

# Seasonal variation of nutrient loads in treated wastewater effluents and receiving water bodies in Sedibeng and Soshanguve, South Africa

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**Abstract** The discharge of inadequately treated wastewater effluent presents a major threat to the aquatic environment and public health worldwide. As a water-scarce country, South Africa is facing an alarming situation since most of its wastewater discharges are not meeting the permissible limit. The aim of this study was to assess the physicochemical quality of treated wastewater effluents and their impact on receiving water bodies. During the study period, pH, temperature, free chlorine residue ( $\text{Cl}^-$ ), dissolved oxygen (DO), nitrate ( $\text{NO}_3^-$ ), orthophosphate ( $\text{PO}_4^{3-}$ ) and chemical oxygen demand (COD) were measured in order to ascertain whether the selected wastewater systems in Sedibeng and Soshanguve complied with the South African and World Health Organization standards during wet and dry seasons. These parameters were analysed for samples collected from raw wastewater influent, treated wastewater effluent and receiving water bodies. The study was carried out between August 2011 and May 2012, and samples were collected on a weekly basis during both seasons. The physicochemical quality of effluents did not comply with the regulatory limits set by South Africa in

terms of pH in Meyerton, Rietgat and Sandspruit (pH 7.6 to 8.1); free chlorine in Sandspruit ( $0.27 \pm 0.05$  mg/L); nitrate in Leeuwkuil and Rietgat (2.1 and 3.8 mg/L, respectively) during the wet season; orthophosphate in Meyerton during the wet season and in Sandspruit during the dry season ( $1.3$  mg  $\text{PO}_4^{3-}$  as P/L and  $1.1$  mg  $\text{PO}_4^{3-}$  as P/L, respectively); and chemical oxygen demand in Rietgat during the dry season and in Sandspruit during the wet season (75.5 and 35 mg/L, respectively). Furthermore, the quality of the receiving water bodies did not comply with the South African standards recommended for pH, chemical oxygen demand and orthophosphate and DO (5 mg/L) in Rietgat during the wet season. The geometric mean of the water quality index values ranged between 32.4 and 36.9 for the effluent samples and between 38.1 and 65.7 for the receiving water bodies. These findings revealed that the receiving water bodies were classified as having “poor” quality status, except Leeuwkuil receiving water body (Vaal River) and Sandspruit upstream (Sandspruit stream). The dry season showed a relatively lower water quality index. This situation might be attributed to the higher amount of organic matter and lower microbial activities in the receiving water bodies. This study suggests that wastewater effluents and receiving water systems should be monitored regularly to ensure best practices with regard to nutrient treatment and discharge of wastewater.

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## Introduction

Water is an essential ingredient for human health and wellbeing. Presently, however, clean water resources have become scarce in countries like South Africa due to climate changes and pollution. Recycled water is used by many countries to supplement dwindling freshwater supplies. South Africa is no exception, and treated wastewater effluent is the second top potential source in terms of its contribution (14 %) to the country's total water supply (van Vuuren 2009). However, human activities, i.e., population growth, urbanisation, improved living standards, and pollution are having a severe impact on this scarce commodity. In order to guarantee the safety and potential in water supply, wastewater disposal must comply with stringent standard limits stipulated by regulatory bodies (Kamika and Momba 2011). Treated wastewater effluent has been playing an important role in supplementing drinking water supply and filling the gap between demand and supply (Meehan et al. 2013). About 14 % of the total potential water source in South Africa is treated wastewater effluent (Backeberg 2005). However, the quality of treated wastewater effluent cannot be trusted as the efficiency of treatment plants is poor due to ageing infrastructure, inadequate maintenance and lack of skilled manpower (Samie et al. 2009). This problem is associated with serious health burdens (Okoh et al. 2007) and is aggravated by a continuous increase in population size, industrialisation and urban development (Rensburg 2008). According to the Green Drop Assessment Report of the Department of Water Affairs and Forestry, the performance and efficiency level of South African wastewater treatment works has been shown to be poor (DWAF 2011).

Monitoring of water and wastewater quality is crucial in protecting public health and the environment. However, the current South African water quality data is not well coordinated (Okoh et al. 2007). Wastewater effluent discharge is among the major causes of water pollution that leads to the degradation of the quality of water systems (Morrison et al. 2001; WRC 2000). Degradation of water systems results in the loss of biodiversity which is expected to be higher in aquatic ecosystems than in terrestrial or land ecosystems (Sala et al. 2000). Effluent discharge parameters that do not comply with the standard limits may impair the condition of the aquatic environment to the extent that it may no longer support aquatic life and the innate state of water resources. For example, low pH value ( $\text{pH} < 5$ ) negatively affects the health of surface water intended for recreation.

The decrease in pH may cause a decrease in the solubility of elements such as selenium. Low pH may also increase the solubility of some carcinogenic metals, such as cadmium and mercury (DWAF 1996a, c). According to Qasim (1999), the failure of the biological treatment system is one of the main causes high nitrate concentrations in treated final effluents and surface waters are common. Furthermore, high nitrate and nitrite concentration have been reported to contribute to eutrophication of freshwater (Kamika et al. 2014) and leading to public health concerns like cancer, increased risk of foetal abnormalities and methaemoglobinaemia (Weyer et al. 2001; USEPA 1997). Degradable organic matter has also been reported among the main constituents in the inadequately treated wastewater effluent (Momba et al. 2006), leading to the reduction of DO (below 5 mg/L) in water bodies. The present study assessed the quality of wastewater final effluent of the target treatment plants and respective receiving water bodies using both the South African-recommended standards for compliance as well as the water quality index. Although the aquatic environment and health of the community residing downstream of the effluent discharge point might not be affected, there is a need for thorough monitoring of the wastewater effluents and receiving water bodies.

## Materials and methods

### Study area

This study was conducted between August 2011 and May 2012 at wastewater treatment facilities and their respective receiving water bodies in the Sedibeng District and Soshanguve peri-urban area of the Tshwane Metropolitan Municipality.

Sedibeng District Municipality is located in the southernmost part (former Vaal Triangle) of the Gauteng Province with a geographical area of 4185 km<sup>2</sup>. It is the only district of Gauteng that is situated on the banks of Vaal River and Vaal Dam. It comprises three category B municipalities (Emfuleni, Midvaal and Lesedi) that border the city of Johannesburg to the north, Ekurhuleni (East Rand) to the north-east, Mpumalanga to the east and north-east, Free State to the south, North West Province to the west and West Rand to the north-west. A dominant feature of the economy of Sedibeng is heavy manufacturing (35.3 %) and other important sectors, including social services, trade, transport, electricity, construction and

agriculture. The population size of the district is 805,168, and Emfuleni Local Municipality is the most populous, representing 80.9 % of the entire population. Emfuleni is followed by Lesedi (9.56 %) and Midvaal (9.50 %) (Sedibeng District Municipality (SDM) 2012). During the past 15 years the peri-urban or semi-urban face of Sedibeng District has changed as it became urbanised at a rate of up to 88.8 % in 2008; however, the urbanisation rate has declined since 2000 when it reached a high of 93.6 %. Sedibeng District has a high level of water and sanitation services, with 95.5 % and 91.2 % of the households having access to piped water and sanitation, respectively. Water and sanitation service levels are high in Emfuleni (96.1 %) and Midvaal (95.3 %), with 11 497 and 22 136 households lacking these services, respectively (Sedibeng District Municipality (SDM) 2012).

