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Assessment of the Viability of the Reuse of Sedibeng District Municipal Secondary Effluent in Southern Gauteng, South Africa

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Abstract

Population growth, urbanization, water resources pollution, environmental awareness, uneven distribution of water resources and water scarcity have necessitated water reuse especially in arid and semi-arid countries. Influent and effluent data of chemical and biological analyses from four wastewater treatment plants (WWTPs) in the Sedibeng district municipality (SDM) were used to assess the viability of water reuse. Available worldwide water reuse criteria of Water Reclamation Plants (WRPs) for different reuse options were used to characterize the SDM's four WWTPs for potable water, power and steel industrial water reuse. Only WWTP4 does not meet the influent design criteria of the New Goreangab WRP in Windhoek, Namibia of 43 mg/ℓ and the DWAF general limit of discharge of 75 mg/ℓ used by Beaufort West WRP in South Africa for COD. WWTP2 and 4 do not meet the DWAF general limit of 25 mg/ℓ for suspended solids. Some of the water quality parameters of the effluents from these plants were non-compliant to the requirements for reuse in power generation and steel manufacturing. However, the implementation of advance treatment technologies such as membrane or advanced oxidation processes (AOPs) as part of the treatment train in a potential WRP would address the water quality issues. Water reclamation of SDM effluent either through direct (DPR) or indirect potable (IPR) water reuse, power generation and steel manufacturing industry has the potential of reuse in the Southern Gauteng region. The success of the selected option would be depended on cost effectiveness, stakeholder commitment and public acceptance of the reuse strategy.

Keywords

Water Reclamation, Indirect/Direct Potable Reuse, Advanced Treatment, Wastewater Effluent

1. Introduction

The increase in demand of water because of the requirements for human consumption, agriculture, mining and industrial development complicated by inaccurate pre-empting of impacts of climate change makes a search for alternative water sources. In many situations, municipal wastewater effluent would be a feasible alternative water source as it is available throughout the year, and would thus reduce the demand for conventional source water. Additional benefits in agriculture would be for example a decrease in fertilizer cost due to the presence of essential plant nutrients if used as irrigation water. Furthermore, the negative environmental impacts of discharging semi-treated or untreated municipal wastewater would be reduced since the wastewater would require treatment to a specific improved quality as required for the intended use.

Existence or nonexistence of an environmental buffer by default or design differentiates between direct and indirect reuse. This buffer is a water body or aquifer, perceived by the public as natural which can serve to sever the connection between water and its history and based on its attributes removes and/or dilutes contaminants by providing residence time [1] [2] [3] [4]. Worldwide main reuse applications of municipal wastewater are agricultural and urban irrigation, non-potable reuse (e.g. toilet flushing, mining and industrial applications) and rarely for DPR [5]. However, the planned or unplanned IPR can be identified in many countries and is common in semi-arid regions such as South Africa where downstream abstraction occurs after effluent discharge. The dynamics of climate and geology, water availability, population growth and urbanization, industrialization, economic growth and perceptions on wastewater reuse determine the type of wastewater reuse option for an individual country [1] [4].

Countries such as Australia and the United States, where water reuse is established, widespread and has specific guidelines and standards for reuse are benchmarked in this study. These can be emulated by South Africa where existing guidelines used were not developed specifically for water reuse. These are, South African Water Quality guidelines for different sectors, SANS 241:2015 drinking water standards, general and special limits for wastewater discharge which are referenced in this study [6] [7]. A separate section on water reclamation for SANS 241 is proposed by Swartz *et al.* even though the previous SANS 241-1:2015 standard specifies that final drinking water from water reclamation systems shall comply with SANS 241-1:2015 numerical specifications. A further disclaimer is added that in using the limits, account shall be taken of the relatively high risk of microbiological contamination in reuse water [8] [9].

South Africa is a pioneer with institutional memory capacity of potable water reuse, having researched in the 1960s and been part of the plans for the Goreangab WRP in Windhoek [10]. It has already installed and run, since 2011, the Beaufort West WRP designed for 2.1 ML/day to reclaim water that forms 20% of the town's water in a mixing ratio of 1:4 [4] [11] [12]. Industrial wastewater reclamation specifically from treated municipal wastewater is not generally practised in South Africa. Only internal on-site generated wastewater recycling following the zero liquid effluent discharge (ZED) philosophy occurs at certain industrial sites [10] [13] [14]. Few cases of water reuse from treated municipal wastewater are in the pulp and paper (e.g. Durban Mondi and Sappi Enstra Paper Mill) and oil (e.g. Durban Sapref and Sasol Sasolburg) industries as examples [3] [10] [15]. The other two industries in the study area, namely power and steel, with the potential to reuse municipal wastewater are Eskom's Lethabo power station and ArcelorMittal which have also adopted the ZED philosophy in 1987 and 2005 respectively. This has necessitated installation of reverse osmosis water treatment processes for example to meet their recycling water quality requirements [16] [17]. These industries thus provide the opportunity to augment their recycled water with reuse of municipal wastewater.

Irrigation of sports fields, golf courses, parks and other recreational facilities is practiced but on a limited scale. An exception is in the city of Cape Town, where 20ML/day reclaimed from the Potsdam WWTP, is for this agricultural use [10] [18]. Similarly in Polokwane SAB Miller's manufacturing plant treats its wastewater and uses the effluent for irrigation of adjacent apple orchards [19]. A proposal to supply small scale farmers or resource poor agriculture in the Southern Gauteng region with locally treated municipal effluent was rejected previously. This was because of the fear that point source salt loading will find its way back into the Vaal River through difficult to monitor diffuse source from run-off, hence irrigation is not part of the results of this study [20].

