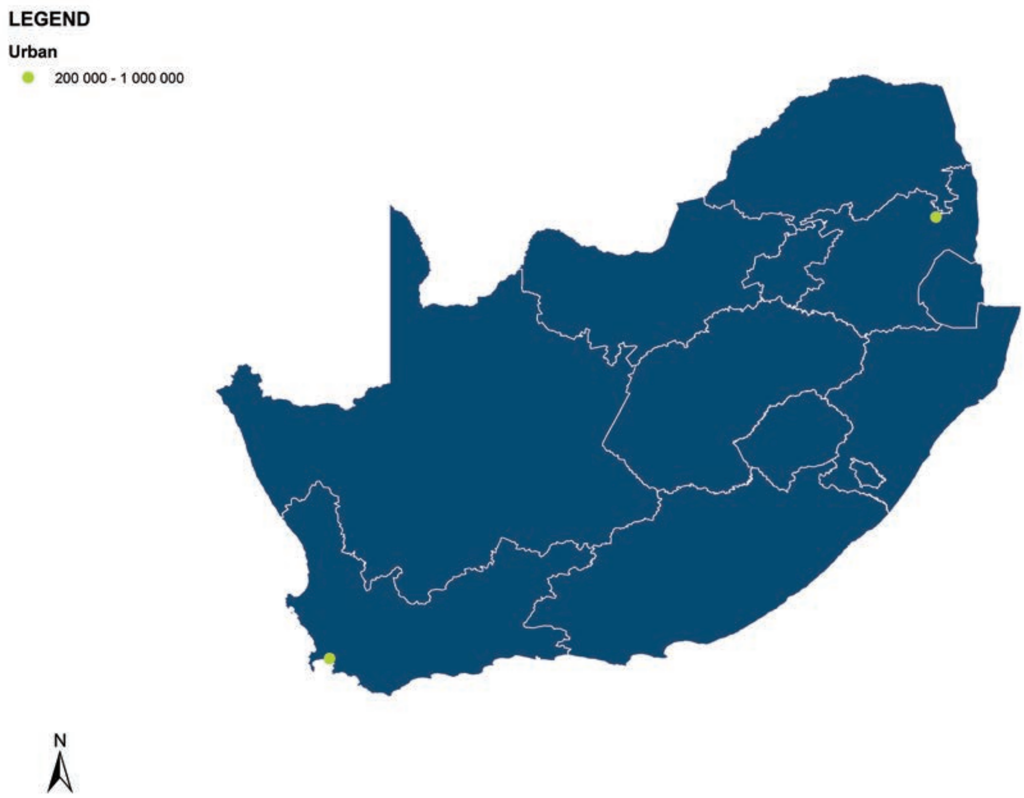


Figure 5: National bulk water use map

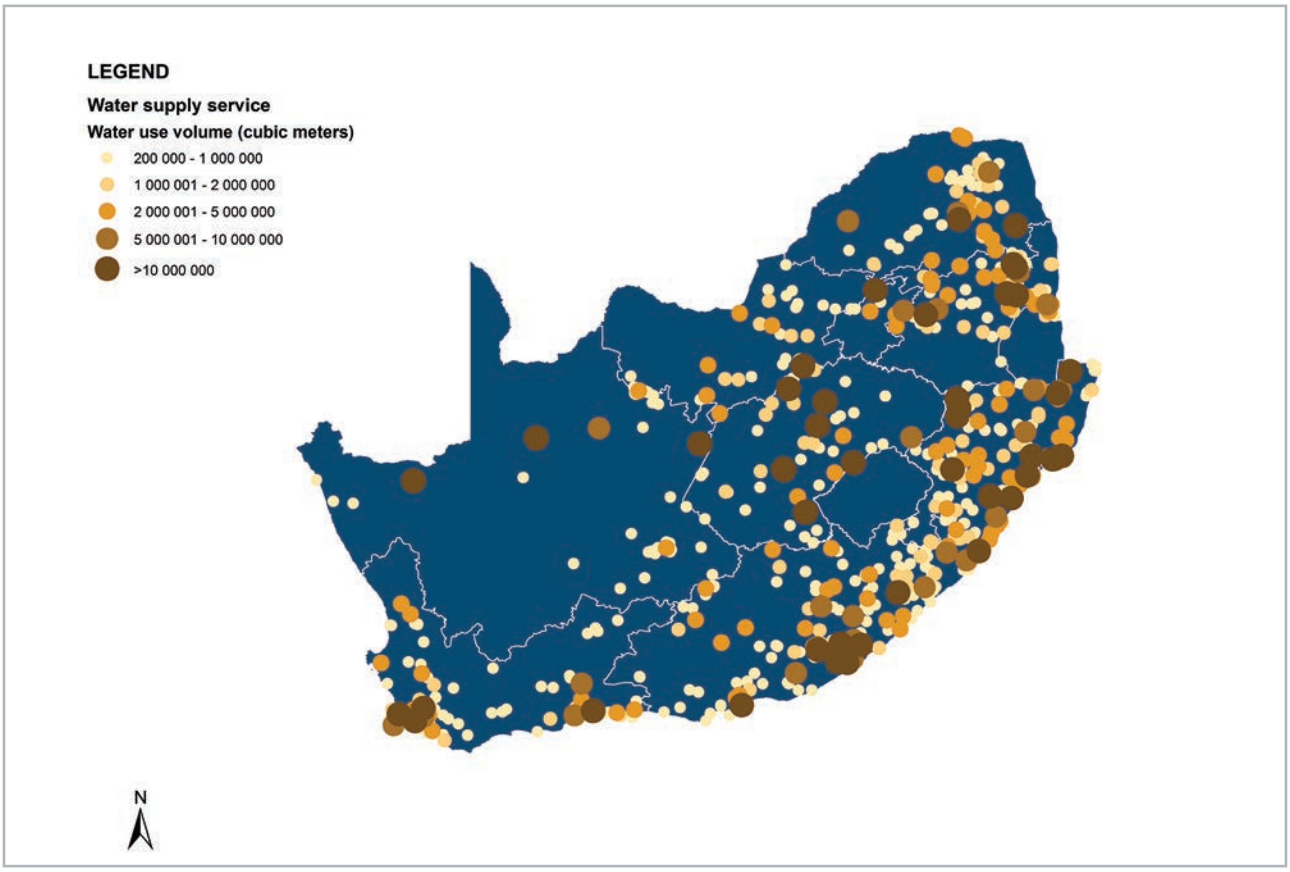


Figure 5: National bulk water use map

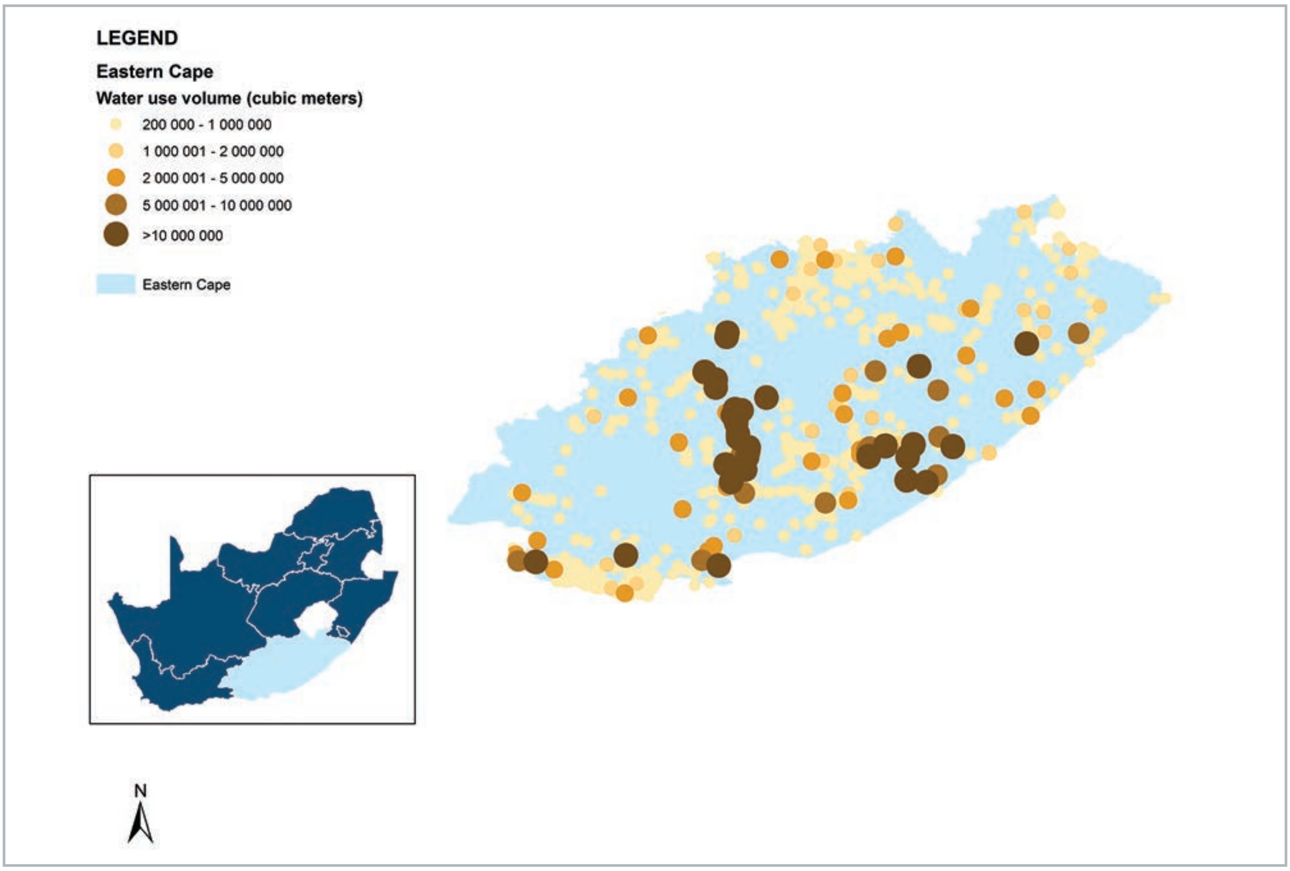


Figure 6: Bulk water use in the Eastern Cape

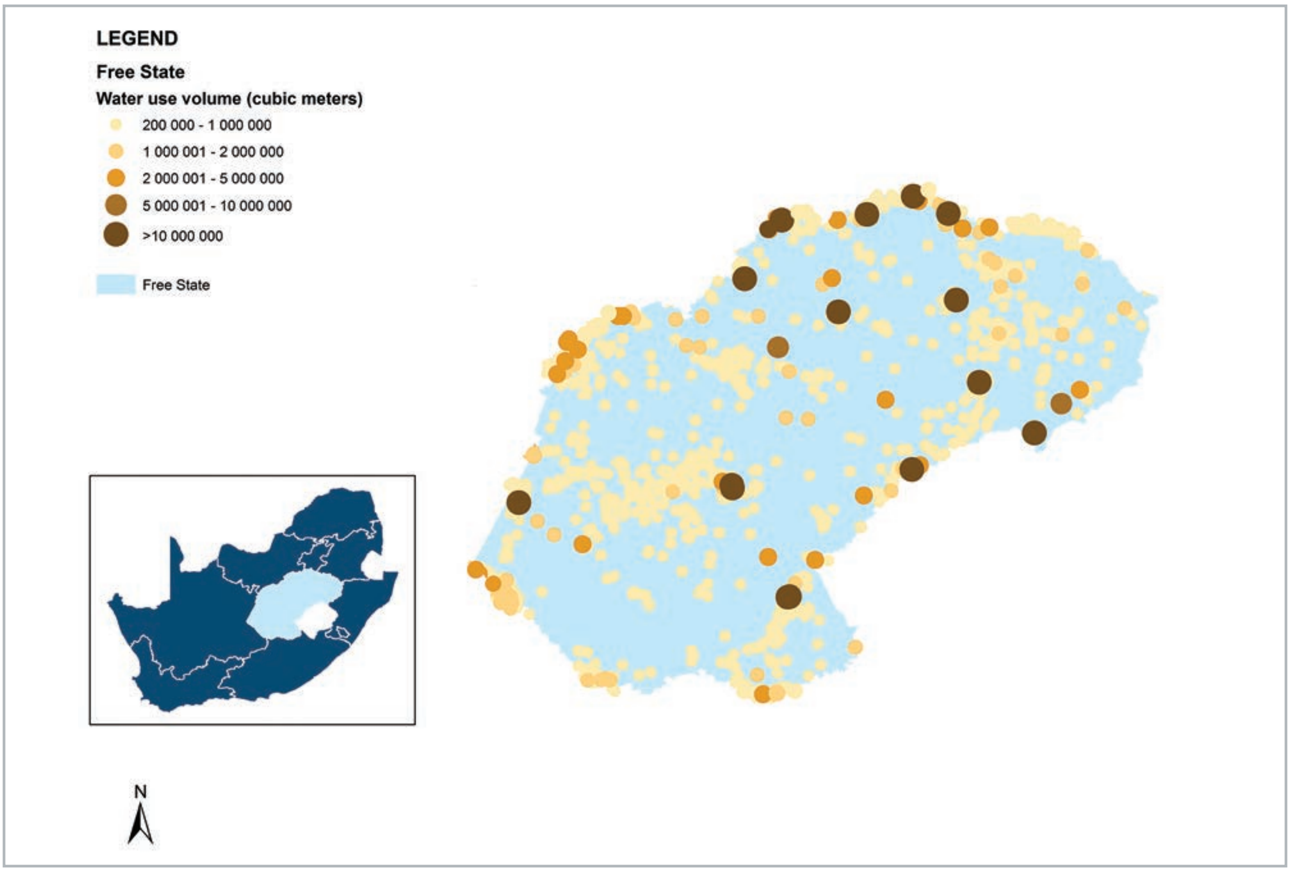


Figure 7: Bulk water use in the Free State

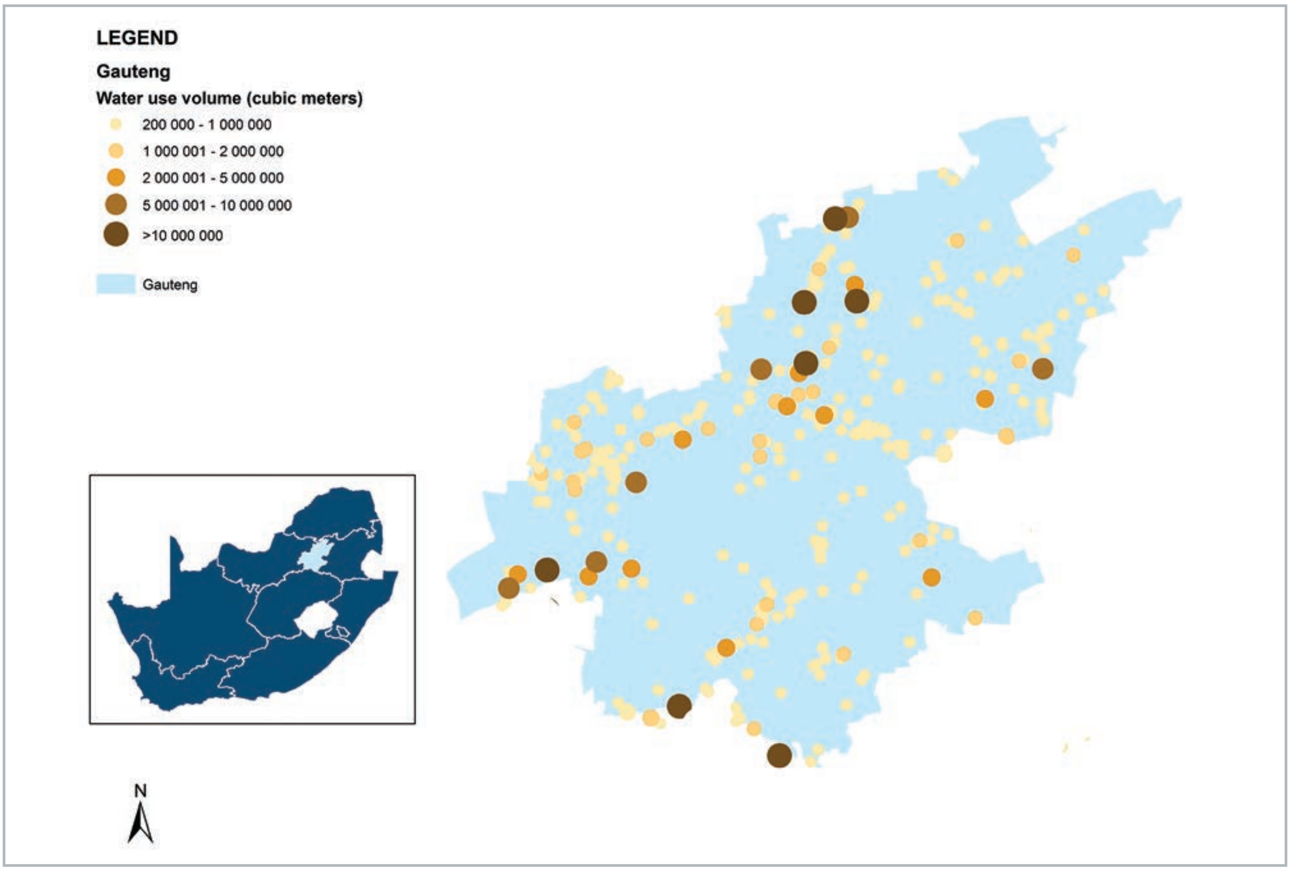


Figure 8: Bulk water use in Gauteng

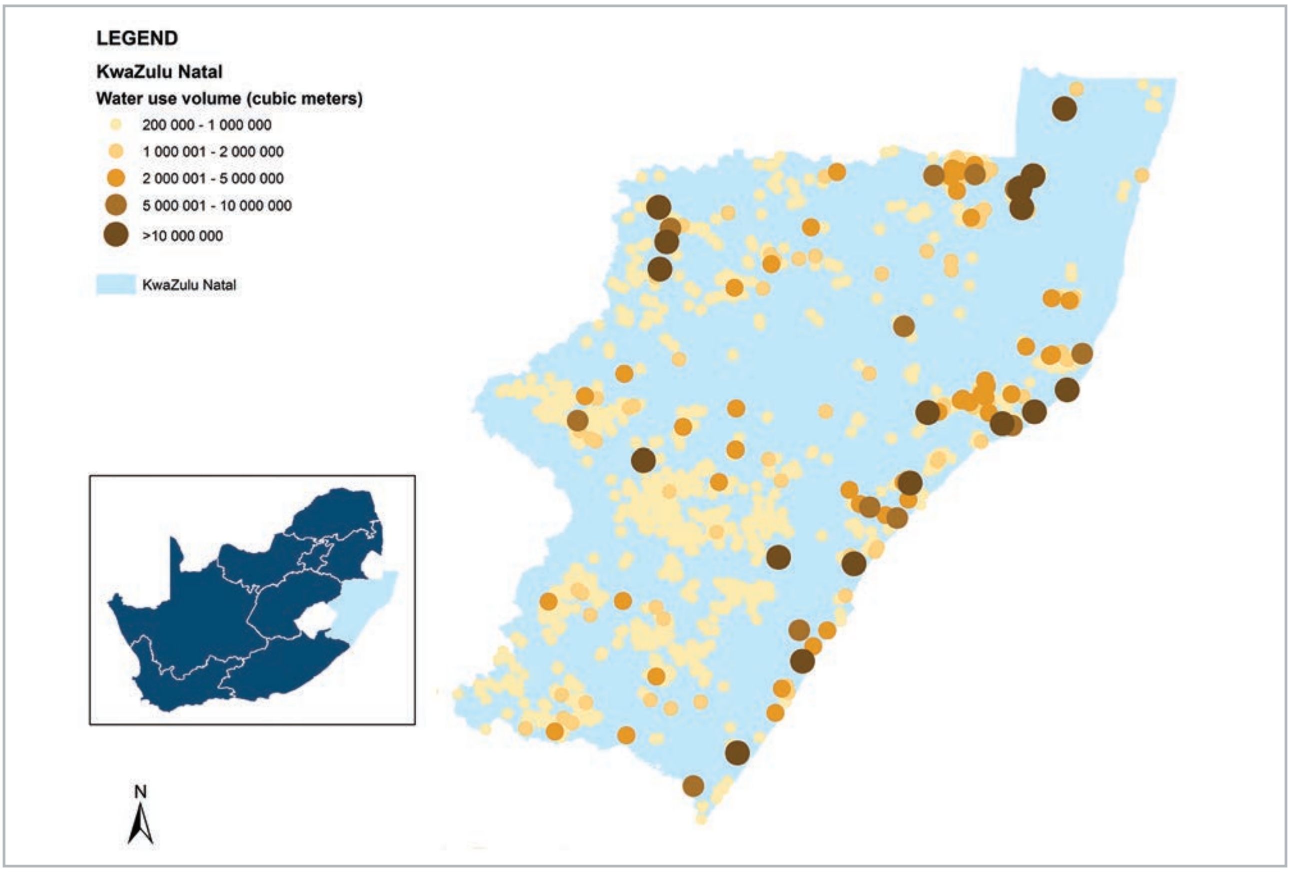