For the purpose of the present study, sampling sites were selected based on the year of establishment, efficiency of the wastewater treatment plants and the population size of the local municipalities (Fig. 1). The Meyerton Wastewater Treatment Plant (Midvaal Local Municipality) was selected because it is old, already overloaded and has never been upgraded since its establishment. In addition, Leeuwkuil Wastewater Treatment Plant was selected because it is one of the treatment facilities serving the most populous local municipality (Emfuleni) in the Sedibeng District and is believed to be capable of producing high-quality effluent.

Soshanguve peri-urban area is located within the north-west region of the Tshwane Metropolitan Municipality with a population of 664,900 people (City of Tshwane (CoT) 2009). Soshanguve is situated about 45 km north of Pretoria, Gauteng, South Africa. It was established in 1974 by the black settlers from different provinces and the name Soshanguve is an abbreviation for Sotho, Shangaan, Nguni and Venda, being the languages spoken in Soshanguve (Nkwonta and Ochieng 2009). It is characterised by a rapidly growing population resulting in an increase in informal settlements. As one of the previously disadvantaged areas, Soshanguve is one of the most densely populated areas of the Tshwane Metropolitan Municipality. In 2009, the water and sanitation backlog of the City of Tshwane was 69 987 households, of which Soshanguve contributes 13.93 % (City of Tshwane (CoT) 2009). It is bordered by the Tswaing Meteorite Crater Reserve to the north, Hammanskraal to the north-east, Mabopane and Winterveldt to the north-west and De Onderstepoort Private Nature Reserve and the Pretoria North suburbs

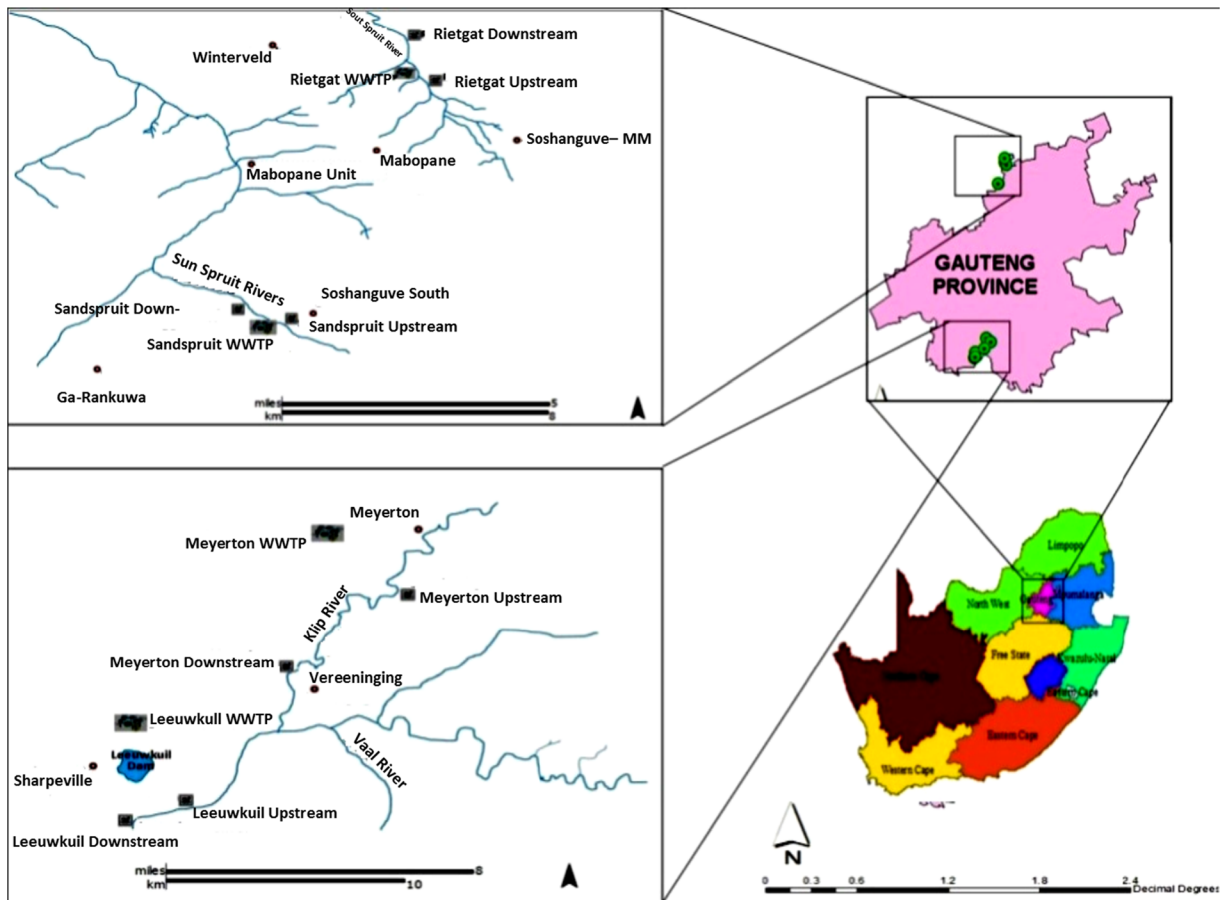
to the south. The selection of wastewater treatment plants was based on the percentage of services provided by these treatment plants, and it was found that Rietgat and Sandspruit Wastewater Treatment Plants exclusively serve the population of Soshanguve. It should be mentioned that all the plants in the present study are biological nutrient removal plants with at least three stages, anaerobic, anoxic and aerobic. In the Leeuwkuil, the coarse screen during the experimental period was not having the racks to trap the solids. The Huber Fine Screen was out of commission due to a worn out motor; this means that solids such as rags, debris and plastics were passing through the inlet works to the Primary Settling Tanks (PSTs). The BNR plant has two PSTs, but due to the unavailability of the screens, one PST is being used at a time to avoid tends to blockages.

#### Collection of samples

Sample collection was conducted on a weekly basis between the months of August 2011 and May 2012, by alternating the days of the week, in order to assess the pollutant removal efficiency of the wastewater treatment works. The sampling period was selected as per wet season with temperature ranging between 9 and 30 °C and dry season ranging between 0 and 15 °C. Raw influent, treated final effluent and receiving water bodies of the above-mentioned wastewater treatment plants were sampled. Samples were collected using 1 L plastic bottles cleaned with detergents, soaked in 10 % nitric acid and rinsed thoroughly using distilled water in order to ensure that samples were free of contaminants. Samples were transported in a cooler box containing an ice-pack, and all sample analyses were performed in accordance with Standard Methods (APHA 2001). Samples were analysed in triplicate at the Tshwane University of Technology Water Research Group Laboratory.

#### Field determination and laboratory analyses

All the equipment used to measure the physicochemical parameters were checked and calibrated according to manufacturers' specifications and instructions. Temperature, pH and dissolved oxygen were measured onsite using a multi-parameter ion-specific metre (HACH HQ40d; HACH, SA). The concentrations of total  $\text{PO}_4^{-3}$ ,  $\text{NO}_3^{-1}$  and chemical oxygen demand (COD) were determined in accordance with standard techniques, such as Method



**Fig. 1** Maps showing sampling sites in Sedibeng District Municipality and Soshanguve peri-urban area of Tshwane Metropolitan Municipality

424f, sodium salicylate method (Monterio et al. 2003) and Method 5220A (APHA 2001), respectively, using a spectrophotometer (SPEKOL 1300). For COD analysis, sample solutions were placed in glass vials containing COD solution and digested in a COD thermo-reactor, model ABH 3 (FMH instruments, Separation Science, South Africa) prior to analysis. The absorption spectra of the samples were recorded at 600 nm against blanks. Finally, concentrations were determined using the sample's absorbance against the calibration curve.