The aim of the investigation was to characterize influent and effluent's physical, chemical and microbiological determinants of the four SDM's wastewater treatment plants (WWTPs) for potential of water reclamation and reuse consideration in the area. This was done by comparing these determinants to worldwide water quality criteria and standards of reuse which can determine suitable treatment technology options.

Geographical context

The SDM is part of the strong urban and industrial southern Johannesburg-Vereeniging-Vanderbijlpark complex of the Upper Vaal WMA [21] [22]. Influent and effluent data of four WWTPs in the SDM, three in the Emfuleni local municipality (ELM) and one in the Midvaal local municipality (MLM) was used to assess the viability of water reuse (**Figure 1**). WWTP1 in ELM (26˚34'29.03"S and 27˚49'2.64"E) is the largest WWTP in the region (>100 ML/day), receives part of its sewer inflows from ELM and across its border from south of Johannesburg and MLM [23] [24]. WWTP2 (36 ML/day) in ELM, (26˚41'38.67"S and 27˚45'43.10"E), receives its influent from the Vanderbijlpark area. WWTP1 and 2 discharge their final effluent into the Rietspruit River [25].

WWTP3 (26˚40'20.88"S and 27˚53'43.96"E) in ELM, treats effluent from Vereeniging, Sharpeville, Kwaggastroom and effluent from MLM's Risiville, Duncanville Ext. 3, Mackay and Uitvlugt [23]. WWTP4 in MLM (26˚34'58.60"S and 27˚58'24.62"E) exceeding over design capacity 8 ML/day producing 16.8 ML/day dry weather flow, discharges mainly Meyerton and Henley-on-Klip treated effluent into the Klip River [26] [27] [28].

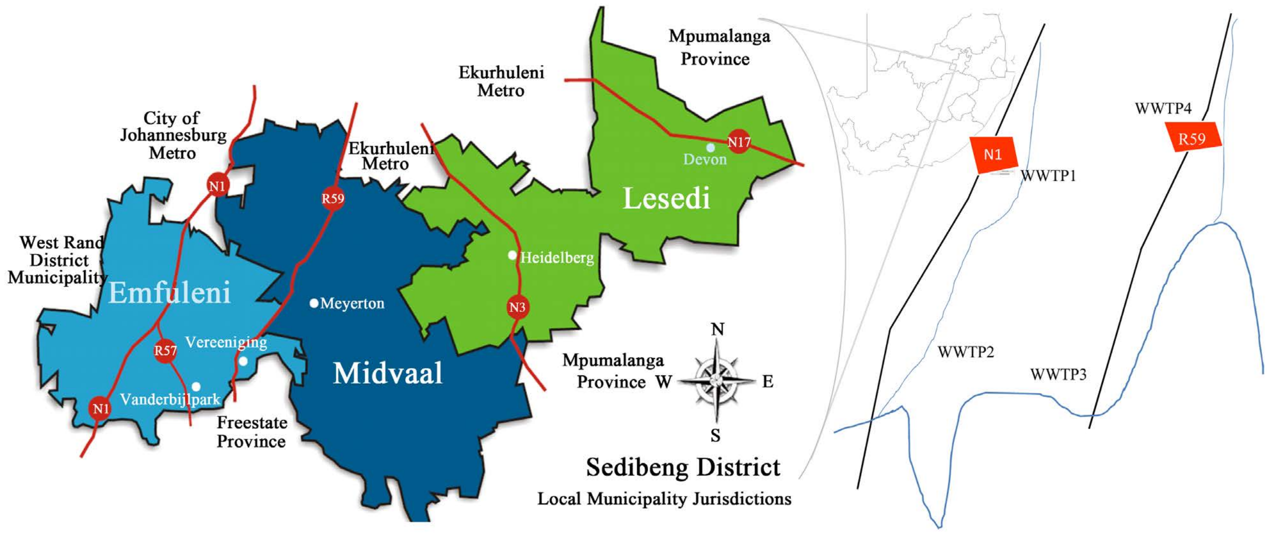

Figure 1. Geographical context of study area (adapted from [27]).

2. Materials and Methods

Sampling was conducted every second week from January 2012 to December 2013 at the four SDM's WWTPs to determine the physical, chemical and microbiological parameters. The specific parameters include chemical oxygen demand (COD), total suspended solids (TSS), nutrients, trace metals, conductivity, total dissolved solids (TDS), alkalinity, chlorides, sulphates, pH, *E. coli* and faecal coliforms. The data was analyzed to test the viability of different reuse options and technology required based on comparison with existing international and national water quality standards and criteria.

3. Results and Discussion

Worldwide COD is not used as a primary aggregate parameter for WWTPs, but in South Africa and neighbouring Namibia it is used extensively [9] [29]. Secondary treatment effluent from the Gammams municipal WWTP in Windhoek, Namibia that supplies the Goreangab WRP has COD concentrations of approximately 60 mg/ℓ. However, the secondary effluent is discharged into maturation ponds where the COD is reduced to 30 - 40 mg/ℓ after 2 - 4 days to meet the design capacity of 43 mg/ℓ of the Goreangab WRP [30] [31]. The Beaufort West WRP for potable drinking water purposes COD maximum concentration requirement from the WWTP is the DWAF general limit of 75 mg/ℓ which is less stringent compared to the Goreangab WRP [32] [33]. The COD averages for the four WWTPs during the study period were 19.7, 21.3, 26.9 and 130.8 mg/ℓ respectively for WWTP1, WWTP2, WWTP3 and WWTP4 (**Table 1**). Only WWTP4 did not meet the COD design capacity of the Goreangab WRP and the DWAF because of capacity constrains (**Figure 2**, [26]).