Figure 9: Bulk water use in KwaZulu-Natal

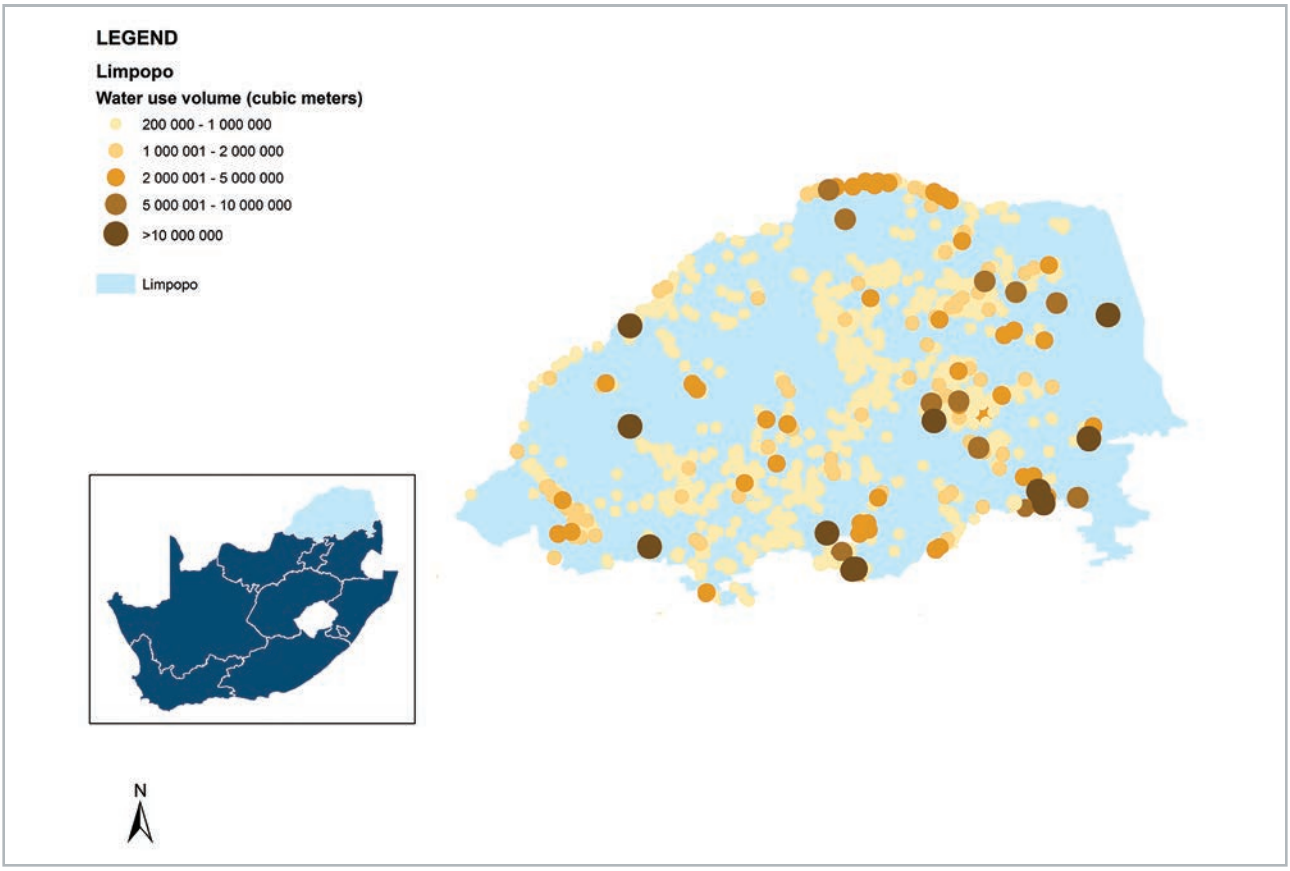


Figure 10: Bulk water use in Limpopo

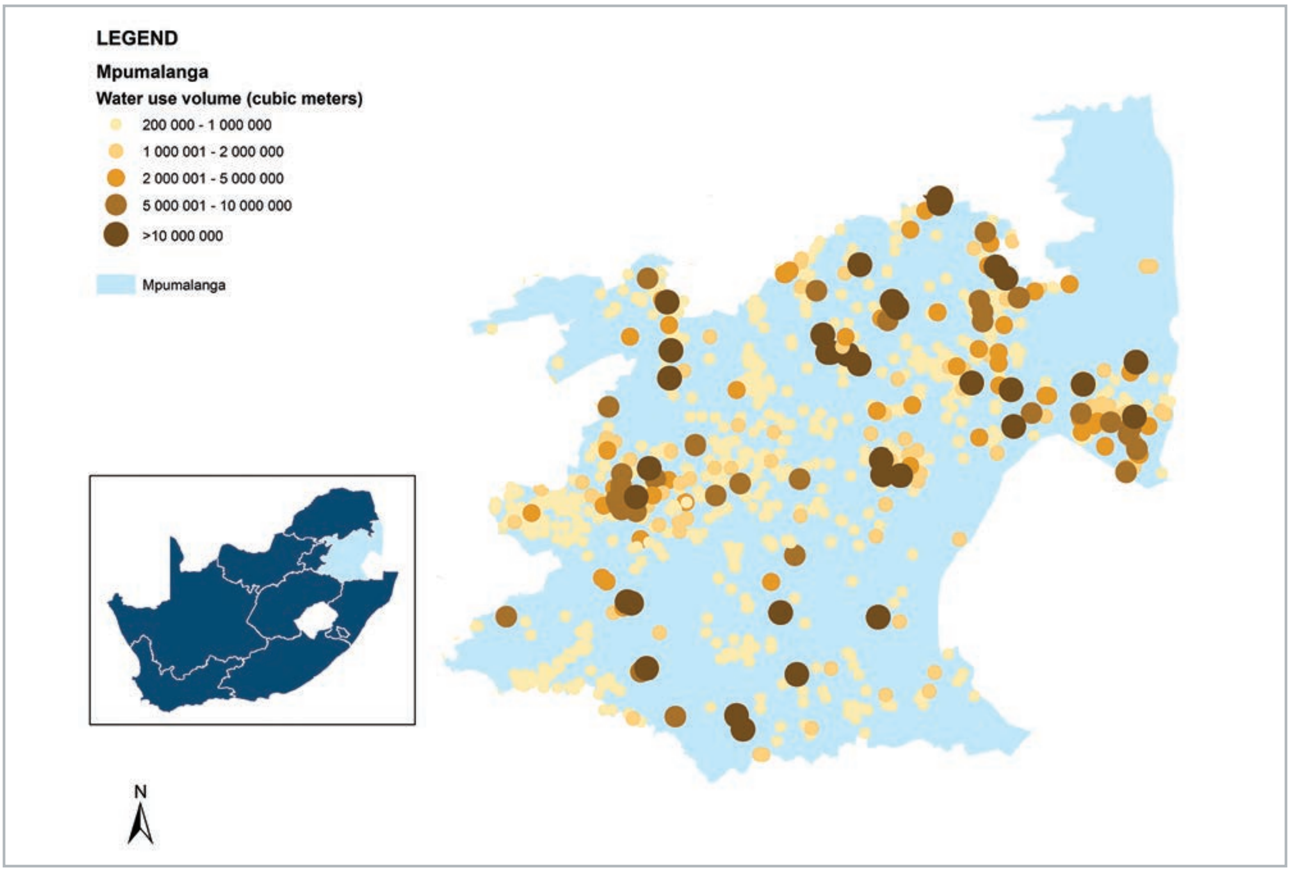


Figure 11: Bulk water use in Mpumulanga

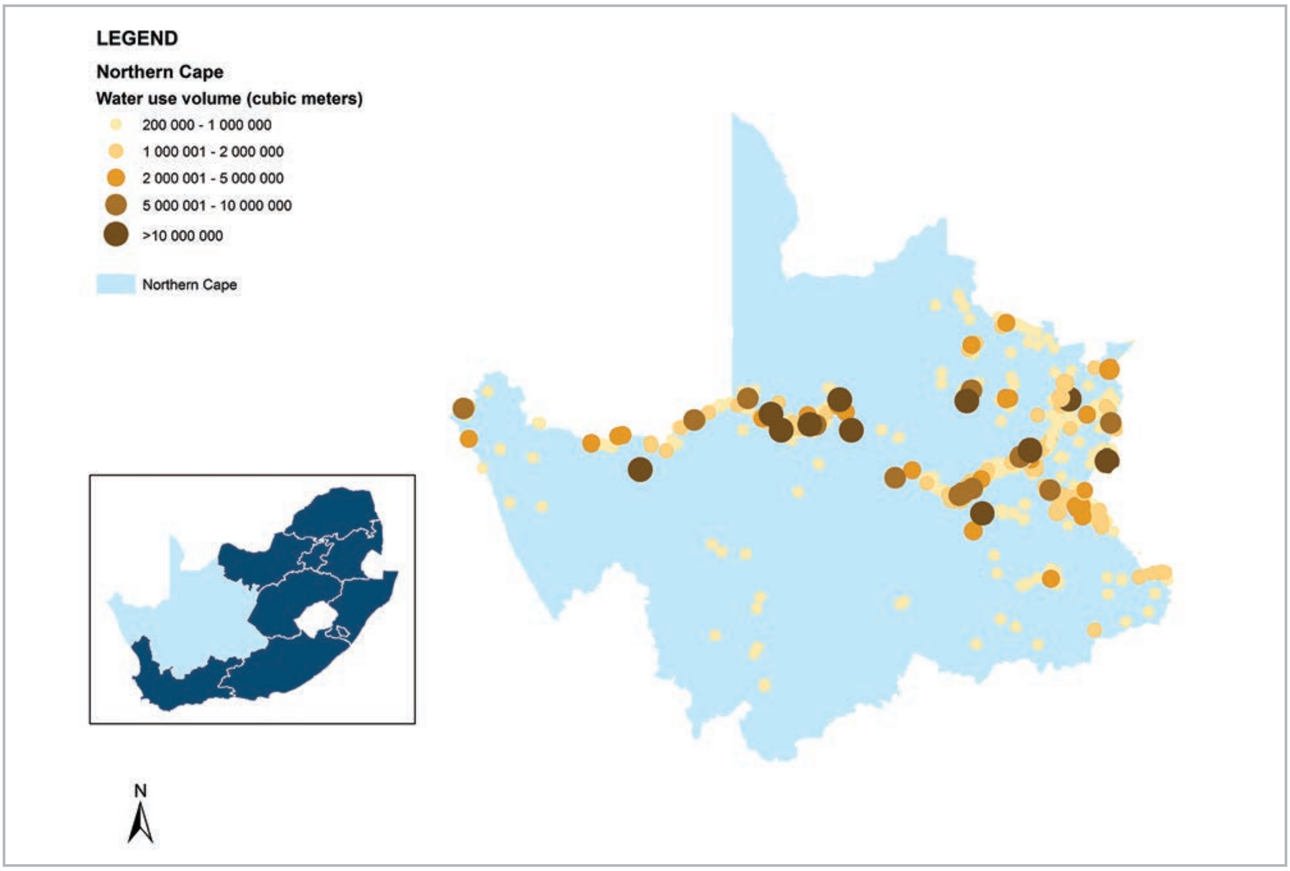


Figure 12: Bulk water use in the Northern Cape

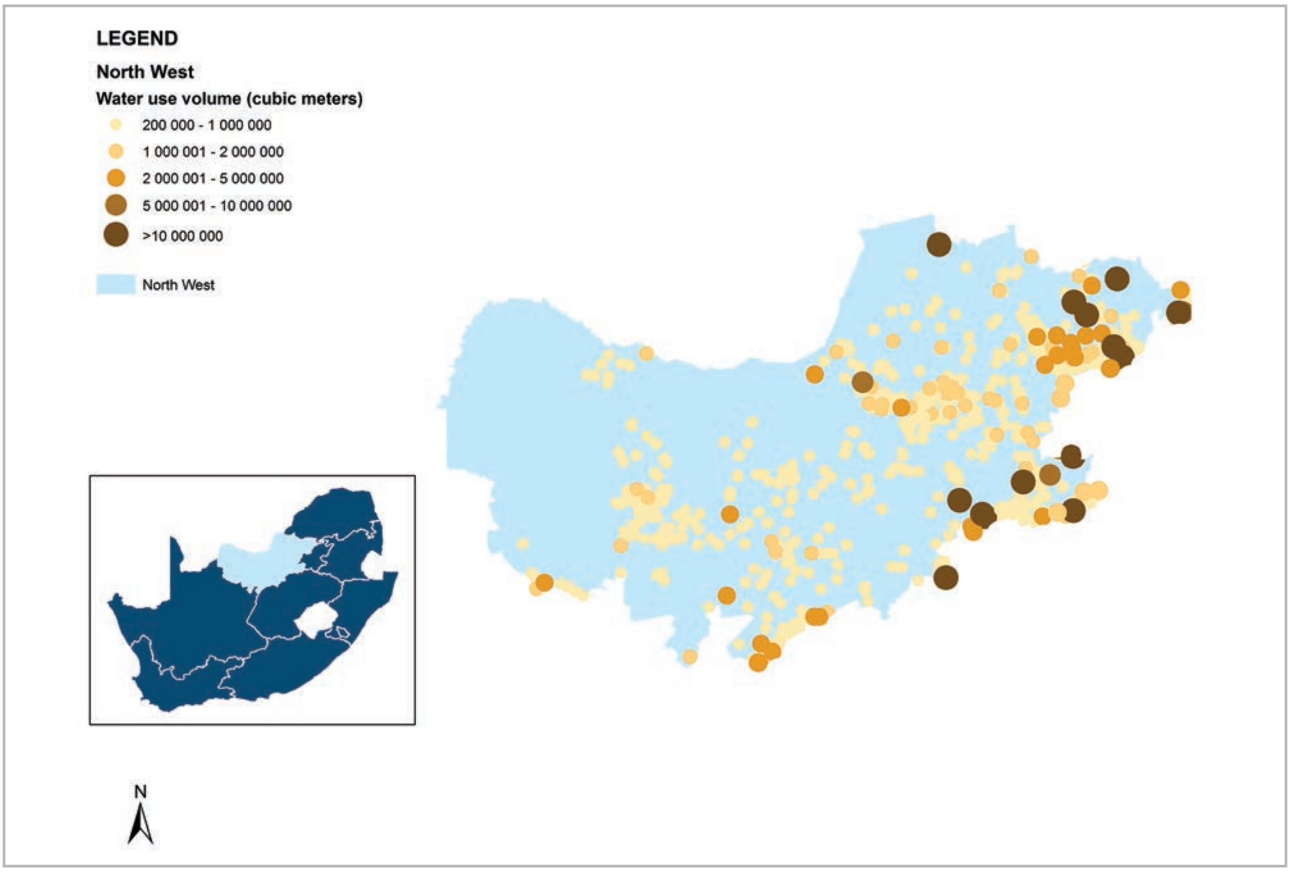


Figure 13: Bulk water use in the North West Province

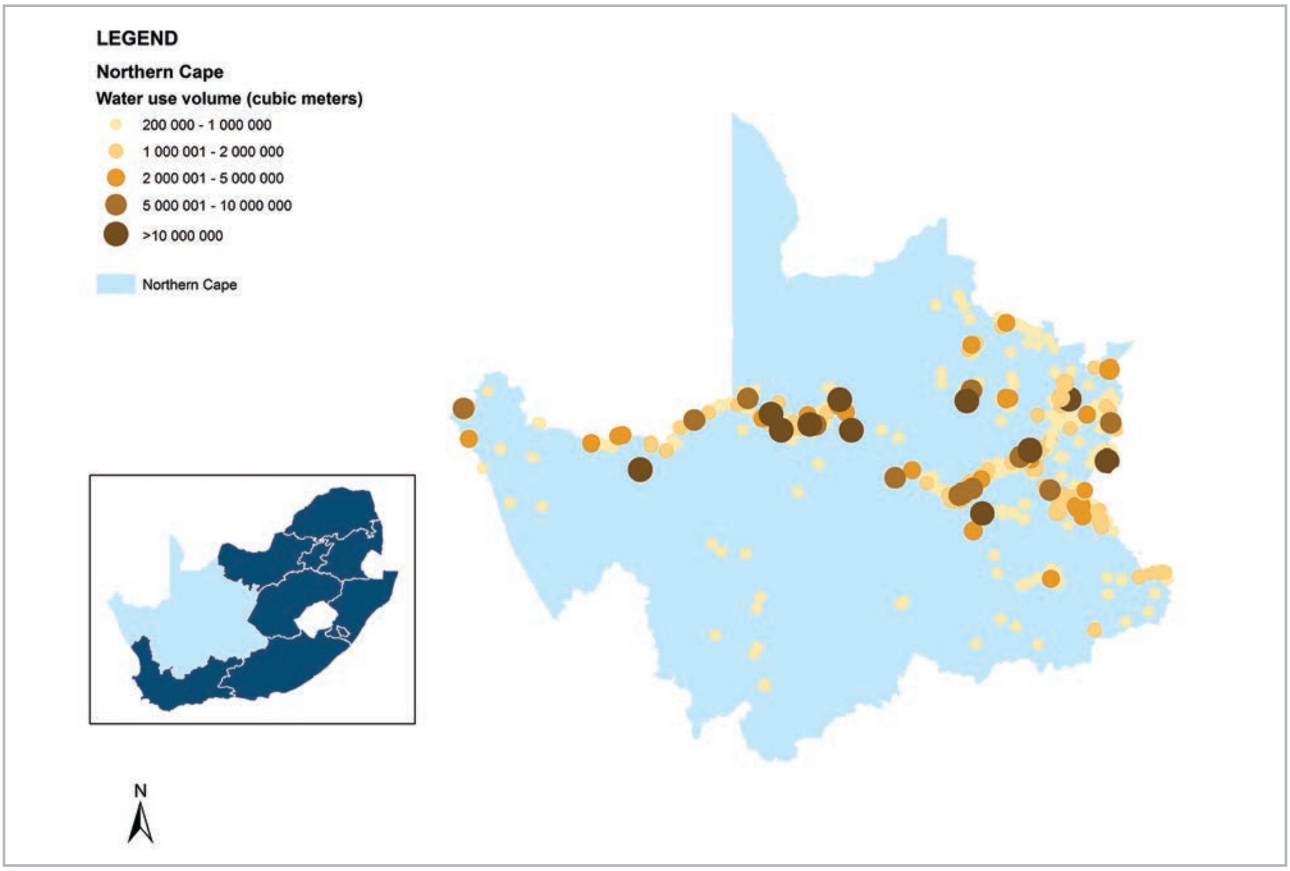


Figure 14: Bulk water use in the Western Cape

9 MAPS: NATIONAL AND PROVINCIAL REGISTERED BULK INDUSTRIAL EFFLUENT DISCHARGE

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.

Figure 15 represents the national effluent discharged from industry. From a national perspective, the highest effluent produced is registered by urban/domestic (sewage treatment works), followed by mining (although mining effluent is recorded in all provinces except the Western Cape).

Figures 16–24 represent provincial effluent discharged from various water use sectors. Gauteng is the highest ranked province in terms of discharging wastewater, followed by Mpumalanga and the Eastern Cape provinces, respectively. Discharging wastewater effluent is 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 registering the lowest effluent volumes included Limpopo and Northern Cape provinces.

