The impact of various land uses on the microbial and physicochemical quality of surface water bodies in developing countries: prioritisation of water resources management areas

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Abstract

To protect water resources, the WHO recommends assessing land use influence on water quality, taking into consideration residential development and waste disposal amongst others. Thus, we investigated the impact of unconstructed plots, an informal settlement, an urban residential area, and an industrial area on the microbiological and physicochemical quality of two main tributaries within the Klein Jukskei catchment, Johannesburg, South Africa, to identify areas where immediate resource management strategies were needed. Water samples collected from the tributaries' sources and upstream and downstream from each land use type (Winter and Spring) were analysed for *E. coli* (indicator organism), using the Colilert® 18 system. Physicochemical parameters (Temperature, pH, dissolved oxygen, electrical conductivity, turbidity and total dissolved solids) were measured using multiparameter instruments. The tributaries' sources had the lowest *E. coli* counts (Sandspruit - 0.74; North Ridingspruit - 1.18 $\log_{10}$ MPN/100 mL) during the study. After flowing through the various land uses, mean *E. coli* counts reached 5.98 (Sandspruit) and 4.85 $\log_{10}$ MPN/100 mL (North Ridingspruit). *E. coli* values and all physicochemical parameters (but for pH) downstream from most of the land uses did not meet the South African drinking water quality guidelines. The informal settlement had the most negative impact on the microbial and physicochemical quality of the water within the tributaries. Thus, providing informal settlements with appropriate sanitation facilities is likely to prevent pollution of the water bodies. Protection of the sources should also be implemented

while industrial wastes need to be monitored for conformity with water quality guidelines before discharge.

Keywords: Land uses; microbial quality; *Escherichia coli*; water resource management; water quality

1. Introduction

The detrimental effects of water pollution on environmental and human health have been reported for many decades through numerous studies conducted in many different parts of the world. Despite this abundance of knowledge, the world's water resources continue to face extreme challenges regarding their quantity and quality, mostly due to a fast growing global population (Lee and Schwab, 2005; Okello et al., 2015). The quality of these water resources is usually influenced by the different types of land uses around the water catchments (Ding et al., 2015; Yang et al., 2016). Other factors that have been found to influence the water quality of catchments include: (i) prevailing weather conditions, (ii) the characteristics of the catchment, and (iii) the nature of the drainage system within the catchment (Tran et al., 2015). Different land uses have been found to exert varying degrees of pressure on aquatic environments in different parts of the world. In a study conducted along the Florida coastline, USA, the authors found out that surface runoff from urban areas, and cattle ranches had the highest number of faecal indicator bacteria than that from other sources (Liang et al., 2013). In their study, the authors looked at the quality of runoff over different land use types following rainfall events. Similarly, Ding et al., (2015) concluded that urban land use was the primary source of pollutants in a subtropical river basin in China. This conclusion was based on computer simulations through remote sensing, geographic information systems, and statistical techniques. In Malawi, urban areas and sewage treatment works (point-sources) and agricultural areas, industrial activities mining and residential areas (non-point sources) were reported to negatively affect the waters of the Likangala catchment, with the quality (physical, chemical and microbial) degrading even more during rainfalls (Pullanikkatil et al., 2015). Several other studies around the world have reported similar impact on the chemical as well as on the microbial quality of water catchments (Ding et al., 2015; Mei et al., 2014; Schreiber et al., 2015; Singh, 2014; Sliva and Williams, 2001; Sun et al., 2016; Tong and Chen, 2002; Walsh and Wepener, 2009; Wilbers et al., 2014; Yang et al., 2013, 2016). However, most of these studies have focused on surface runoff over the land uses and have not looked at how the water from these catchments deteriorates as it leaves the source and flows through the different land uses. As such, investigating the quality of water from its source and after it has passed through a given land use, one can conclude that the pollution observed downstream is as a result of that particular land use, especially in the absence of any impact of runoff from rainfall events.