Typical suspended solids tolerable concentration required for the petrochemical, textiles, paper and pulp industries processes water are between <10 and <30 mg/ℓ for WRP influent depending on specific use and <25 mg/ℓ for

Table 1. Water quality criteria compared with SDM's WWTPs effluent quality.

Worldwide standard parameters	Sedibeng district WWTPs averages				Potable water reuse				Industrial reuse	
	WWTP1	WWTP2	WWTP3	WWTP4	SANS 241: 2015$	Beaufort west 2^0 effluent+	Namibia final++	DWAF general limit#	*Eskom cooling	Bluescope 2^0 effluent***
COD (mg/ℓ)	19.7	21.3	26.9	130.8	-	47	15	75	75	-
TSS (mg/ℓ)	0.6	29.7	3.0	28.2	-	20		25	-	1
NH_4^+ (mg/ℓ)	0.5	1.0	3.2	25	1.5	4.9	0.1	3	15	1
NO_3^- (mg/ℓ)	3.7	4.6	3.5	2.6	11	16	10	15	15	4
PO_4^{2-} (mg/ℓ)	0.3	1.0	0.9	4.1	-	5.1		10	-	1
SO_4^{2-} (mg/ℓ)	37.9	-	55.6	33.3	500	-	200	-	100	1
Cl^- (mg/ℓ)	30.2	-	75	65.2	300	-	250	-	180	20
pH	7.07	7.06	7.11	7.6	5 - 9.7	7.5	-	5.5-9.5	9	7.5
Conductivity (mS/m)	40.8	63	60.4	92.8	170	122	-	150	400	-
Alkalinity (mg/ℓ as $CaCO_3$)	182	241.6	293	419.3	-	-	-	-	150	-
Faecal coliforms (CFU/100 mℓ)	4776	15979	1443		0	-	0	1000	10^6	1
E. coli (MPN/100 mℓ)	5259	12783	1589	1.5×10^6	0	-	0	-	-	-

NOTES: $[8] (+[33], 2^0 = Secondary effluent from WWTP); ++[34]; #[32]; *[35]; [36]; ***[37].

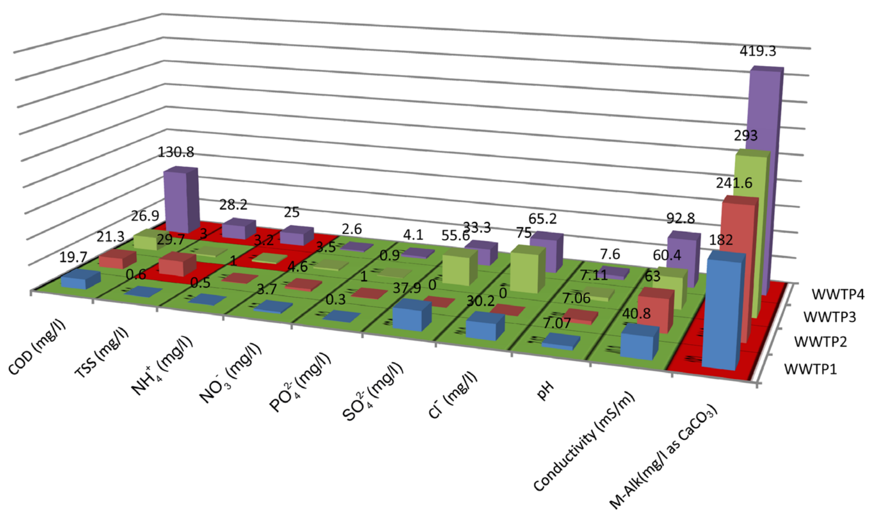

Figure 2. SDM's WWTPs water quality compliance to standards and criteria.

DWAF general limit [32] [38] [39]. The suspended solids in the SDM WWTPs effluent varied considerably with WWTP2 and WWTP4 having the highest values non-compliant with DWAF general limit (**Figure 2**) and WWTP1 and WWTP3 the lowest (**Table 1**). WWTP2 had the highest average suspended solids value of 29.7 mg/ℓ and this was attributed to operational failure due to heavy rainfall, inconsistent recycling and scum draw-off system [40].

Ammonia concentration in the effluent, which is expected to decrease after the activated sludge process, is at 0.5, 1.0, 3.2 and 25 mg/ℓ for WWTP1, WWTP2, WWTP3 and WWTP4 respectively. The latter two WWTPs do not comply to the <1.5 mg/ℓ using the SANS 241:2015 class 1 drinking water standard and the DWAF general limit of 3 mg/ℓ (**Figure 2**) [8] [32]. Reclaimed water that has not been nitrified or denitrified can contain ammonia-nitrogen concentrations of >20 mg/ℓ which is the case with WWTP4 and can exert a nitrogenous oxygen demand of up to 100 mg/ℓ [3]. The averages for nitrate were 3.7, 4.6, 3.5 and 2.6 mg/ℓ for WWTP1, WWTP2, WWTP3 and WWTP4 respectively (**Table 1**). WWTP2 has the highest nitrate concentration possibly due to operational failures which lowers the sludge age even though it complies with the SANS 241 standard and DWAF general limit of 11 and 15 mg/ℓ respectively [8] [32] [41].