#### Water quality verification

For the determination of the overall water quality of the treated effluents and respective receiving water systems, the parameters DO, COD,  $\text{NO}_3^-$ ,  $\text{PO}_4^{3-}$ , pH and temperature were used to calculate the Bascaron Water Quality Index ( $\text{WQI}_{\text{BA}}$ ) using the following equation (Bascaron 1979):

$$\text{WQI}_{\text{BA}} = K \left( \frac{\sum_i C_i P_i}{\sum_i P_i} \right) \quad (1)$$

where:

$C_i$  = Normalisation percentage value corresponding to each parameter, defined in Table 1.

$P_i$  = Parameter weight with the maximum value of 4 assigned to parameters of relevant importance for aquatic life as for example DO, while the minimum value of 1 was assigned to a parameter with relatively minor relevance, such as total phosphate.

$K$  = Constant of adjustment in function of the visual aspect of the water with a maximum value of 1.00 for apparently good quality water and 0.25 for apparently highly polluted water.

In this study, like in other investigations reported in the literature, the constant  $K$  was not considered in order not to introduce a subjective evaluation (Hernández-Romero et al. 2004).

**Table 1** Values of  $C_i$  and  $P_i$  and percentage values of water quality parameters to calculate the water quality index ( $WQI_{BA}$ )

| Para.                                | $P_i$ | Values ( $C_i$ ) |      |       |      |       |       |      |      |      |      |      |
|--------------------------------------|-------|------------------|------|-------|------|-------|-------|------|------|------|------|------|
|                                      |       | 100              | 90   | 80    | 70   | 60    | 50    | 40   | 30   | 20   | 10   | 0    |
| Analytical values of parameters      |       |                  |      |       |      |       |       |      |      |      |      |      |
| DO (mg/L) (mg/L)                     | 4     | ≥7.5             | >7   | >6.5  | >6   | >5    | >4    | >3.5 | >3   | >2   | 1    | <1   |
| COD (mg/L)                           | 3     | <5               | <10  | <20   | <30  | <40   | <50   | <60  | <80  | <100 | 150  | >150 |
| NO <sub>3</sub> <sup>-</sup> (mg/L)  | 2     | <0.5             | <2   | <4    | <6   | <8    | <10   | <15  | <20  | <50  | 100  | >100 |
| PO <sub>4</sub> <sup>3-</sup> (mg/L) | 1     | <0.16            | <1.6 | <3.2  | <6.4 | <9.6  | <16   | <32  | <64  | <96  | 160  | >160 |
| pH                                   | 1     | 7                | 7–8  | 7–8.5 | 7–9  | 6.5–7 | 6–9.5 | 5–10 | 4–11 | 3–12 | 2–13 | 1–14 |
| Temperature (°C)                     | 1     | <21              | <22  | <24   | <26  | <28   | <30   | <32  | <36  | <40  | <45  | >45  |

Six parameters were used to calculate the  $WQI_{BA}$ , namely DO, COD, NO<sub>3</sub><sup>-</sup>, PO<sub>4</sub><sup>3-</sup>, pH and temperature. Values of  $C_i$  and  $P_i$  and percentage values of water quality parameters to calculate the water quality index are given in Table 1, and the correspondence between the qualitative results and the water quality index calculation is indicated in Table 2.

Statistical analysis

Data were statistically analysed using the two-way ANOVA in order to determine how each parameter from the effluent, upstream and downstream positions differs between the four plants by taking into consideration the seasons. This was performed to assess the possible impact of the four plants to their respective receiving water bodies. Interpretation was performed at the 95 % confidence interval. The significance of variation and correlations between or among various parameters was carried out using a statistical software package, Stata V13 (StataCorp LP, 2009; Texas, USA). The Pearson correlation test was used to determine the strength of the correlation where  $0.1 < |r| < 0.3$ ,  $0.3 < |r| < 0.5$  and  $|r| > 0.5$

**Table 2** Correspondence between the qualitative results and the water quality index ( $WQI_{BA}$ ) calculation

| Water quality index ( $WQI_{BA}$ ) calculation | Corresponding qualitative results |
|--|-----------------------------------|
| $91 \leq WQI \leq 100$                         | Excellent                         |
| $71 \leq WQI \leq 90$                          | Very good                         |
| $51 \leq WQI \leq 70$                          | Good                              |
| $25 \leq WQI \leq 50$                          | Poor                              |
| $0 \leq WQI \leq 25$                           | Very poor                         |

coefficient values were associated to the small correlation, moderate correlation and strong correlation, respectively.

Results and discussion

In South Africa, wastewater effluents are disinfected before discharge mostly using chlorine. However, the free Cl<sup>-</sup> residual is intended to always comply with the South African general limit of 0.25 mg/L or special limit of 0 mg/L of no risk (DWAF 2004). During the study period, Cl<sup>-</sup> concentrations between the dry and wet seasons did not vary significantly ( $P > 0.05$ ) except in the Leeuwkuil effluent samples ( $P = 0.004$ ) and ranged from 0.047 to 0.27 mg/L during the dry season and 0.047 to 0.07 mg/L during the wet season (Table 3). The current study revealed that the geometric mean of Cl<sup>-</sup> concentration for the dry season in Sandspruit exceeded the general limit, while all the other results obtained exceeded the South African special limit of no risk (0 mg/L). This suggested that the effluent can affect the chemical composition of the receiving water bodies.

In a country like South Africa, temperature plays a major role in determining the quality of water by influencing the solubility and availability of oxygen, toxicity of some chemicals and metabolic rates of organisms (Akan et al. 2008; DWAF 1996d). The geometric mean of the temperature between dry and wet seasons did not show significant variation ( $P > 0.05$ ) in all the wastewater treatment plants for all the sampling points and ranged from 16.56 to 20.53 °C during the dry season and 19.64 to 25.29 °C during the wet season. A statistically significant variation was observed between the treated wastewater effluent and receiving water bodies downstream of the discharge point, except

**Table 3** Seasonal variation in the concentrations of parameters used as water pollution indicator ( $n = 160$  samples per season)