Africa as a whole has been reported to be arid despite its high annual rainfall, due to the higher temperatures experienced by the continent (Pimentel et al., 2013). In addition to the water shortages due to increased demand for food production (intensive irrigational agriculture), there is also an ever-increasing deterioration of water quality as a result of the waste discharged by these same processing industries into the water bodies (Pimentel et al., 2013). This constant pressure accompanied by a lack of proper environmental management of these resources ultimately results in a reduction in water availability for human needs as well as loss of biodiversity (Durand, 2012; Johnson and Paull, 2011). In South Africa, major surface water resources are facing even more severe reductions due to a significant drop in the total amount of rainfall and number of rain days which the country has experienced over the years (MacKellar et al., 2014). The available water resources are also being highly polluted by the country's growing population, rapid industrialisation and unregulated industrial and municipal wastewater discharge from failing sewage treatment infrastructures (Bezuidenhout et al., 2013; Mema, 2010; Nkwonta and Ochieng, 2009; Teklehaimanot et al., 2015). Some of the pollutants that enter into surface water sources could be chemicals such as antibiotics (Zheng et al., 2011) or microorganisms (Hampson et al., 2010). These organisms which include bacteria, viruses, and parasites (Abraham, 2011) have been shown to constitute the greatest threat to human health associated with water quality as a result of the many waterborne diseases they cause (Schreiber et al., 2015; UNEP GEMS/Water Programme, 2008).

Adverse impacts of improper water resource management plans are mostly felt in highly populated low-income settlements (Neswiswi, 2014). As a central role in the management of drinking water sources, the WHO recommends the protection of such sources as the first line barrier (World Health Organization, 2011). Many countries have also set country-specific guidelines for managing their water resources. In South Africa for example, to address the growing concern of pollution of the country's water resources, guidelines have been set at the national level for the management of the different water classes (DWAF, 1996a, 1996b, 1996c, 1996d, 1996e). Like in many developing countries, however, at the municipal level the ecological health of rivers and streams is usually not well documented. The lack of such information could be a significant impediment to the setting up of sound management strategies for the protection of water resources in these countries. To setup such management plans therefore, it is important to understand how different land uses affect the quality of these water resources, especially in most developing countries with insufficient or total lack of access to clean pipe-borne water. Highly polluted waters represent a public health threat to users of such water as well as may increase the cost of treating the water for supply to communities. Therefore, the current study aimed at investigating the impact of different land uses on the microbiological and physicochemical quality of surface water, using two main tributaries within the Klein Jukskei catchment in the city of Johannesburg, South Africa, as a case study.

2 Material and Methods

2.1 Study site

This study was carried out on two large tributaries that form part of the Klein-Jukskei River, between the month of July 2016 and September 2016. The Klein Jukskei River (a.k.a. Little Jukskei River) rises in Roodepoort (Florida Hills) at a height of 169 meters above mean sea level. From Roodepoort, it flows into Randburg in the Gauteng Province of South Africa. At its upper reach, the river flows through informal settlements, residential and industrial areas, while in the northwestern and northern part it flows mainly through agricultural holdings where it is used for irrigation. The two tributaries included in the present study were selected based on the various land uses around them. From its source, the first tributary (Sandspruit) flows through Zandspruit (informal settlement) and Cosmo Cities (urban residential area) before joining the main Klein Jukskei River. The second tributary (North Ridingspruit) on the other hand, flows through small unconstructed plots and then through Kya Sand (industrial area) before entering the main river. The industries in this area usually discharge poorly treated or untreated effluents into the tributaries, thereby affecting their qualities (Fig. 1). The Klein-Jukskei River forms part of the river network that flows into the Hartbeespoort Dam (Dudula, 2007).

Fig.1 Change in physical quality of the water within the tributaries due to industrial discharge

2.2 Sample collection

Sampling was done in July (winter) and September (spring) 2016. Eight sampling sites were selected as indicated in Fig. 2.