In domestic wastewater, ions contributing to salinity, caused by TDS, include cationic species such as sodium, calcium, magnesium, potassium and anionic species such as bicarbonate, carbonate, chloride, fluoride and sulphate [42]. Chloride and sulphate concentrations, highest for WWTP3 at 75 and 55 mg/ℓ respectively (**Table 1**) for the study, may affect the taste of water at 250 mg/ℓ depending on associate cations. It is important to note that the WHO gives no health based guideline value for drinking water even though at higher concentration laxative effects might occur [43]. However, SANS 241 Drinking Water Standard divides acute health and aesthetic effects for sulphates at 250 and 500 mg/ℓ respectively [8] [43]. High alkalinity in cooling and other industrial systems provide carbonate and bicarbonate ions that can lead to scaling in the presence of calcium ions. Alkalinity of <20 mg/ℓ as $CaCO_3$ for recycled cooling water and <500 mg/ℓ as $CaCO_3$ for once through water, 125 mg/ℓ and 500 mg/ℓ for chemical and petroleum products respectively is recommended [36]. Eskom's cooling towers, that recycle water, has an allowable maximum alkalinity of 180 mg/ℓ which none of the Sedibeng WWTPs effluents meet [35].

The faecal coliform measurement for WWTP1, WWTP2 and WWTP3 with the Log_{10} values at approximately 1.4, 3.5 and 2 respectively are similar to *E. coli* measurement values (**Figure 3**). Since *E. coli* which is a part of faecal coliforms

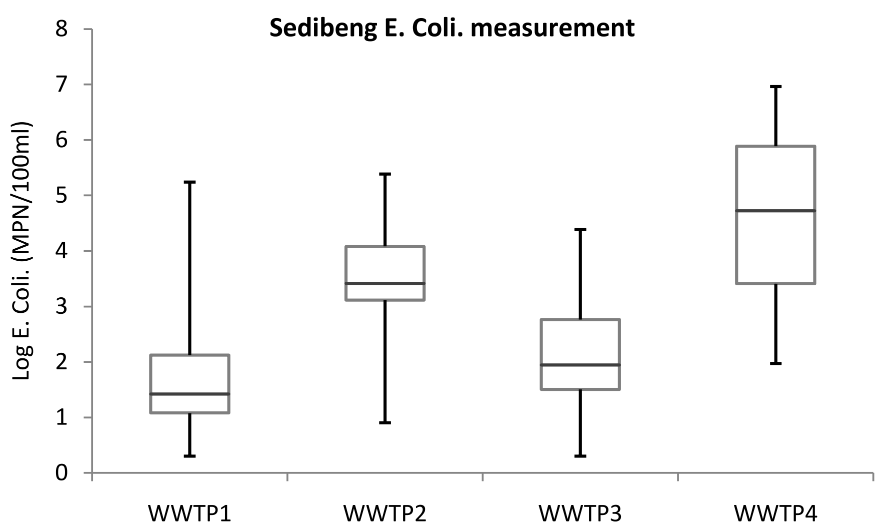

Figure 3. The *E. coli* measurement of the four Sedibeng WWTPs.

dominates, it can be concluded that the effluent is predominantly of a domestic source or human faecal pollution [28] [44]. A similar conclusion can be derived for WWTP4 which had the highest *E. coli* values. Exceeding capacity resulting in limited sludge retention times and operational non-availability of tertiary chlorine dosing have been highlighted as a reason for faecal coliform non-conformance of effluents from WWTP1, WWTP2 and WWTP3 [40].

Reclaimed water with a high microbiological content can harm workers and affect processes by bio-corrosion and bio-fouling [39]. The recommended secondary effluent microbiological quality for faecal coliforms is $<1 \times 10^6$ CFU/100 mℓ for the Australian Eraring power plant, which mainly uses reclaimed water for cooling systems. The faecal coliform mean values for WWTP1, WWTP2 and WWTP3 were 4776, 15,979 and 1443 CFU/100 mℓ respectively. All of these comply with the 1×10^6 CFU/100 mℓ Australian maximum even though there is non-compliance with the 1000 CFU/100 mℓ DWAF general limit [32] [45]. Faecal coliforms were not measured for WWTP4 and *E. coli* mean value for this plant was over the 1×10^6 limit at 1.4×10^6 CFU/100 mℓ since they are similar to the former (**Figure 4**; **Table 1**).

The results for SDM's four WWTPs show water quality determinants mainly complying with the design criteria for further advanced treatment of effluent destined for water reclamation and reuse. This effluent meets the Namibian Goreangab and Beaufort West WRP influent design criteria for DPR in most aggregate, nutrient and ionic parameters except microbiological parameters. Advanced treatment of this effluent to improve microbiological quality would make it suitable for indirect potable reuse (IPR) with blending, industrial cooling, heat exchange and dust suppression.