| Sampling sites | Parameter     | Season | Sampling points (geom. mean $\pm$ SD) |                  |                  |                  |
|----------------|---------------|--------|---------------------------------------|------------------|------------------|------------------|
|                |               |        | INF                                   | EFF              | UPS              | DWS              |
| Meyerton       | pH            | DRY    | 7.27 $\pm$ 0.27                       | 7.37 $\pm$ 0.78  | 7.85 $\pm$ 0.24  | 7.87 $\pm$ 0.32  |
|                |               | WET    | 7.32 $\pm$ 0.34                       | 8.13 $\pm$ 0.28  | 8.27 $\pm$ 0.29  | 8.22 $\pm$ 0.27  |
|                | Temperature   | DRY    | 18.91 $\pm$ 1.19                      | 18.00 $\pm$ 1.90 | 18.25 $\pm$ 2.30 | 17.75 $\pm$ 2.38 |
|                |               | WET    | 24.73 $\pm$ 1.42                      | 22.47 $\pm$ 2.12 | 20.80 $\pm$ 2.17 | 20.91 $\pm$ 2.25 |
|                | Free chlorine | DRY    |                                       | 0.05 $\pm$ 0.04  |                  |                  |
|                |               | WET    |                                       | 0.07 $\pm$ 0.04  |                  |                  |
| Leeuwkuil      | pH            | DRY    | 7.08 $\pm$ 0.20                       | 7.32 $\pm$ 0.75  | 7.81 $\pm$ 0.19  | 7.99 $\pm$ 0.23  |
|                |               | WET    | 7.67 $\pm$ 0.28                       | 7.28 $\pm$ 0.34  | 8.93 $\pm$ 0.48  | 9.01 $\pm$ 0.55  |
|                | Temperature   | DRY    | 18.22 $\pm$ 1.37                      | 17.53 $\pm$ 1.30 | 19.34 $\pm$ 2.45 | 18.88 $\pm$ 2.38 |
|                |               | WET    | 23.09 $\pm$ 1.42                      | 22.22 $\pm$ 1.80 | 23.48 $\pm$ 2.53 | 23.02 $\pm$ 2.75 |
|                | Free chlorine | DRY    |                                       | 0.07 $\pm$ 0.03  |                  |                  |
|                |               | WET    |                                       | 0.05 $\pm$ 0.03  |                  |                  |
| Rietgat        | pH            | DRY    | 7.45 $\pm$ 0.19                       | 7.10 $\pm$ 0.75  | 7.93 $\pm$ 0.21  | 7.91 $\pm$ 0.20  |
|                |               | WET    | 8.57 $\pm$ 0.21                       | 7.60 $\pm$ 0.49  | 7.83 $\pm$ 0.28  | 8.05 $\pm$ 0.29  |
|                | Temperature   | DRY    | 20.59 $\pm$ 1.71                      | 19.50 $\pm$ 1.69 | 16.66 $\pm$ 1.91 | 17.31 $\pm$ 2.45 |
|                |               | WET    | 25.31 $\pm$ 1.02                      | 24.17 $\pm$ 1.57 | 19.74 $\pm$ 2.05 | 21.36 $\pm$ 2.37 |
|                | Free chlorine | DRY    |                                       | 0.10 $\pm$ 0.06  |                  |                  |
|                |               | WET    |                                       | 0.06 $\pm$ 0.07  |                  |                  |
| Sandspruit     | pH            | DRY    | 7.46 $\pm$ 0.25                       | 7.79 $\pm$ 1.04  | 8.18 $\pm$ 0.35  | 8.18 $\pm$ 0.30  |
|                |               | WET    | 8.64 $\pm$ 0.28                       | 8.03 $\pm$ 0.32  | 8.51 $\pm$ 0.39  | 8.10 $\pm$ 0.30  |
|                | Temperature   | DRY    | 19.75 $\pm$ 1.75                      | 18.81 $\pm$ 2.00 | 17.56 $\pm$ 1.97 | 18.38 $\pm$ 1.81 |
|                |               | WET    | 24.29 $\pm$ 1.26                      | 23.14 $\pm$ 1.83 | 20.04 $\pm$ 1.83 | 22.99 $\pm$ 1.83 |
|                | Free chlorine | DRY    |                                       | 0.27 $\pm$ 0.05  |                  |                  |
|                |               | WET    |                                       | 0.06 $\pm$ 0.03  |                  |                  |

pH: SA special limit, 5.5 to 7.5; SA general limit, 5.5 to 9.5; WHO limit, 5.5 to 8.0. Temperature: SA special limit, 25 °C; SA general limit, 35 °C. Free chlorine: SA special limit, 0 mg/L; SA general limit, 0.25 mg/L

DRY dry season, WET wet season, INF influent, EFF effluent, UPS upstream, DWS downstream

in the case of Sandspruit ( $P = 0.14$ ). Moreover, a statistically significant difference ( $P < 0.05$ ) was observed between the temperature measurements obtained for all upstream and downstream samples except for Meyerton ( $P = 0.34$ ). The treated wastewater effluents showed temperature ranges of between 17.49 and 24.13 °C that fell within the acceptable South African special standard limits ( $\leq 25$  °C) (DWA 2004). The significant variation observed between the temperatures of the effluents and downstream and between upstream and downstream samples suggests that effluents did not seem to pose any threat to the homeostatic balance of the receiving water bodies. These research findings are in agreement with the results reported by both Jaji et al. (2007) and Igbinosa and Okoh (2009).

As it can also be seen in Table 3, the pH regime varied significantly ( $P < 0.05$ ) in influent samples throughout the study period, except for Meyerton ( $P = 0.73$ ) and ranged from 7.08 to 8.17 for the dry season and 7.27 to 8.99 during the wet season. Specifically, pH values for the treated final effluents were measured between 7.07 and 8.02, and no significant statistical difference ( $P > 0.05$ ) was observed except in Meyerton ( $P = 0.02$ ). The geometric means of the pH values both for the dry and wet seasons fall within the South African general and special standard limits (pH = 5.50 to 9.50 and pH = 5.50 to 7.50, respectively) and WHO general limit (pH = 5.50 to 8.00) except those which were measured for Meyerton during the wet season and Sandspruit (pH = 8.13 and 8.02, respectively) (WHO 2001; DWA 2004).

Geometric means of pH values of the receiving water bodies showed significant statistical variation in Meyerton and Leeuwkuil ( $P < 0.05$ ) but lie within the standard limits set by World Health Organization (7.00 to 8.50) for drinking water and the South African standard limits set for full contact recreation (6.50 to 8.50) (DWAF 1996b; WHO 1989), except for Leeuwkuil. No significant statistical difference was observed between the pH values of effluent and downstream samples in Meyerton and Sandspruit ( $P > 0.05$ ). The higher pH level observed in the receiving water bodies for Leeuwkuil and Sandspruit compared with the levels for the final effluents suggested that there were other unidentified factors, presumably the non-point sources along the water-shed. This indicated that the effluent may not pose negative impact on the quality of receiving water bodies that can be used for domestic, fishery and recreational purposes. It should be mentioned that the pH value of a water system determines the solubility of chemical pollutants and some essential elements, which may cause intoxication of having toxic effects on aquatic life (Morrison et al. 2001; DWAF 1996d).

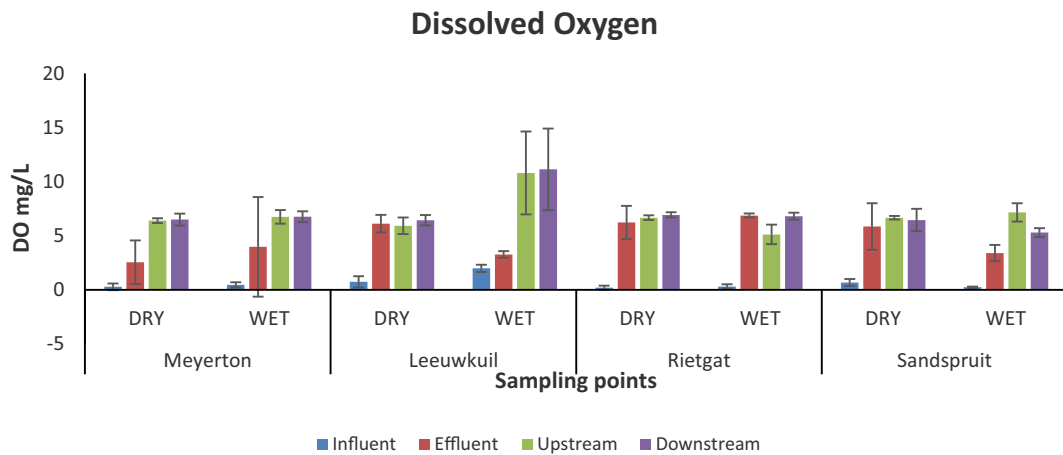
According to DWAF (1996c), oxygen plays a significant role for the survival and functioning of aquatic life. The concentration of DO in unpolluted surface water is expected to be between 8 and 10 mg/L. Concentrations below 5 mg/L indicate that the quality of water is poor and it adversely affects aquatic life (Rao 2005). Low DO levels affect the survival of fish by increasing their susceptibility to disease, which affects swimming, feeding, migration and reproductive behaviour. At critical stages, this will eventually lead to death (Environment Canada 2001). In the present study, the DO levels in all Leeuwkuil samples, Rietgat upstream samples and Sandspruit influent, effluent and downstream samples for the dry and wet seasons showed significant variations throughout the seasons ( $P < 0.05$ ), while the variation between the DO concentrations in all Meyerton samples, Rietgat influent, effluent and downstream samples and Sandspruit upstream samples was observed to be insignificant ( $P > 0.05$ ).