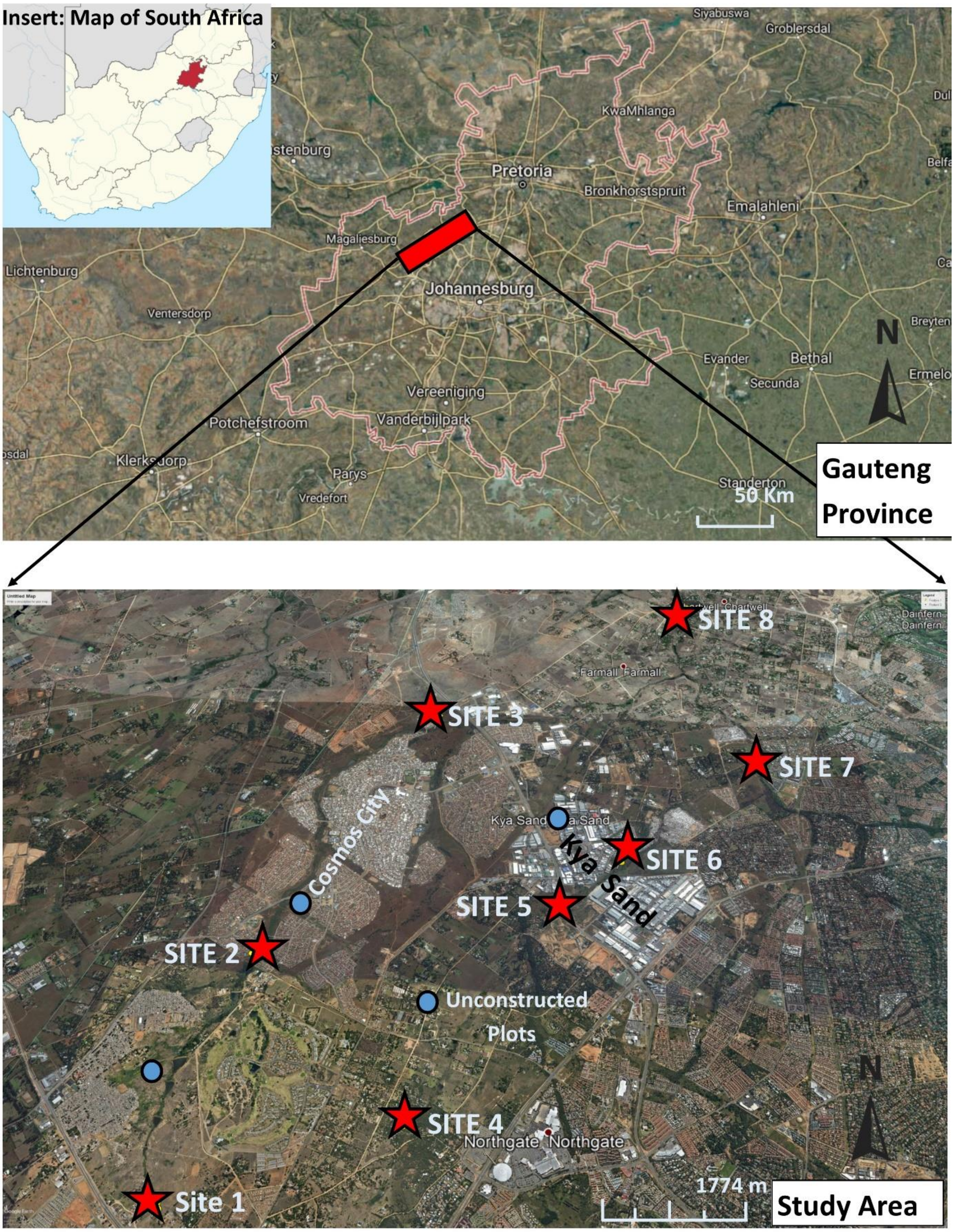

Fig.2 Map of the study area showing various land uses and sampling sites (Site 1 – 8). Source: Google earth

Sites one to six were all located on the two selected tributaries while sites seven and eight were on the main Klein Jukskei River, upstream and downstream from the points where the tributaries entered the river. A total of 192 triplicate samples were collected during the entire study. Water samples were collected at each site in sterile 1 L bottles following standard procedures (APHA/AWWA/WEF, 2001). The water samples were collected approximately 10 cm below the water surface, depending on the depth of the sampling point and extreme precaution was taken not to disturb the bottom sediments as this could affect the microbial count. The samples were transported to the laboratory at 4 °C in a cooler box containing ice packs, where the samples were then analysed within 8 h from the time of collection.

2.3. Enumeration of *E. coli* in water samples

The enumeration of *E. coli* from each sample taken was achieved using the Colilert® 18 / Quanti-tray® 2000 system developed by IDEXX Laboratories (IDEXX, South Africa). Before analysis, each sampling bottle was shaken and inverted several times to ensure proper mixing of the sampled water. Sealed Quanti-Tray® 2000 plates were incubated at 35 ± 1 °C for 18–24 hours. Plates were then examined under UV light, fluorescent wells counted, and the most probable number (MPN) of *E. coli* in the water sample inferred from the statistical table provided with the Colilert® system.