Wastewater can be effectively treated to any desired standard but the feasibility of different treatment trains is limited by the cost of the technology, nature of influent wastewater and desired quality for intended use [6]. Out of the 24 operational reclamation plants listed by [4] for potable reuse, after secondary treat-

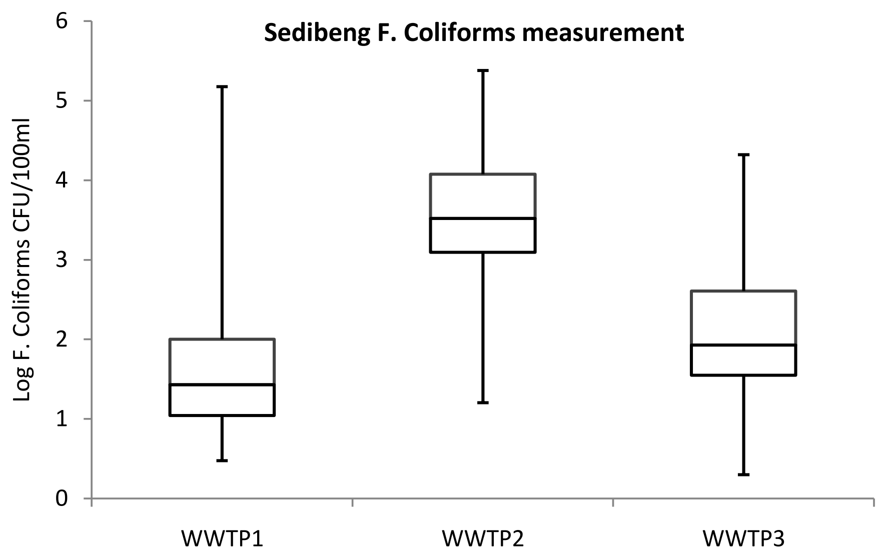

Figure 4. The *E. coli* measurement of the four Sedibeng WWTPs.

ment, six follow the micro/ultrafiltration MF/UF, reverse osmosis (RO) and ultraviolet (UV) configuration and five follow the MF/UF, RO and UV/AOP with or without chlorination at the end depending on application [4]. Over the 50 years of wastewater reclamation in the United States there has been a shift from the reliance on lime clarification and activated carbon adsorption of contaminants to membrane filtration and advanced oxidation [2].

There are different underlying philosophies to choice of treatment technology which are based on cost, water quality, risks and intended use among others. The multi-barrier safety approach is the preferred strategy applied by the Windhoek, Namibia's Goreangab WRP, Beaufort West WRP, South Africa and Singapore's four WRPs [12] [34] [46] [47]. The Goreangab treatment works considers three types of barriers in its philosophy of multi-barrier approach namely 1) non-treatment (e.g. diversion of industrial effluent and blending), 2) treatment and 3) operational barriers [29] [37]. Singapore uses an eight multi-barrier safety approach from source to tap for water reclamation with barrier aspects such as enforcement, water quality monitoring, plant design, operation and maintenance. The multi-barrier approaches applied by the Goreangab and the Singapore WRPs are viable options to be adopted when considering WWTP effluent reuse for the Southern Gauteng region.

Reuse options for South Gauteng

Reuse options that could be considered in the South Gauteng region would be linked to potable water production, power generation, chemical industry and steel production. These are, Rand Water the bulk water utility with a projected demand of approximately 1700 million m^3 per annumup to 2030, Eskom's Lethabo power station, Sasol the petrochemical company and the large steel industry Arcelor Mittal. Eskom's 2008 projected water requirements for the Lethabo power station was on average at 48.7 million m^3 per annum and Arcelor Mittal to reduce its water use from 17.4 million m^3/annum to 16.6 million m^3/annum up to 2030 [48]. These industries abstract some or all of their water from the Vaal Dam and water reuse from return flows and the SDM effluent can reduce this demand. For these water intensive industrial users secondary effluent reuse could include cooling and heat exchange processes among others after advance treatment.

Centralized or regional wastewater collection WRPs are used extensively in urbanized or developed areas and will be well suited when there is no suitable IPR or ground water recharge system such as in the study area [42]. This would also improve the performance of the individual SDM's WWTPs as improvement and constant monitoring would be required for their individual effluent inputs. This is because meeting discharge standards is critical for integration of water reuse in South Africa water supply [49].

Potable reuse

Rand Water the bulk potable water utility in the area could use the WRP water to add to its capacity either by blending directly at its head of works or with the Vaal Dam water or alternatively with the drinking water treatment residue

DWTR (Figure 5). Its source water is described as low electrolytic averaging 20 mS/m and turbid over 100 NTU maximum compared to high electrolytic averaging 92.8 mS/m for WWTP4 and low turbidity and suspended solids SDM's WWTPs (Table 1 and Table 2; [50]). Alternatively the bulk water utility can build and own a separate WRP and use some of its distribution capacity extending trans-provincial borders to sell reclaimed water at a reduced tariff compared to potable water to low quality users. The Vaal Barrage reservoir for IPR could only be used if point source discharges improve their quality and an increase in monitoring to include water reuse parameters of concern is implemented.

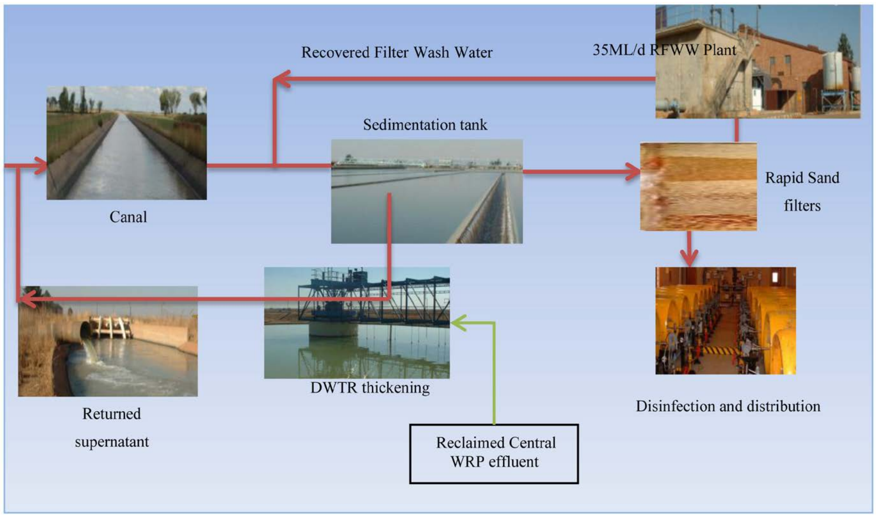

Figure 5. Rand water DWTR and potential potable reuse (Adapted from [51]).