Averages of the DO concentrations ranged from 0.20 to 6.92 mg/L across the sampling points during the dry season and between 0.23 and 10.78 mg/L during the wet season (Fig. 2). The concentrations for the treated effluents varied from 2.54 to 6.86 mg/L. The DO concentrations for Meyerton-, Leeuwkuil- and Sandspruit-treated wastewater effluents and downstream samples showed significant statistical difference ( $P < 0.05$ ). These results suggest that treated effluents produced by these

wastewater treatment plants might not contribute nutrient loads to the receiving water bodies. The DO levels of the receiving water bodies were observed to be at concentrations of above 5 mg/L which poses no risk to aquatic life (Fatoki et al. 2003). Various sampling points at the receiving water bodies had acceptable DO concentration able to support plants and other organisms living in these waters.

Despite the above, the present study also investigated on nitrate fluctuation from both wastewater treatment plants as well as their receiving water bodies. Nitrate is the main source of nitrogen that supports the growth and development of living organisms when it is available at suitable concentrations. At higher concentration, it may lead to eutrophication of water systems which in turn result in the loss of biodiversity in the aquatic environment (CCME 2006). Nitrate concentration above 45 mg/L may result in the blue baby syndrome, anaemia in pregnant women and formation of carcinogenic nitrosamines (Manassaram et al. 2010; Akan et al. 2008). During the present study, the general geometric means of  $\text{NO}_3^{-1}$  concentrations ranged from 0.02 to 3.84 mg  $\text{NO}_3^{-1}$  as N/L (Fig. 3). Significant variation was observed between  $\text{NO}_3^{-1}$  concentrations for the dry and wet seasons in all Leeuwkuil sampling points, Meyerton influent and effluent samples, Rietgat effluent, upstream and downstream samples and Sandspruit effluent, upstream and downstream samples ( $P < 0.05$ ). The geometric means of  $\text{NO}_3^{-1}$  concentrations of treated wastewater effluents fell within the acceptable South African special standard limit (1.50 mg  $\text{NO}_3^{-1}$  as N/L), except for Leeuwkuil and Rietgat  $\text{NO}_3^{-1}$  concentrations produced during the wet season that were observed to exceed the safety limit for treated wastewater effluent (2.08 and 3.84 mg  $\text{NO}_3^{-1}$  as N/L), and this situation could also be due to runoff.

The variation in  $\text{NO}_3^{-1}$  concentrations observed between all effluent and downstream samples and Rietgat upstream and downstream samples was revealed to be significant, except between Meyerton effluent and downstream samples and between upstream and downstream samples of Meyerton, Leeuwkuil and Sandspruit wastewater treatment plants ( $P = 0.76$  and  $P = 0.89$ , 0.21 and 0.55, respectively). The South African guideline for the quality of water intended for domestic use suggests that the  $\text{NO}_3^{-1}$  concentration should not exceed 6 mg  $\text{NO}_3^{-1}$  as N/L (DWAF 1996a). Based on this guideline,  $\text{NO}_3^{-1}$  concentrations for the receiving water bodies of the present study were within the stipulated South African standard limit. This situation suggests that the effluents discharged by the respective wastewater

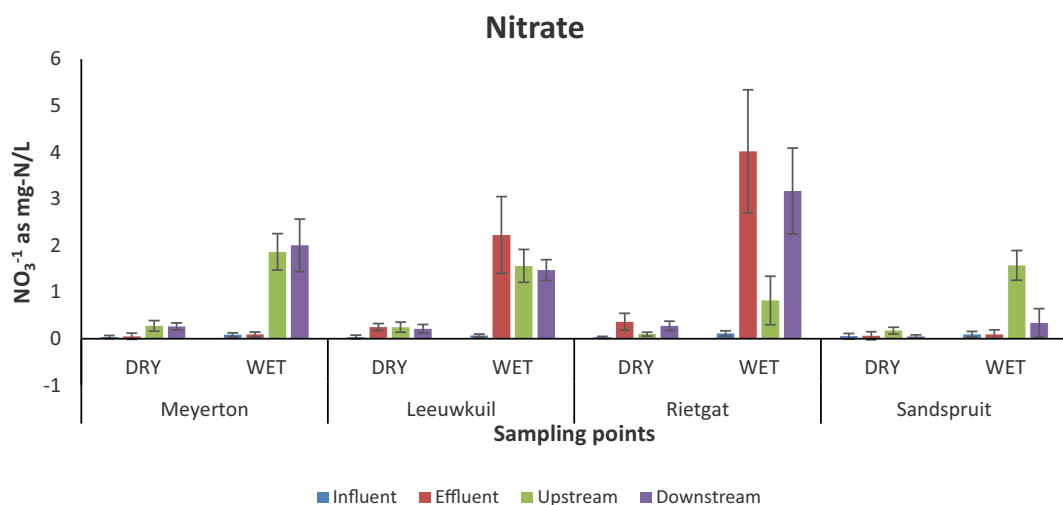


**Fig. 2** DO concentrations for the influent, final effluent and receiving water bodies representing the dry and wet seasons ( $n = 160$  samples per season). *DRY* dry season, *WET* wet season

treatment plants were not contributing to the increment of the  $\text{NO}_3^{-1}$  level for the receiving water bodies and the later are suitable for domestic use in relation with  $\text{NO}_3^{-1}$  load. The concentrations of  $\text{NO}_3^{-1}$  for both the dry and wet seasons are illustrated in Fig. 3.

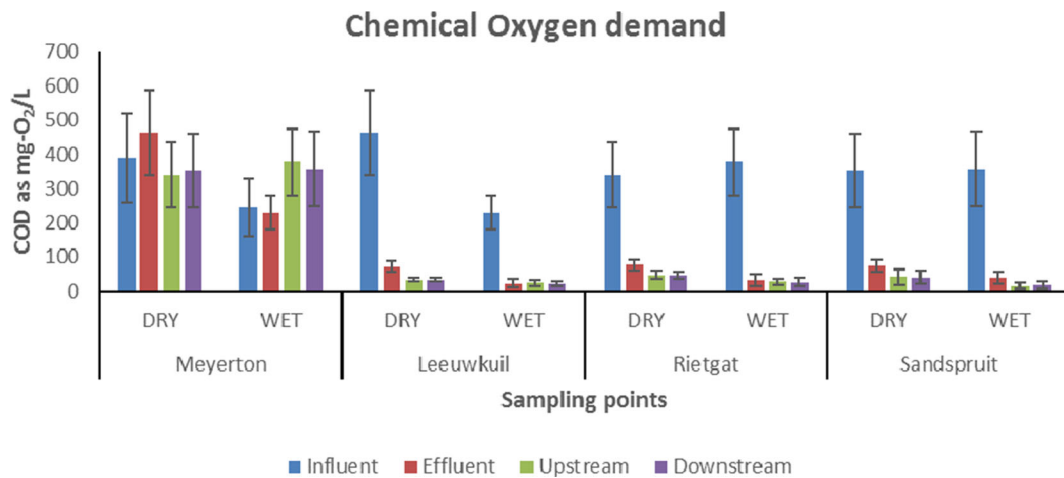
In addition, this finding revealed significant ( $P < 0.05$ ) variation in COD concentration between dry and wet seasons, except in the influent samples for Leeuwkuil and Sandspruit wastewater treatment plants ( $P = 0.10$  and  $P = 0.15$ , respectively) and effluent samples for Meyerton and Sandspruit ( $P = 0.17$  and  $P = 0.49$ , respectively). COD levels varied from 32.13 to 445.83 mg of COD as  $\text{O}_2/\text{L}$  for the dry season and 14.95 to 366.32 mg of COD as  $\text{O}_2/\text{L}$  for the wet season,