2.4. Determination of physicochemical parameters

Physicochemical parameters of the water, which included dissolved oxygen (DO), electrical conductivity (EC), pH, and total dissolved solids (TDS), were measured for each site upon arrival in the laboratory using an HQ40d Portable Multi-Parameter Meter (Hach, USA). Water temperature was measured *in situ* using a thermometer. Water turbidity was measured using a T100 portable turbidity meter (EUTECH Instruments, Germany).

2.5. Mapping of the study site

ArcGIS v10 was used to map the entire study site. Most current vector layers of the land use, rivers, wetland areas, and sample sites were combined and clipped to form an overall study site map specific to the Klein Jukskei and its tributaries. The mean *E. coli* counts per sampling site for each month were calculated, loaded into the software and the data was then classified into bar graphs for visual comparison.

2.6. Statistical analysis

All data analysis was carried out using MS Excel 2010 and SPSS (Statistical package for the social sciences) version 20 (IBM Corporation, Armonk, New York, USA). A one-way analysis of variance (ANOVA) was used to compare the *E. coli* counts between the different sites as well as the means of the various physicochemical parameters for the seasons. The non-parametric Spearman's rank correlation was used to measure any possible association between the abundance of *E. coli* and the physicochemical parameters, the relationship between the individual physicochemical parameters, and the relationship between the various land uses and the different water parameters. All statistical analyses were performed at a 95% confidence limit. The data was $\log_{10}$ transformed before carrying out the statistical analysis. To compute the geometric means and perform subsequent calculations, *E. coli* counts that were <1 MPN/100 mL were assumed to be 1, while counts >2419.6 MPN/100 mL were converted to the nearest whole number (2420 MPN/100 mL).

3 Results

3.1 Mean *E. coli* count during entire study

The mean *E. coli* counts for each sampling site during the entire sampling period are shown in Fig. 3. The description of each of the sampling sites is shown in Table 1S (Supplementary materials)