Table 2. Rand water's stations five years bi-weekly average raw water quality.

	Vereeniging source water (A18)						Zuikerbosch source water (VD and Canal)					
	Mean	Median	Mode	Min	Max	*SD*	Mean	Median	Mode	Min	Max	*SD*
COD (mg/ℓ)	15	13	11	10	36	4.2	15	15	12	10	32	3.9
DOC (mg/ℓ)	5.8	5.5	6.0	3.6	10	1.27	5.7	5.7	5.7	3	8.8	1.3
Turbidity (NTU)	69	73	92	25	110	21.3	61	64	71	15	100	20.5
TOC (mg/ℓ)	6.4	6.2	6.5	2	10	1.64	6.0	6.0	5.1	2.2	19	2.3
NH_4^+ (mg/ℓ)	-	-	-	-	-	-	-	-	-	-	-	-
NO_3^- (mg/ℓ)	0.42	0.39	0.43	0.05	2.6	0.35	0.40	0.38	0.38	0.1	1.6	0.2
PO_4^{2-} (mg/ℓ)	-	-	-	-	-	-	-	-	-	-		
pH	7.58	7.63	7.78	6.43	8.86	0.54	7.72	7.85	8.06	6.4	8.8	0.5
Conductivity (mS/m)	20	19	18	10	30	2.9	20	19	18	9.9	50	4.5
TDS	-	-	-	-	-	-	-	-	-	-	-	-
M-Alkalinity (mg/ℓ as $CaCO_3$)	68	65	60	54	99	8.9	72	68.5	65	55	115	10.8
SO_4^{2-} (mg/ℓ)	15	15	15	8.3	47	4.7	16	15	14	6.7	88	8.3
Na^+ (mg/ℓ)	8.6	8.5	11	3.7	16	2.0	9.0	8.4	10	4.7	46	4.6
Cl^- (mg/ℓ)	6.7	6.4	6.3	2.7	23	2.14	6.9	6.3	6.7	4.5	47	4.6

The Vereeniging and Zuikerbosch purification plants use the conventional treatment processes of coagulation/flocculation, sand filtration and disinfection where waste is generated and recycled in the first two processes (**Figure 5**). This includes recovered filter wash water from backwashing sand filters, which is returned to the head of works at Vereeniging or treated at the 35 ML/d filter wash water recovery plant at Zuikerbosch [25].

DWTR or sludge (120 ML/d DWTR ≈ 3% (m/v) of raw water treated) from coagulation/flocculation (C/F) is thickened, dried and the supernatant recycled. This DWTR is lime based and lime at high pH is capable of significant removal of suspended and colloidal matter, inorganic and organic matter including phosphates and heavy metals and inactivate most microorganisms [51] [52] [53]. The DWTR supernatant can be recovered and used to improve the SDM's WWTPs discharged secondary effluent quality with further membrane and AOPs or disposed of in IPR.

Ferric chloride in the DPR Beaufort West WRP is dosed in the activated sludge to treat ortho-phosphates and as flocculent to clarify suspended solids in the secondary settling tank [12]. This could also be applied in the study area as separate units or in activated sludge process in WWTPs (**Figure 6**) in combination with lime or existing recovered coagulant from DWTR. Phosphates levels at Beaufort West are comparable to WWTP4 in this study area at 5.1 and 4.1 mg/ℓ respectively which is way below the other three WWTPs at average 0.3, 1.0 and 0.9 mg/ℓ for WWTP1, WWTP2 and WWTP3 respectively (**Table 1**). Breakpoint chlorination that further reduces nutrients applied in the Beaufort West case is not necessary in the study area with these low levels of nutrients and lime clarification from DWTR [2].

Sand filtration which reduces the load by removing macro organic matter and suspended solids to prevent fouling for subsequent membrane processes of ultrafiltration (UF) and microfiltration (MF) could be optional in the study area. This is because the organic matter represented by COD and suspended solids of Beaufort West secondary effluent are on average 47 and 20 mg/ℓ respectively

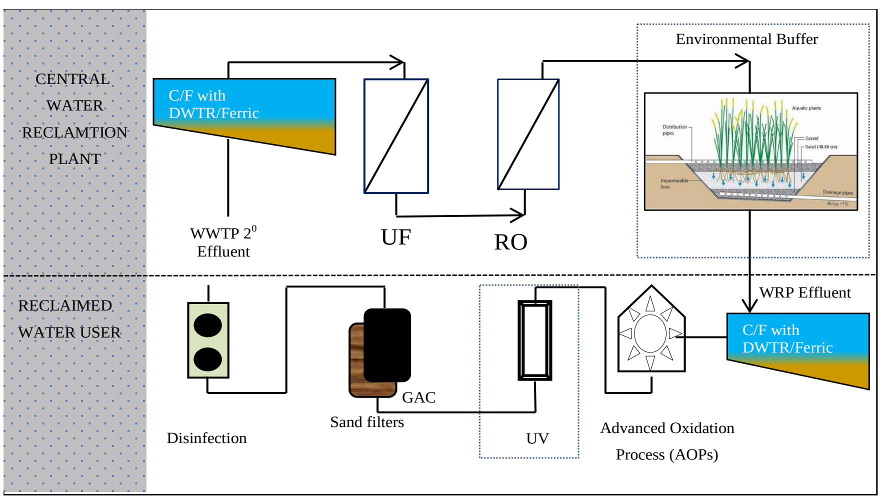

Figure 6. Proposed treatment train for DPR of Sedibeng WWTPs effluent.