with the geometric mean of the effluent COD concentrations varied between 20.05 mg of COD as  $\text{O}_2/\text{L}$  and 75.50 mg of COD as  $\text{O}_2/\text{L}$  (Fig. 4). However, COD concentration in Rietgat effluent for the dry season was higher than the South African general limit (75.00 mg of COD as  $\text{O}_2/\text{L}$ ). The COD concentrations during the wet season were reduced, but the level for Sandspruit wastewater treatment plant was still above the South African special limit (30.00 mg of COD as  $\text{O}_2/\text{L}$ ). The variation between the effluent and downstream COD concentration revealed to be significant in all wastewater treatment plants ( $P < 0.05$ ). The difference between the COD concentrations between upstream and downstream showed no statistical significance in



**Fig. 3** Comparative results of nitrate concentrations analysed during the dry and wet seasons ( $n = 160$  samples per season). *DRY* dry season, *WET* wet season





**Fig. 4** Seasonal distribution of COD concentrations of wastewater influents, treated effluents and samples from receiving water bodies ( $n = 160$  samples per season). *DRY* dry season, *WET* wet season

Meyerton and Leeuwkuil ( $P > 0.05$ ), while significant variation between COD concentrations for Rietgat and Sandspruit ( $P < 0.05$ ) were observed. The elevated COD concentration in the receiving water bodies during the dry season could be attributed to the increase in concentration of the organic pollutants in the system. These results corroborate the findings reported by Morrison et al. (2001) on the Keiskammahoe Sewage Treatment Plant (Eastern Cape).

COD concentrations in samples from river sampling points upstream of the wastewater treatment plants ranged between 14.95 and 44.77 mg of COD as O<sub>2</sub>/L and samples from downstream of the effluent discharge points varied between 16.63 and 45.51 mg of COD as O<sub>2</sub>/L. South African water quality guidelines for COD (DWA 1996c) only specify standard limits for water intended for industrial purposes. Such standard limits are 0.00 to 10.00 mg of COD as O<sub>2</sub>/L, 0.00 to 15.00 mg of COD as O<sub>2</sub>/L, 0.00 to 30.00 mg of COD as O<sub>2</sub>/L and 0.00 to 75.00 mg of COD as O<sub>2</sub>/L corresponding to industries grouped under categories 1, 2, 3 and 4, respectively. Although the COD concentrations in the river water were within the South African standard limit for industrial use in category 4, the present concentrations observed during the dry season fell outside the limits recommended for industries under categories 1, 2 and 3, and this situation may harm aquatic life. Though there are no COD guidelines for aquatic ecosystems, the elevated COD concentration would have a deleterious effect on the aquatic biodiversity. The high levels of COD in the effluent as well as water bodies can lead to oxygen depletion which in turn can adversely

affect living organisms in the water systems (Fatoki et al. 2003; Akan et al. 2008). COD concentrations of the receiving water bodies significantly varied with changes in season ( $P < 0.05$ ), and the values were higher in the dry season (Fig. 4). The higher concentrations of COD during the dry season could be attributed to the lower microbial activities, which result in minimal degradation of organic matter (Regueiro et al. 2012). During the dry season, COD concentrations for the final effluents were higher when compared with the receiving water bodies. Further statistical analysis assessing the difference between plants revealed that there was a significant difference in the COD concentration between Meyerton and all the other plants. The concentration at Sandspruit, Rietgat and Leeuwkuil is on average 351.8, 346.8 and 355 units respectively less than at Meyerton. The concentration differences between the other plants were not significant. Results from the current investigation correspond to those attained by Morrison et al. (2001).

As phosphorus is also an important nutrient, which stimulates growth of algae and aquatic macrophytes as well as the main pollutant causing eutrophication and osmotic stress in the aquatic biota (DWA 1996d; CCME 2006; Yu et al. 2014), this study also assessed its presence in both wastewater treatment plants and their receiving water bodies. The variation between the dry and wet seasons was not statistically significant ( $P > 0.05$ ), except in influent samples for Leeuwkuil and Sandspruit ( $P = 0.003$  and  $0.000$ , respectively), in influent, upstream and downstream samples for Meyerton ( $P = 0.003$ ,  $0.027$  and  $0.047$ , respectively)

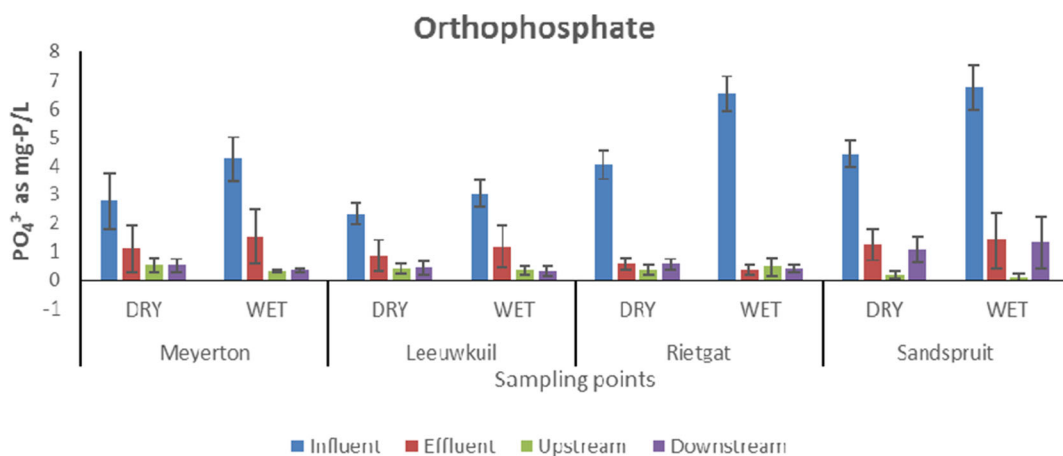
and in influent and downstream samples for Rietgat ( $P = 0.000$  and  $0.042$ , respectively). Geometric means of the  $\text{PO}_4^{3-}$  concentrations in all the effluent samples varied from  $0.29 \text{ mg PO}_4^{3-}$  as P/L to  $1.26 \text{ mg PO}_4^{3-}$  as P/L. The  $\text{PO}_4^{3-}$  concentrations were observed to lie within the South African special phosphate standard ( $1.00 \text{ mg PO}_4^{3-}$  as P/L), except in the case of Meyerton for the wet season and Sandspruit for the dry season (DWA 2004). The difference between  $\text{PO}_4^{3-}$  concentrations of effluent and downstream samples for Meyerton, Leeuwkuil and Sandspruit ( $P = 0.003$ ,  $0.004$  and  $0.033$ , respectively) was statistically significant. Moreover, a significant variation was revealed between  $\text{PO}_4^{3-}$  concentrations of Sandspruit upstream and downstream samples ( $P = 0.0002$ ). The  $\text{PO}_4^{3-}$  concentrations for all the receiving water bodies, except in the case of Sandspruit during the wet season, were observed to exceed the stipulated World Health Organization standard limit of  $0.05 \text{ mg PO}_4^{3-}$  as P/L for water systems intended for the production of potable water. This situation suggested that the river water is polluted from sources along the watershed and it may pose serious eutrophication problems to the aquatic ecosystem. Seasonal variation in  $\text{PO}_4^{3-}$  concentrations of treated wastewater effluents and their respective receiving water bodies is shown in Fig. 5.