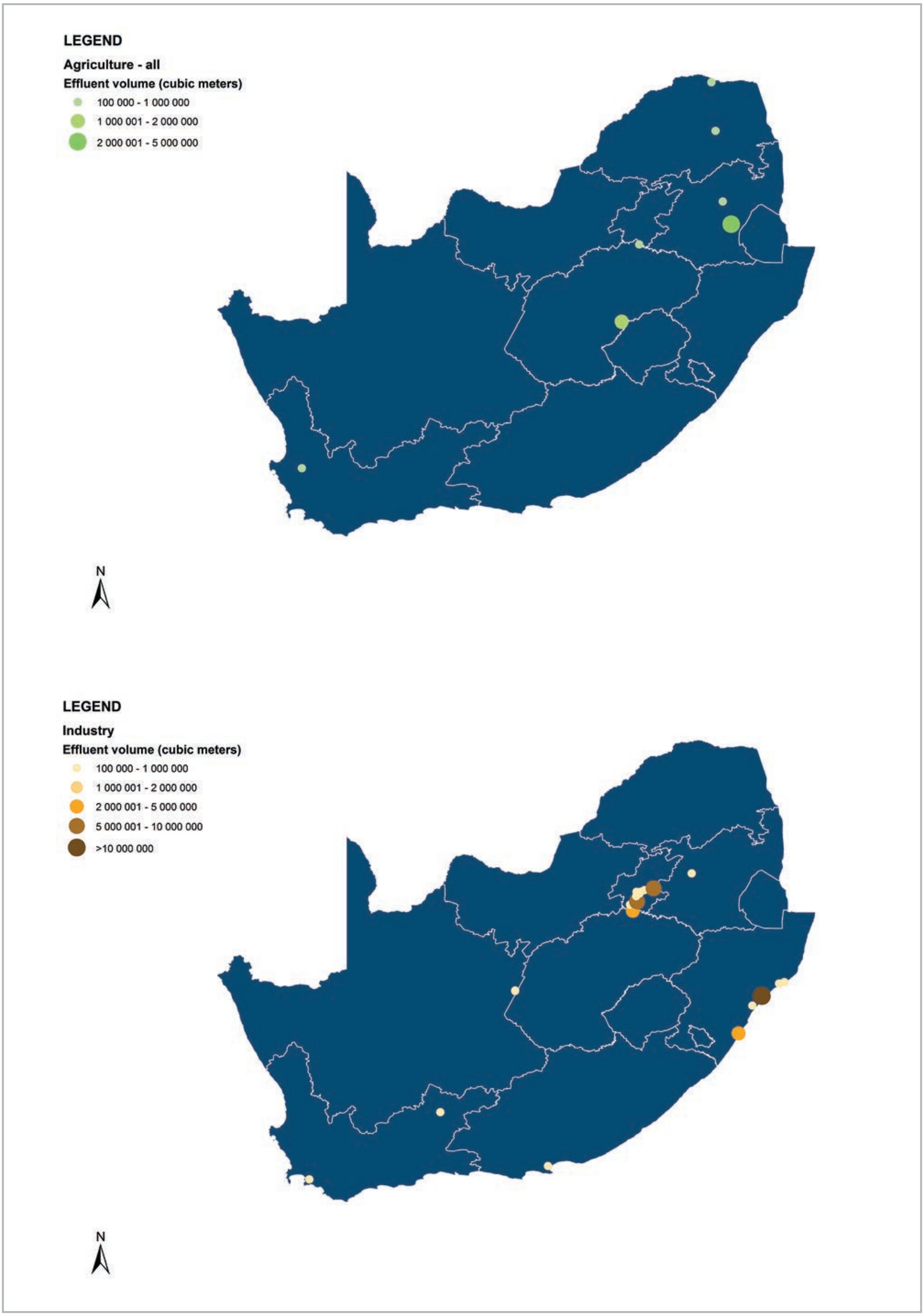
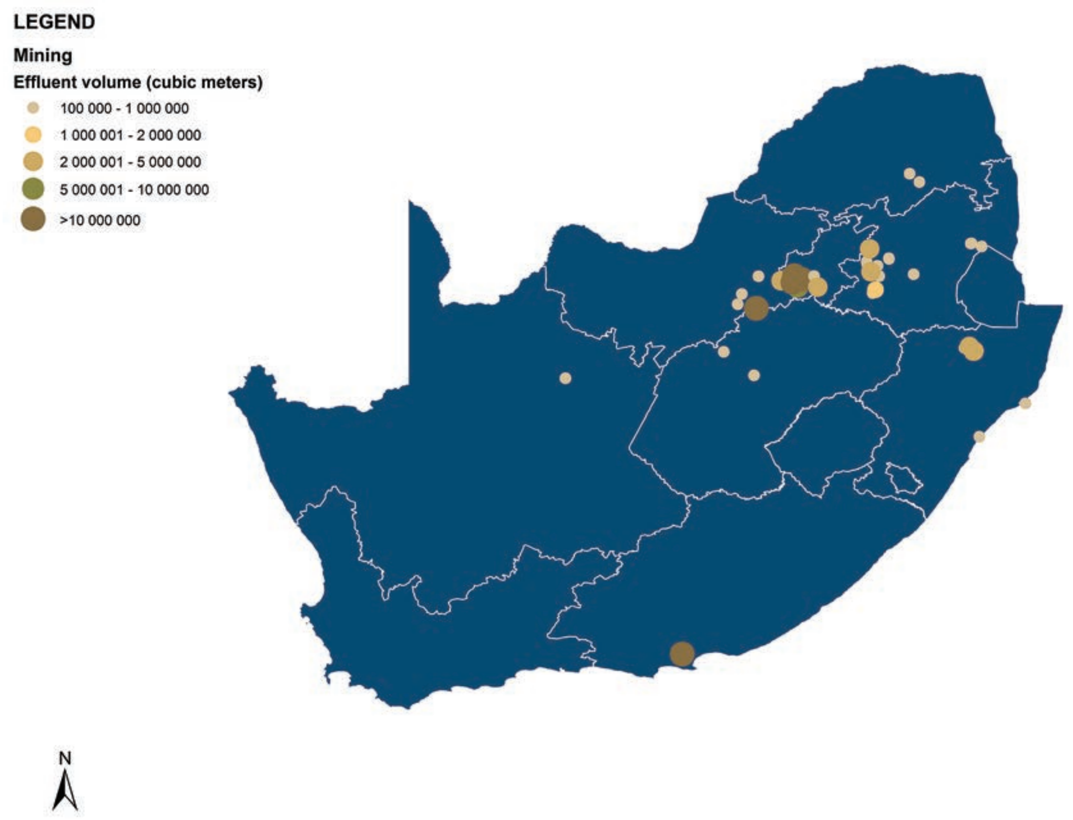