[33], higher than those of the Sedibeng WWTPs except WWTP4 (**Table 1**). Alternatively sand filtration can be included to reduce membrane operational costs and increase their longevity. UF removes viruses in addition to removal of suspended solids compared to MF hence it is preferable. The suspended solids are variable for the results of the study which are at the lowest (0.6 mg/ℓ) for WWTP1 compared to the highest (29.7 mg/ℓ) for WWTP2 (**Table 1**). Bacteria, *Cryptosporidium* and *Giardia* prevalent in the study area caused by increasing urbanization and subsequent overload of the wastewater treatment plants can increase if mitigation measures such as both UF and MF are not followed [12] [54].

The pressure driven dense membrane process nano-filtration and reverse osmosis (NF/RO) will remove the remaining organics, hormones, pesticides, contaminants of emerging concern (CEC), aqueous salts and metal ions [12]. RO typically removes 95 to 99.5% of the total dissolved solids and 95% to 97% dissolved organic matter [36]. RO efficiency is demonstrated in the Beaufort West WRP where the RO system operates at 80% recovery with feed water of TDS 1200 - 1520 mg/ℓ and final water quality of <30 mg/ℓ. This represents a 98% TDS removal rate, comparable to a 99.8% (4000 to 5 μS/cm) WABAG study, and significantly exceeds the SANS 241 (2015) drinking water standard in terms of acceptable health, palatability and aesthetics [55]. In the study, WWTP4 has the highest conductivity at 92.8 compared to 40.8, 63 and 60.4 mS/m for WWTP1, WWTP2, and WWTP3 respectively. WWTP4 also has the highest TDS at 800 mg/ℓ and it is still 30% lower than the Beaufort West WRP's feed (**Table 2**). In the Beaufort West WRP for DPR the activated carbon step is not present but the RO step is present and in the Namibia WRP the RO step is absent but the activated carbon step is present (**Figure 6**). RO/NF, activated carbon and advanced oxidation processes (AOPs) are technologies used to reduce TOC concentrations, hence in the study area, either RO or activated carbon can be used depending on costs especially energy costs for pumping [4] [56] [57].

AOPs which are non-selective, hence TOC is used as an indicator parameter in photocatalysis for example in assessing its progress and not an indicator of the abundance of the chemical of concern. It is applied after RO to reduce the effects of suspended material shielding the light transmission and applied after scavenging carbonate, bicarbonate, reduced metals, COD and TOC are removed [34] [58]. An AOP step of UV/H_2O_2 after reverse osmosis and before disinfectionis used in the Beaufort West WRP to destroy the remaining dissolved organic carbons, remove all endocrine disrupting chemicals (EDCs) and add to the safety of the water [12]. The objective of inclusion of AOPs and other oxidative processes in the treatment train is to degrade biologically recalcitrant organic constituents that are poorly retained by membranes [4]. Although the energy costs associated with AOP is the process is very effective with the destruction of trace organics, viruses, bacteria and protozoa [2].

Natural barrier systems that include aquifer recharge or reclaimed water reintroduction into the river in IPR (**Figure 6**), from a public outreach perspective, has been perceived as playing an important role for gaining public acceptance [2] [3]. Public perception and acceptance as psychological barriers to water reuse are as important as the latter natural operational barriers. The most important cornerstone in following the over 40 years experience of water reclamation in Windhoek, Namibia; are public acceptance and trust by consumers in good reuse water quality [29]. Continuous education involving taste, smell and touch of reclaimed water turned negative public perception in Beaufort West WRP's, is recommended in the study area, for successful implementation and acceptance of reuse [12].

Power generation

Wet cooling coal fired power stations use up to 90% of water in some cases in cooling towers which do not require high quality water and thus is more sustainable since fresh potable water can be saved [42] [55]. This is especially applicable to systems using water once, such as municipal power plants in South Africa. Currently municipal power plants use treated municipal wastewater and Eskom power plants, in few cases, use in-house domestic treated wastewater. The potential for Eskom power plants to use wastewater should be exploited [42].

Lethabo power station, in the study area, uses approximately 1 ML/day of its on-site treated sewage effluent, raw water from the Vaal River and the New Vaal colliery mine wastewater to feed its 12 ML/day reverse osmosis plant. The permeate from this plant is used as "make up water" for cooling tower water and for boiler feed water after it has undergone further processes such as ion exchange [16] [59]. The potential water source from Sedibeng WWTPs can increase the capacity to the on-site generated treated effluent and can reduce the demand of the power utility's cooling tower water.