The correlation between various physicochemical parameters was assessed and is illustrated in Table 4. The correlation matrices between effluent and downstream samples of various physicochemical parameters at all sites were positive, except for  $\text{NO}_3^{-1}$  concentration in Meyerton and DO concentration in Leeuwkuil

( $r = -0.17$  and  $r = -0.66$ , respectively). A strong correlation was revealed between COD and temperature values for Meyerton; between  $\text{NO}_3^{-1}$  and COD and between DO and temperature levels for Leeuwkuil; between the values for  $\text{PO}_4^{3-}$  and  $\text{NO}_3^{-1}$  and between COD and temperature in Rietgat effluent and downstream samples; and between  $\text{PO}_4^{3-}$  and COD and between DO and temperature; and pH and temperature values for the Sandspruit effluent and downstream samples (Akoteyon and Soladoye 2011). Of these relationships, a moderate negative correlation was observed between the DO concentrations of effluent and downstream samples ( $r = -0.66$ ) for Leeuwkuil. The relationship between the upstream and downstream samples of each parameter was revealed to be significant, except for  $\text{NO}_3^{-1}$  concentration in Meyerton ( $r = 0.28$ ),  $\text{PO}_4^{3-}$  and DO in Rietgat ( $r = 0.40$  and  $0.43$ , respectively) and  $\text{PO}_4^{3-}$  and DO in Sandspruit ( $r = 0.08$  and  $-0.25$ ). This scenario showed that the effluent might not have a serious negative impact on the quality of the receiving environment, except in the case of Sandspruit  $\text{PO}_4^{3-}$  and DO concentrations.

#### Evaluation of the water quality based on WQI

To verify the influence of the nutrient load of the wastewater effluent on the overall quality of the receiving water bodies, the water quality index (WQI) was calculated for the following parameters: DO, COD,  $\text{NO}_3^{-1}$ ,  $\text{PO}_4^{3-}$ , pH and temperature. This WQI as a method is used to enable managers and decision-makers to interpret the results easily and rapidly. The achievability of



**Fig. 5** Seasonal variation in orthophosphate concentrations of wastewater influents, treated wastewater effluents and their respective receiving water bodies ( $n = 160$  samples per season). *DRY* dry season, *WET* wet season

**Table 4** Correlation coefficients (*r*) for the different physicochemical parameters analysed from effluent and receiving water body samples collected from the wastewater treatment plants in Sedibeng district and Soshanguve (*n* = 160 samples per season)

| Parameter                     | Correlation coefficients ( <i>r</i> ) |             |             |             |             |             |             |             |
|-------------------------------|---------------------------------------|-------------|-------------|-------------|-------------|-------------|-------------|-------------|
|                               | Meyerton                              |             | Leeuwkuil   |             | Rietgat     |             | Sandspruit  |             |
|                               | EFF and DWS                           | UPS and DWS | EFF and DWS | UPS and DWS | EFF and DWS | UPS and DWS | EFF and DWS | UPS and DWS |
| PO <sub>4</sub> <sup>-3</sup> | 0.45                                  | 0.95        | 0.33        | 0.69*       | 0.66*       | 0.40        | 0.98***     | 0.08        |
| NO <sub>3</sub> <sup>-1</sup> | -0.17                                 | 0.28        | 0.63*       | 0.85**      | 0.66*       | 0.88**      | 0.47        | 0.87**      |
| COD                           | 0.50*                                 | 0.98***     | 0.89**      | 0.96***     | 0.98***     | 0.66*       | 0.67*       | 0.68*       |
| DO                            | 0.37                                  | 0.53*       | -0.66*      | 0.97**      | 0.08        | 0.43        | 0.89*       | -0.25       |
| pH                            | 0.16                                  | 0.77**      | 0.09        | 0.93**      | 0.42        | 0.76*       | 0.63*       | 0.70**      |
| Temperature                   | 0.92*                                 | 0.96**      | 0.89**      | 0.99**      | 0.82**      | 0.92**      | 0.97**      | 0.89**      |

EFF effluent, UPS upstream, DWS downstream

\*Correlation between the sampling points is statistically significant; \*\*correlation between the sampling points is statistically highly significant; \*\*\* correlation between the sampling points is statistically very highly significant

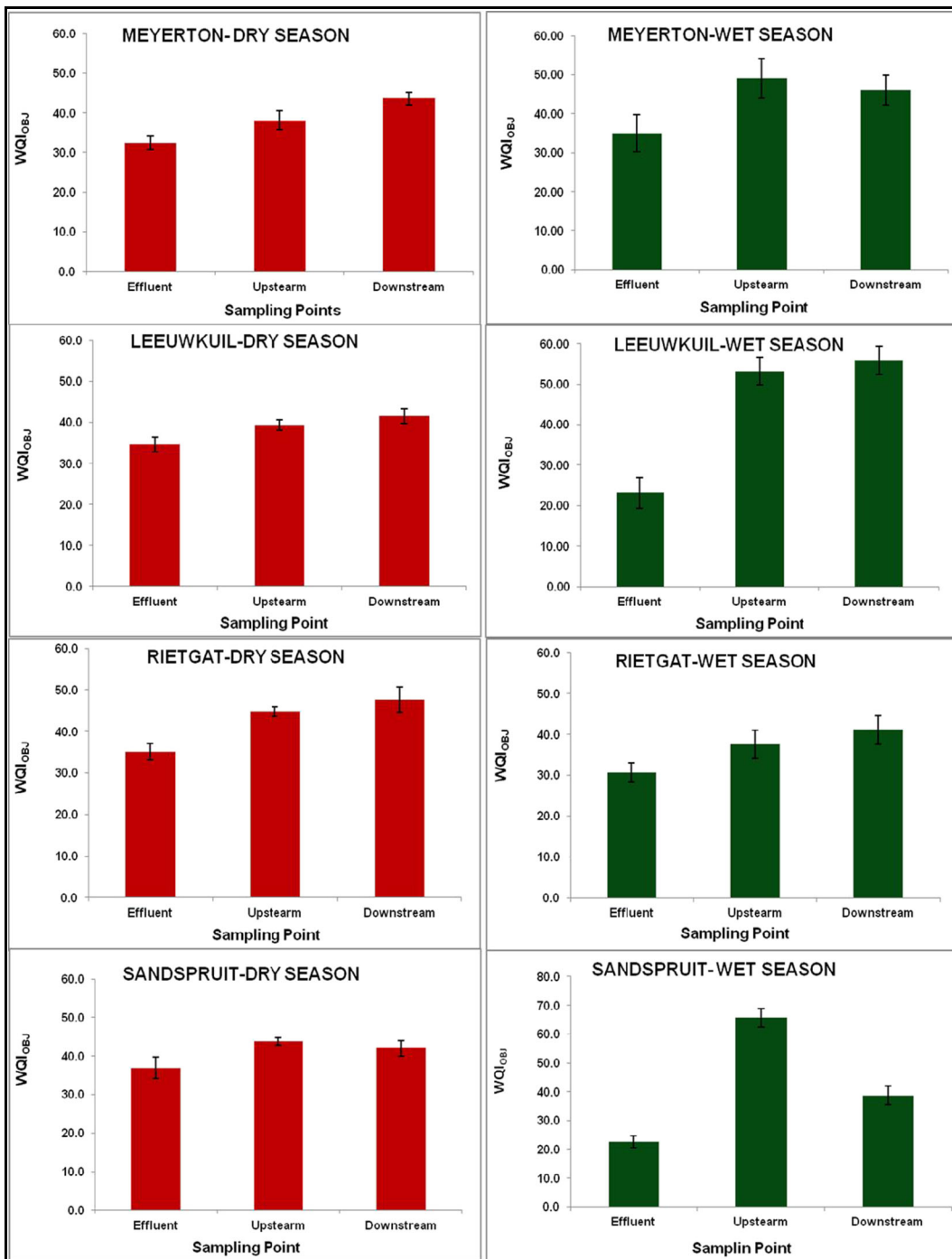
the WQI as an indicator of the level of pollution of the effluent and receiving water bodies was determined in various sampling points of the targeted sampling sites. The WQI was compared with the stringent permissible limits recommended by the government of South Africa. Figure 6 indicates the variations in WQI for the different sampling points in Meyerton, Leeuwkuil, Rietgat and Sandspruit. Based on the water quality parameters given in Table 1, the WQI values for the treated wastewater effluents, upstream and downstream water samples were 32.4 and 35.0, 38.1 and 49.1 and 43.7 and 46.1 in Meyerton; 34.7 and 23.1, 39.4 and 53.2 and 41.6 and 55.9 in Leeuwkuil; 35.1 and 30.6, 44.8 and 37.5 and 47.7 and 41.2 in Rietgat; and 36.9 and 22.6, 43.8 and 65.7 and 42.1 and 38.7 in Sandspruit during the dry and wet seasons, respectively.