Figure 15: National map of bulk effluent producing industries



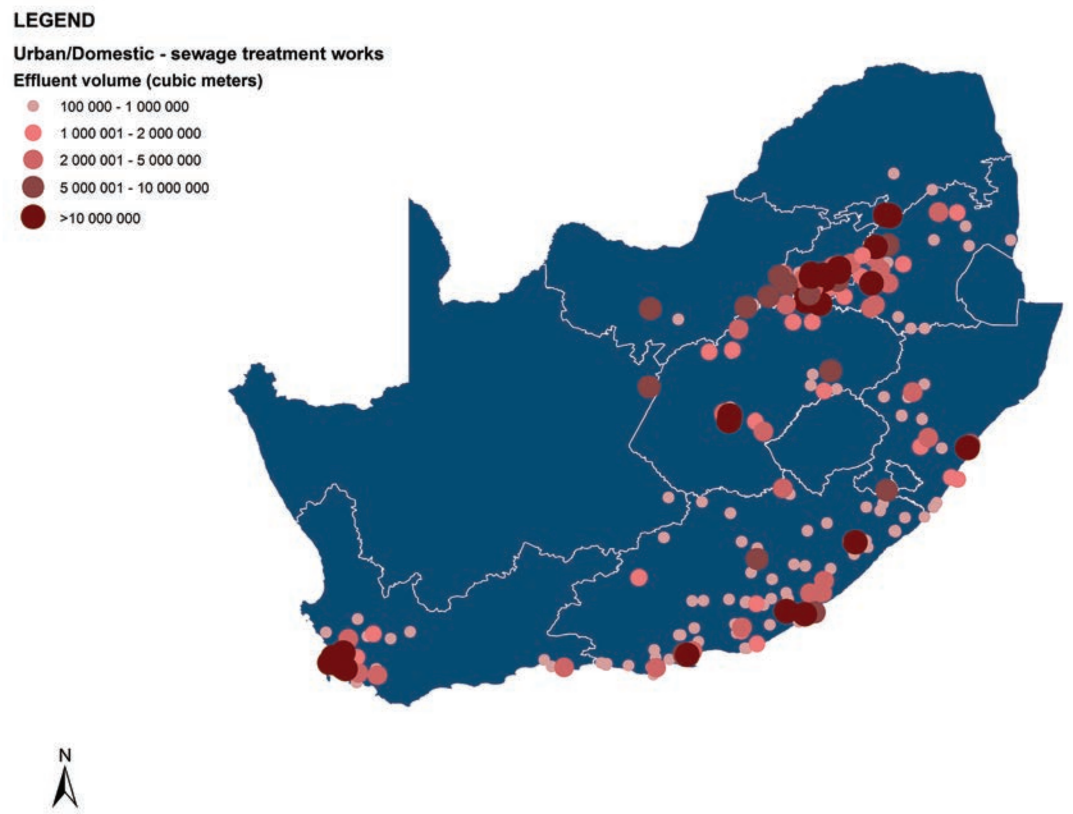


Figure 15: National map of bulk effluent producing industries

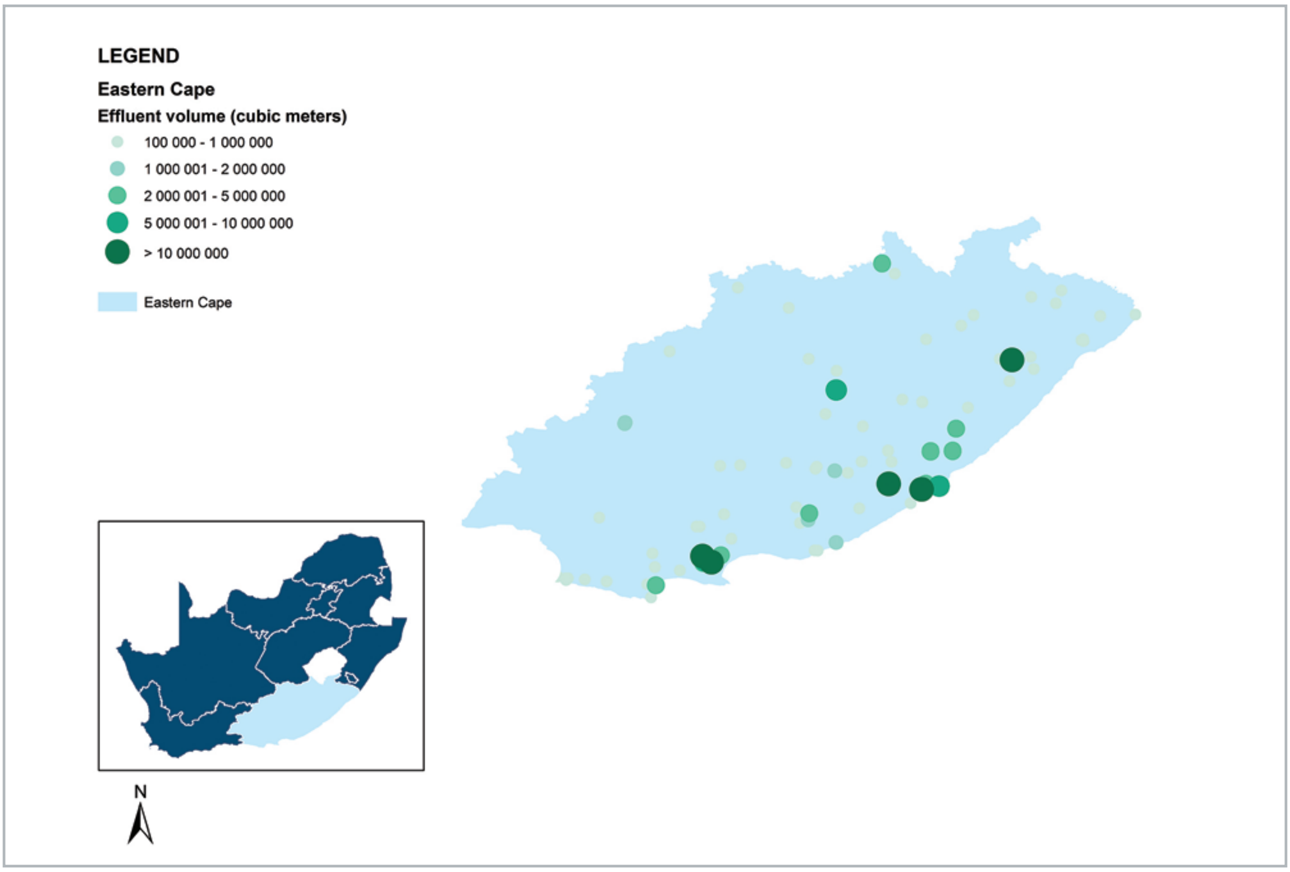


Figure 16: Bulk effluent producing industries in the Eastern Cape

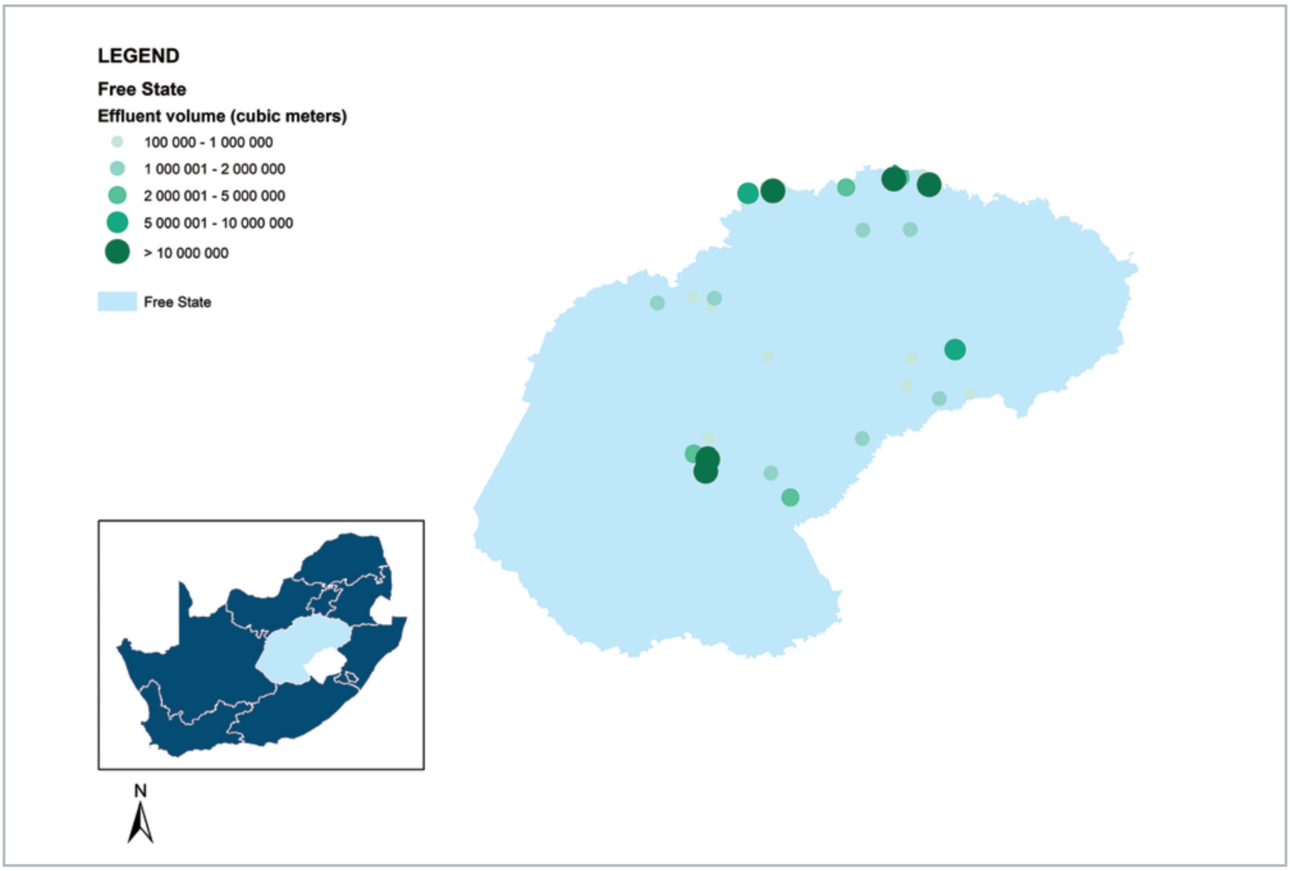


Figure 17: Bulk effluent producing industries in the Free State

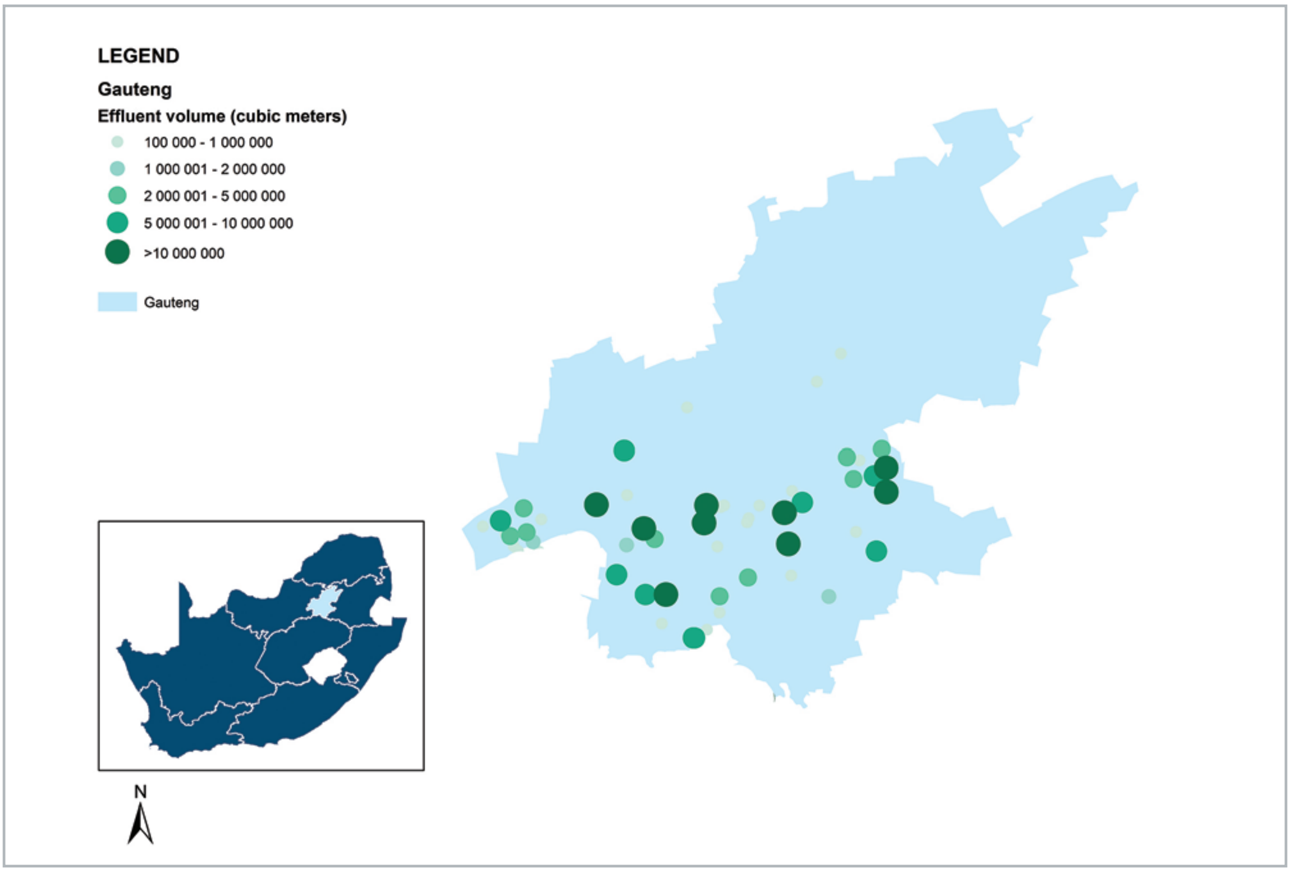


Figure 18: Bulk effluent producing industries in Gauteng

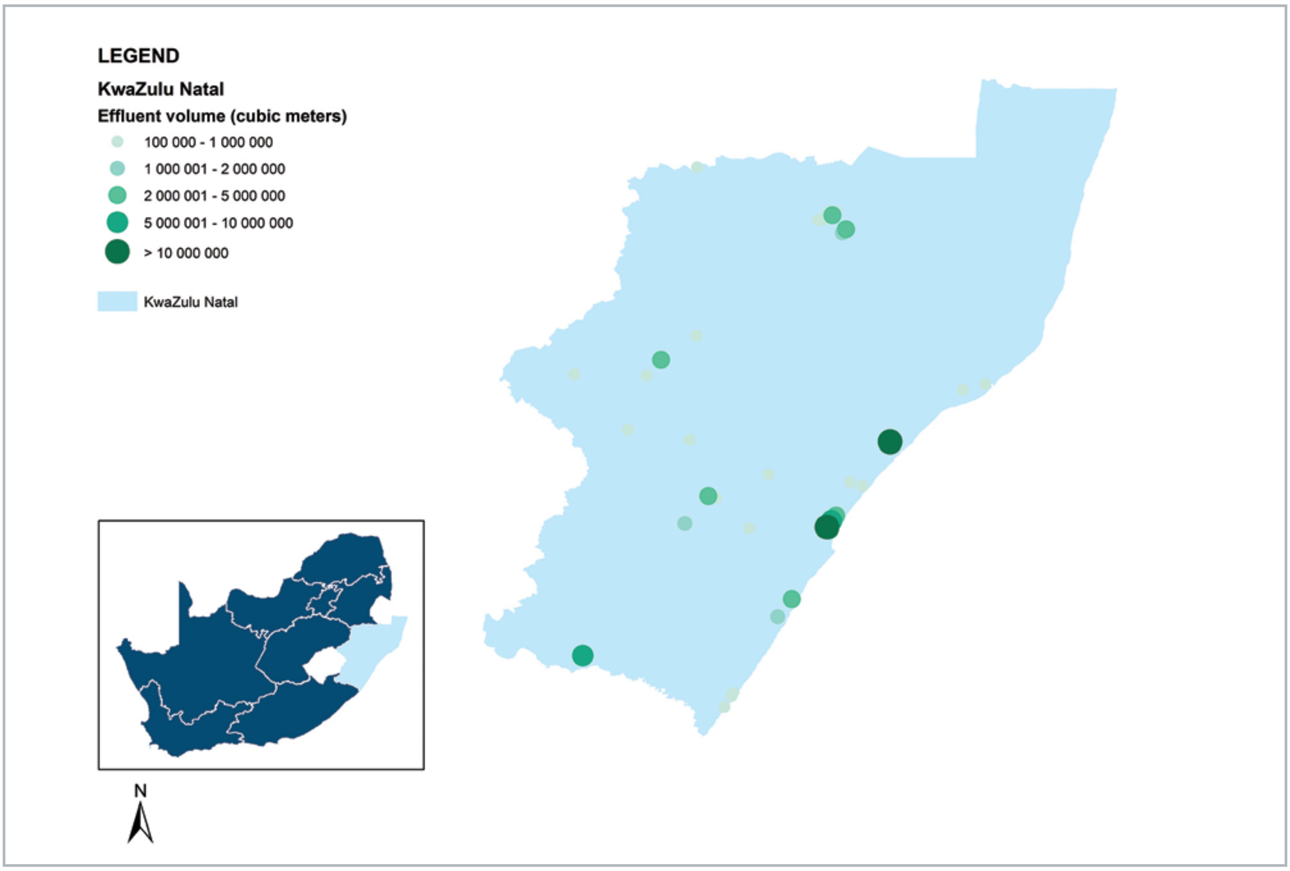


Figure 19: Bulk effluent producing industries in KwaZulu-Natal

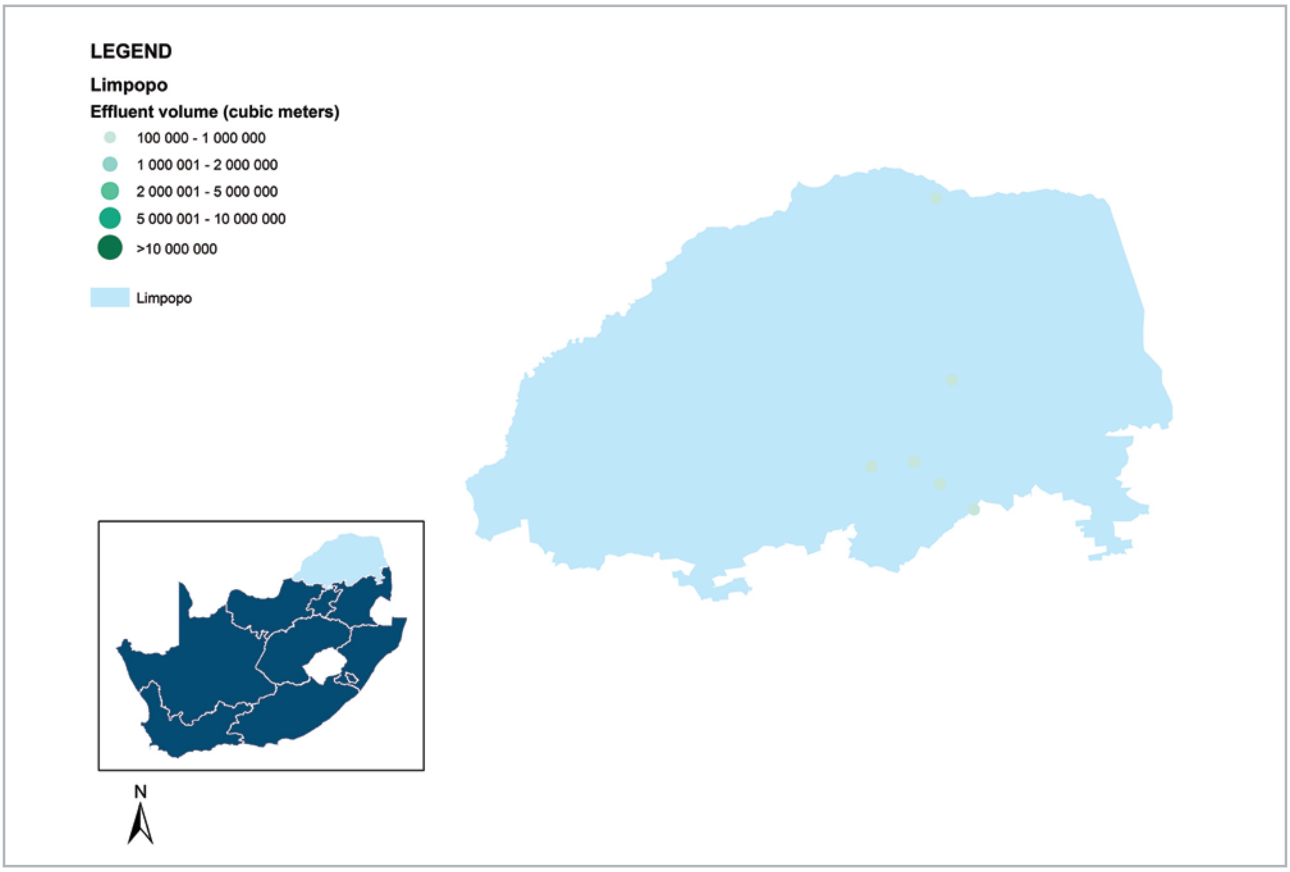


Figure 20: Bulk effluent producing industries in Limpopo

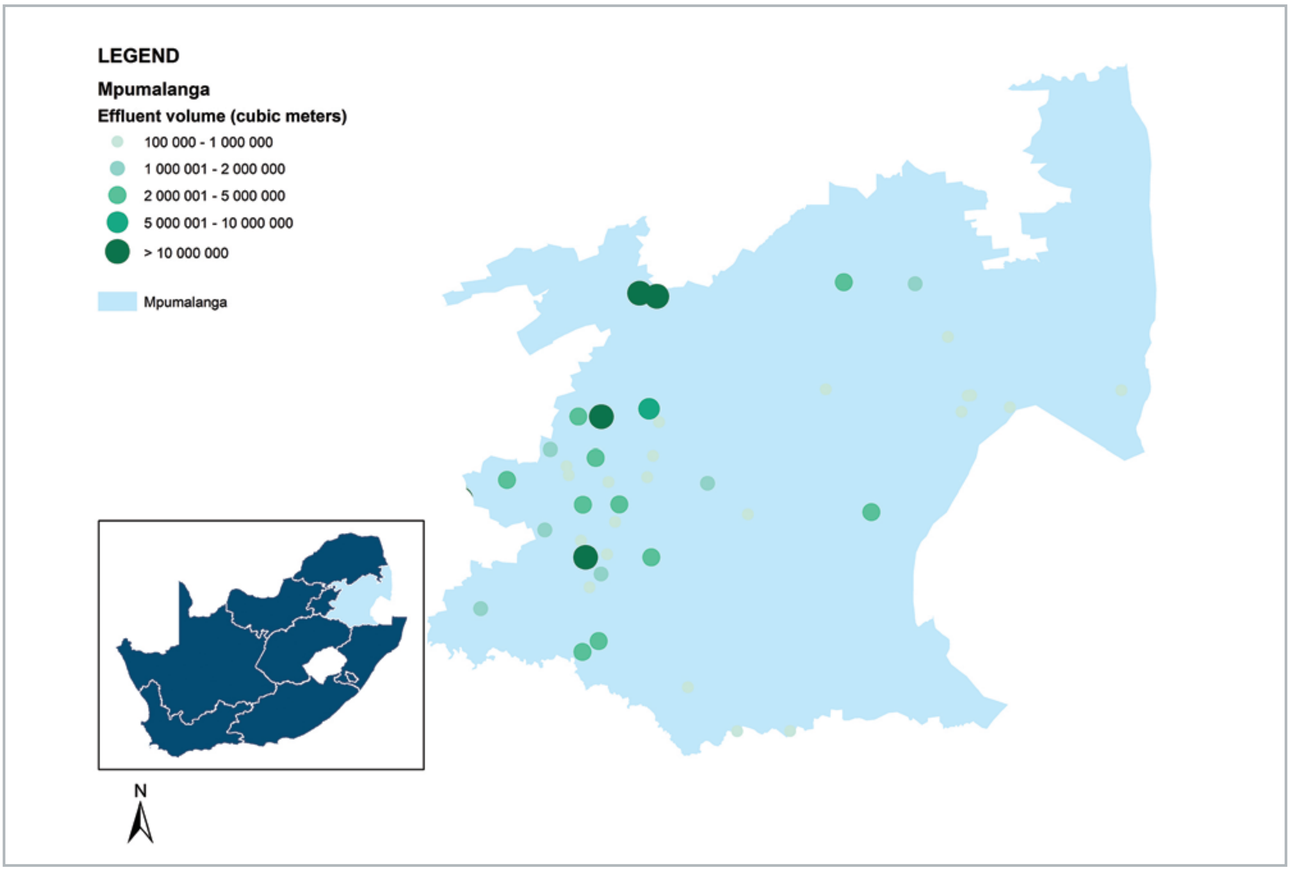


Figure 21: Bulk effluent producing industries in Mpumulanga

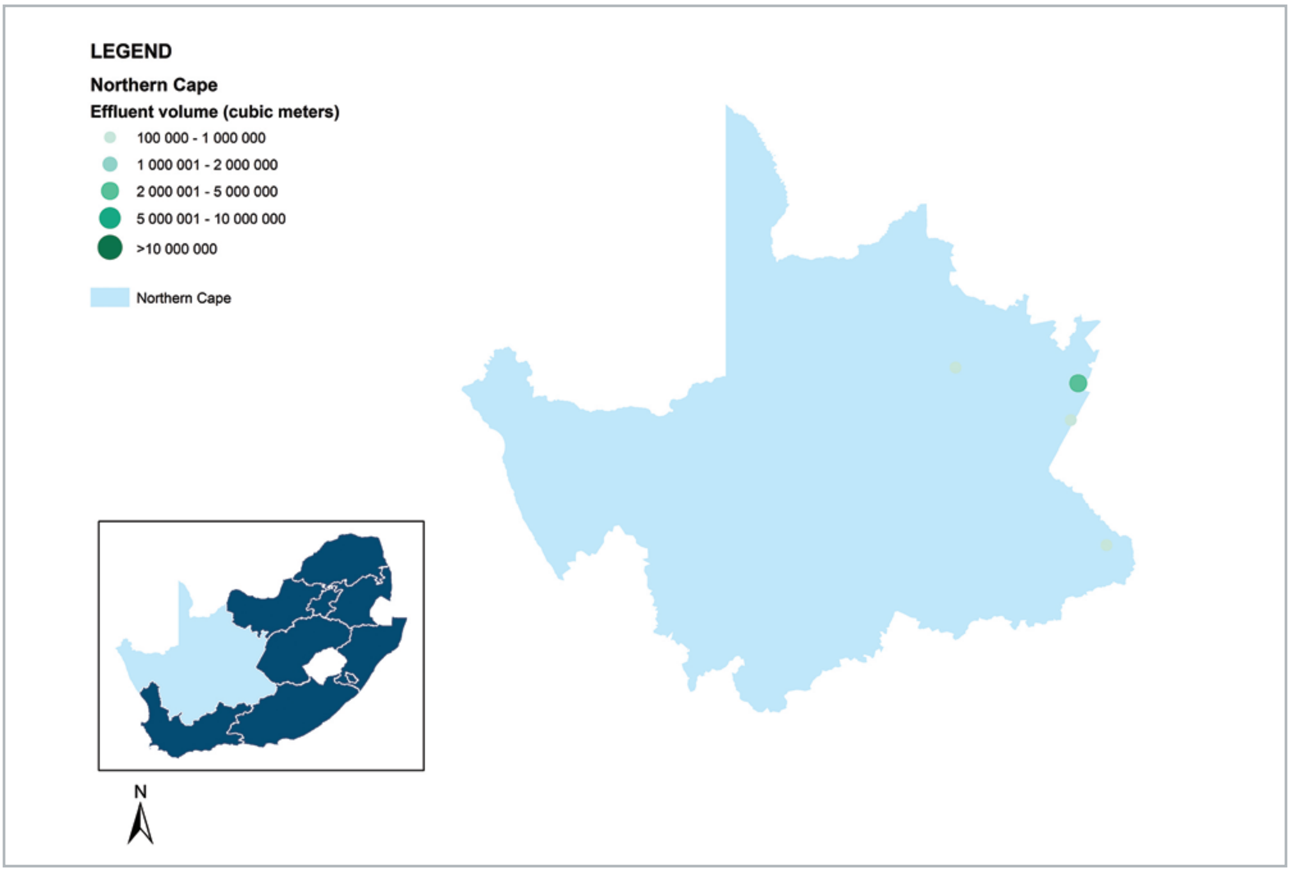


Figure 22: Bulk effluent producing industries in the Northern Cape

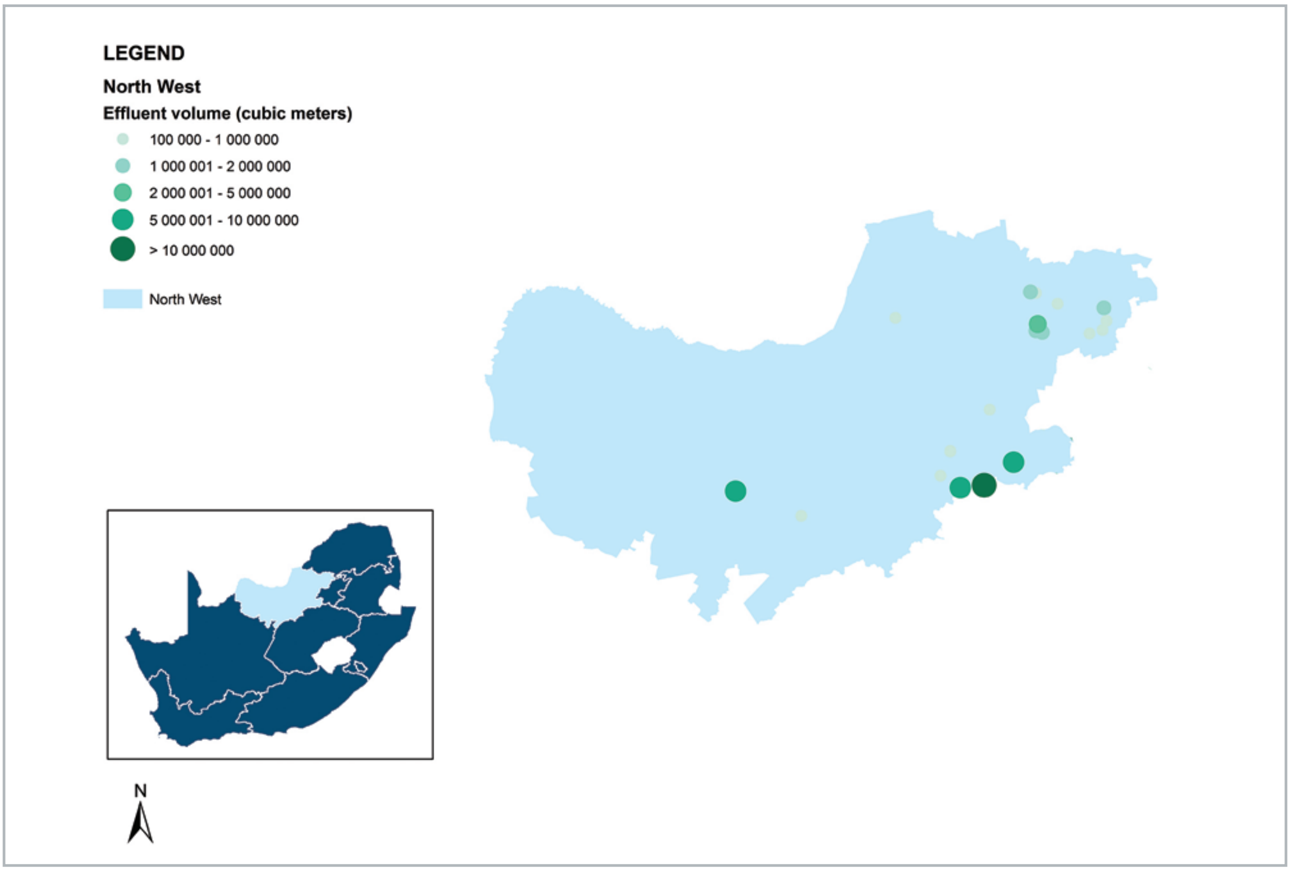


Figure 23: Bulk effluent producing industries in the North West Province

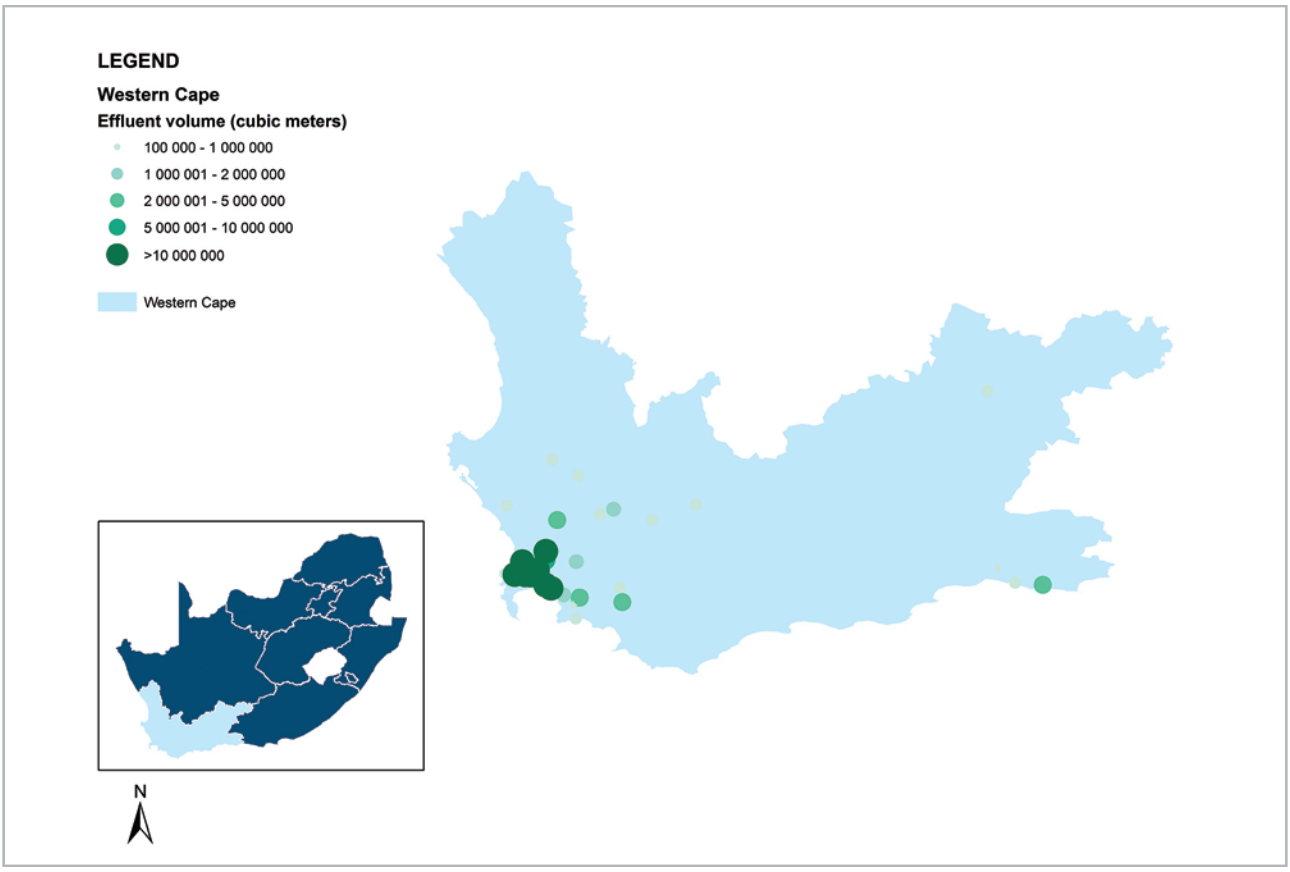


Figure 24: Bulk effluent producing industries in the Western Cape

10 CONCLUDING REMARKS AND RECOMMENDATIONS