Of the four Sedibeng WWTPs effluents only WWTP4 does not meet the requirements for cooling water systems before tertiary treatment. The WWTPs comply in terms of cooling water pH maximum criteria with a turbidity of <100 NTU since suspended solids are on average <30 mg/ℓ for all SDM's WWTPs [16]. Lower suspended solids related to turbidity are important for Eskom's power station since their reduction is related to improved biological quality, reduction in infrastructure fouling and abrasion by sand and grit in cooling tower water. Ammonia, an aggressive corrosion agent of non-ferrous material from sewage, is set at 40 mg/ℓ for Eskom's power plants cooling water and all four WWTPs are below this limit. An arbitrary limit of <400 mS/m conductivity, of which all four WWTPs comply to, is set for Eskom power plants cooling water to limit corrosion. Increased COD concentration from sewage effluent is another concern for Eskom's power plants and it is recommended that preliminary treatment such as clarification be applied before use in cooling tower water [60].

Eskom's Lethabo power station is projected to continue using 48.7 million m^3 of water per annum or approximately 133 ML/d up to 2030 [48]. It has been stated previously that Eskom power stations are not using treated municipal wastewater because their plants are mainly located in small towns away from metropolitan areas near coal mines. The small towns could not provide 120 ML/d water for example required by cooling systems of large power stations and costly long pipelines would have been required to transport municipal effluent [13] [14]. Another stated reason for not using municipal secondary effluent is that the Eskom power plants original design did not cater for third party wastewater and agreements are not entered into with Department of Water and Sanitation for third party water [60]. The predicted increase of treated effluent (up to 390 ML/d by 2025) from the Sedibeng district's WWTPs, [23], and the establishment of a regional collection WRP would address these issues and thus supply the Lethabo power station with the required amount of water.

Steel manufacturing

Water use in the metal industry is for material conditioning, dust control and the largest application is heat exchange (cooling) which can be over 70% in the steel industry's non-contact cooling [37] [61]. Water availability, local conditions and regulation determine the type and extent of water use with once through cooling in steel industry preferred but municipal effluent can also be used to reduce the demand of fresh water [62].

The Arcelor Mittal Vanderbijlpark integrated steel works is one of the world's largest inland plant and the largest flat steel products supplier from raw materials in sub-Saharan Africa. It uses up to 65 ML/d of water of which 30 ML/d is from the Vaal Dam and 35 ML/d is from the Vaal River which demonstrates tolerance of variable water quality requirements in its processes. The steel works implemented a ZED philosophy in 2005 where before implementation its dry weather discharge into the Rietspruit was approximately 31 ML/d which is close to half of the total abstracted volume [17]. After attaining the ZED status, which was part of the water license condition, there was approximately 50% reduction in raw water abstraction even though it was temporarily lost in 2011-2012. The steel works water balance includes water consumption and generation in cooling towers, cold rolling and treatment plants processes [63].

The Vaal Dam water quality, based on the data, as raw water source for potable treatment (**Table 2**) gives an indication of raw water quality requirements for the ArcelorMittal Vanderbijlpark steel works. The Sedibeng WWTPs effluent is comparable to the Vaal Dam water in some aspects and but none of these are not complying with the requirements of some steel manufacturing plants for example the BlueScope Port Kembla Steelworks in Australia. The chlorides which are other important specification for the steelworks comply for the Vaal Dam water but did not comply for the Sedibeng WWTPs.

The Arcelor Mittal ZED plant in Vanderbijlpark treats approximately 48 ML/d of its generated wastewater from internal processes, which is reused within the plant as general utility water. Some of the technologies used to treat separate waste streams such as blow-down and storm water, include lime and soda ash softening, clarification, sand filtration, granular activated carbon and brackish water RO [64]. The targeted contaminants in the waste streams from this plant as in the case of power plants are suspended solids and hardness from process water circuits and dissolved salts in blow down water [37] [64]. Suspended solids give rise to turbidity and the turbidity of the Vaal Dam water used by Arcelor-Mittal is high and variable (15 - 110 NTU). Therefore the Sedibeng WWTPs secondary effluent with suspended solids of 0.6 - 29.7 mg/ℓ is suitable for use in steel manufacturing industry (**Table 2**). Due to macro-ion content, high salt load and eutrophication intensive water user industries such as Sasol (Sasolburg), Mittal and Eskom's Lethabo power station have stopped using the Vaal Barrage water. Cost of desalination treatment technology, such as RO, is decreasing and these water users have already installed this technology as part of their ZED requirements [10] [16] [64]. Therefore there is no technical reason why they should not also add tertiary treated Sedibeng WWTPs water even for low quality uses such as dust suppression, fire-fighting and even some heat exchange processes after tertiary treatment.

4. Conclusion

South Africa has no water reuse guidelines even though there is a strong reuse practice in direct potable reuse such as in the Beaufort West WRP case and "de facto" reuse through downstream abstraction. Industrial reuse and recycling are practised in power generation, steel manufacturing, mining, chemical and paper manufacturing industries such as in the exemplary case of the public-private partnership between eThekwini municipality and Mondi paper/Sapref. Water reclamation of SDM effluent either through direct (DPR) or indirect potable (IPR) water reuse, power generation and steel manufacturing industry have the potential of reuse in the Southern Gauteng region. This reclamation should be in a centralized WRP where all effluent is advanced treated after collection as secondary effluent or alternatively in a decentralized WRP format where each WWTP would improve quality of effluent and supply to the nearest user. For water reuse to be a success, all intensive water user stakeholders must be committed to sustainable water management, selection of cost effective advanced tertiary treatment methodology and effective communication to allay negative public perceptions.

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