The WQI values calculated during this study indicate that the water in the Klip River (Meyerton receiving water body), Vaal River (Leeuwkuil receiving water body), Soutspruit stream (Rietgat receiving water body) and Sandspruit stream (Sandspruit receiving water body) could be classified as having “poor” quality status, except Leeuwkuil and Sandspruit, which could be classified as having “good” quality status during the wet season. The current water quality status of the receiving water bodies indicates that the pollution load was diluted by rain water. When the variations in receiving water WQI<sub>BA</sub> were considered throughout the sampling regime, Meyerton and Leeuwkuil upstream values for the dry season and Sandspruit downstream levels during

the wet season depicted a slightly lower water quality. The decrease in the Meyerton and Leeuwkuil upstream WQI<sub>BA</sub> value might be attributed to non-point (diffuse) source pollutants entering the river upstream of the sampling points. Furthermore, the WQI<sub>BA</sub> values revealed that the effluent discharges from Meyerton and Sandspruit impacted the receiving water bodies downstream of the effluent discharge points. Except for samples from Leeuwkuil upstream, Leeuwkuil downstream and Sandspruit upstream, low WQIs calculated for all the sampling points of the receiving water bodies suggest that the general quality of the water systems is poor.

Significant variations were observed in Leeuwkuil upstream and downstream and Sandspruit effluent WQI values between the dry and wet seasons (*P* < 0.05). The wet season seemed to impact the WQI<sub>BA</sub> values in Leeuwkuil, Rietgat and Sandspruit effluents, Rietgat upstream and downstream samples and Sandspruit downstream water samples, because the increased stormwater runoff might have resulted in uncontrolled non-point source pollution or dilution of the river water and overloading of the wastewater treatment plants. The results of the study indicate possible environmental and public health risks, especially since rural communities in the surrounding areas use raw surface water for recreational and domestic purposes (McCarthy et al. 2007; McCarthy and Humphries 2013).

Globally, several legislations and guidelines have been developed, both at international and national levels



**Fig. 6** Seasonal water quality index (*WQI*) at different sampling points of the selected wastewater treatment plants and their respective receiving water bodies located at Sedibeng District and Soshanguve peri-urban area of the Tshwane Metropolitan Municipality

to minimise the health and environmental concerns associated with the use and discharge of wastewater. The Constitution and other regulations in relations with the Water Act 1998 (No. 36 of 1998) and Water Services

Act 1997 (No. 108 of 1997) were designed to protect the public health and the water environment from reasonably anticipated effects of pollutants contained in the wastewater discharges and other non-point sources of

pollution. The Department of Water Affairs initiated the method of awarding towns within Water Services Authorities with Green Drop status to bring about positive changes to wastewater treatment. As part of the Department's incentive-based regulation approach, a Green Drop Certification Programme was launched in 2008 with the objective to identify and address the main gaps and competencies required, so as to gradually and sustainably improve the level of wastewater management. In 2009, 444 plants in 98 municipalities were assessed, while 821 plants in 156 municipalities were assessed in 2010; Green Drop status was awarded to 40 plants (up from 33 in 2009). At the time, it was found that less than half of the country's wastewater treatment plants are treating effluents to safe and acceptable standards. The latest report (2012) indicates that 831 plants were assessed in 153 municipalities; results indicate that progress has been made in terms of effluent quality and the overall national picture is positive. However, many plants are still not performing as well as they should and the receiving environment will remain under threat (Green Drop Report 2012; DWAF 1996b; DWAF 1996a).

## Conclusion

This investigation was conducted to assess the impact of treated wastewater final effluents produced by the selected wastewater treatment plants in Soshanguve and Sedibeng on the quality of receiving water systems. The water quality of the designated discharge points, as well as upstream and downstream locations was assessed. The results revealed that the effluent quality of wastewater treatment plants complied with South African and WHO stipulated standards for certain parameters, such as temperature and dissolved oxygen, while it fell short of stipulated standards for others. Orthophosphate concentration in the effluent generated from Meyerton ( $1.3 \text{ mg PO}_4^{-3}$  as P/L) and Sandspruit ( $1.1 \text{ mg PO}_4^{-3}$  as P/L) did not comply in wet and dry season, respectively. Moreover, it was revealed that the effluent quality for parameters like free residual chlorine ( $0.27 \pm 0.05 \text{ mg/L}$ ) in Sandspruit, pH (pH 7.6 to 8.1) in both Meyerton and Sandspruit and nitrate Leeuwkuil ( $2.1 \text{ mg/L}$ ) and Rietgat ( $3.8 \text{ mg/L}$ ) were higher than the maximum limit set by the South African and WHO standards. It was also observed that the receiving water quality fell short of the standard limit requirements for

pH (Leeuwkuil and Sandspruit) and orthophosphate (Meyerton). Generally, this study showed that the wastewater final effluent could pose significant public health risks, especially to those who rely on the receiving water bodies for domestic and recreational use without treatment as it was classified as poor and "very poor" and the water quality of the receiving water bodies was poor, except for Leeuwkuil upstream and downstream and Sandspruit upstream that were observed to have good quality water during the wet season.

The results of this study indicate that there is a need for a continuous pollution monitoring program of the treated wastewater effluent and receiving water bodies in developing countries such as South Africa in order to ensure the compliance of wastewater effluent within the stipulated standard limits. Moreover, governments from developing world as well as other concerned bodies should work together in implementing the water laws and regulations and also in developing tangible remedial measures in order to prevent public health concerns due to environmental pollution.

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