This Atlas clearly highlights the urgent need for water reuse to become an integral part of an integrated water management supply approach in South Africa, and there are multiple drivers that necessitate immediate actions for promoting industrial reuse in the country. South Africa has progressive legislation to support the implementation of reuse of wastewater, but these can also be regarded as barriers in implementing reuse projects, as often times 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.

Even though country and municipality specific information on industrial reuse options, water quality and quantity (volumes), are not widely accessible, this Atlas was able to present a "current point in time" reflection which highlights 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 are highlighted per province and at a national level, which provides a good geographical overview of industrial effluent production.

Lastly the authors acknowledge that while this Atlas provides a one dimensional and geographical overview of industrial reuse effluent volumes (based on water use licensed registrations), in order to guide future decision making, it is envisaged that further research that will be conducted by the CSIR and the project team, will lead to the development of a web based electronic decision support system (DSS) that will be made publicly available. This will allow municipalities or specific metropolitan areas to implement more robust and sound decisions with regards to industrial wastewater effluent reuse options across the country. Such a decision support system should allow for fitness of use and bulk scale effluent volumes and quality, as well as a distance calculator in order to match compatible industries or treatment technologies in a specific area. The City of Johannesburg (metro) should for example be able to select a specific area and zoom into the clickable map and have drop down arrows to allow for volume adjustment, water quality criteria and ranges. The DSS could possibly also provide search options for compatible industries within the vicinity of specific water consuming industries, based on costs, fitness for use, available volumes and security of supply.

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Maronel Steyn
Smart Places (CSIR)
msteyn@csir.co.za

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Contact person:
Chavon Walters
cwalters@csir.co.za

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