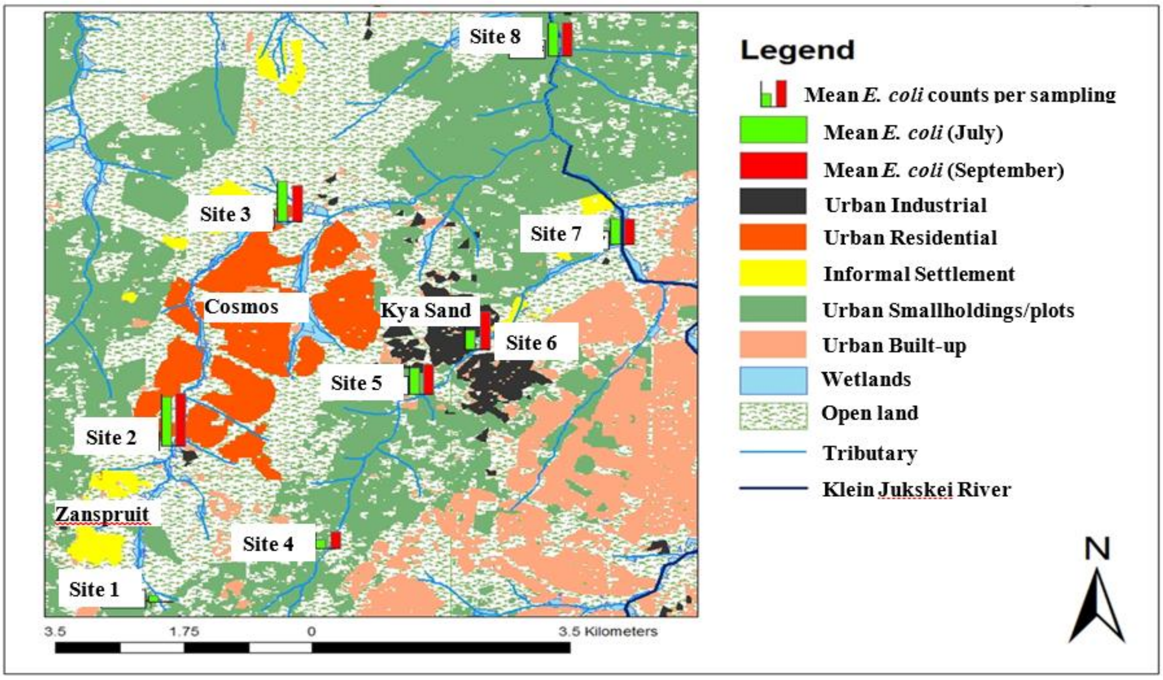

Fig.3 Mean *E. coli* count per site for the winter and the spring sampling seasons

3.1.1 Sandspruit tributary (ST)

Of all the sites of the ST, water samples from Site 1 (the source), which was found just above the Zandspruit informal settlement, had the lowest mean *E. coli* count of 1.04 ± Standard Deviation (SD) during the winter month (July) as well as during the spring month of September (0.74 MPN/100 mL ± SD) (Table 2S; Supplementary material). The highest mean *E. coli* counts during both seasons was observed in water samples collected at Site 2 (below the informal settlement) with mean counts of 5.60 ± SD mL and 5.98 MPN/100 mL ± SD for the winter and spring seasons respectively. There was a statistically significant increase in the *E. coli* counts after the water had passed through the informal settlement in the winter month ($p = 0.000$; $p < 0.05$) as well as during the spring month ($p = 0.000$; $p < 0.05$). The mean *E. coli* count in water samples from Site 2 (below the informal settlement) was over 4 logs (winter) and ~6 logs (spring) higher than in samples collected at Site 1 which was the source of the tributary. In winter, the *E. coil* count decreased by 1.10 logs between Site 2 (below informal settlement and above Cosmos residential area) and Site 3 (downstream from the residential area). Similarly, during the spring month, a 2.04 log decrease in *E. coli* count was observed between Site 2 and Site 3. In both cases, the drop from Site 2 to Site 3 was statistically significant ($p = 0.000$; $p < 0.05$).

3.1.2 North Ridingspruit tributary (NRT)

Like the ST, water samples from the source of the NRT (Site 4) had the lowest mean *E. coli* counts for both the winter (1.18 MPN/100 mL ± SD) and the spring season (1.43 MPN/100 mL ± SD) (Table 2S). However, for this second tributary, the highest *E. coli* count for the winter month (2.98 MPN/100 mL ± SD) was recorded in water samples from Site 5 (above the Kya Sand industrial area) while the highest count for the spring season (4.85 MPN/100 mL ± SD) was recorded in water samples from Site 6 (below the Kya Sand industrial area). In July, there was a significant increase ($p = 0.000$; $p < 0.05$) in the mean *E. coli* count from 1.18 MPN/100 mL ± SD Site 4 to 2.98 MPN/100 mL ± SD, at Site 5. A similar statistically significant increase ($p = 0.000$; $p < 0.05$) was observed for the September month with the *E. coli* count increasing from 1.43 MPN/100 mL ± SD at Site 4 to 3.03 MPN/100 mL ± SD at Site 5. For the industrial area, there was a statistically significant decrease ($p = 0.026$; $p < 0.05$) in the *E. coli* count from 2.98 MPN/100 mL ± SD at Site 5 to 2.17 MPN/100 mL ± SD at Site 6, during the July month. Contrary to the July month, a statistically significant increase ($p = 0.000$; $p < 0.05$) was observed in the *E. coli* count from 3.03 MPN/100 ± SD at Site 5 to 4.85 MPN/100 mL ± SD at Site 6.

Overall, the ST had a statistically significantly higher mean *E. coli* count for the winter ($p = 0.000$; $p < 0.05$) than the NRT. Although there was a similar trend for the spring month, the difference was not statistically significant ($p = 0.397$; $p > 0.05$).

3.1.3 Klein Jukskei River

A statistically significant difference ($p = 0.000$; $p > 0.05$) was observed in the mean *E. coli* count for the month of July between samples collected at Site 7 (2.80 MPN/100 mL ± SD) Table 2S, which is upstream from the tributaries' entry point and those collected at Site 8 (3.77 MPN/100 mL ± SD), downstream from the tributaries' entry point). During the September month, a similar statistically significant difference ($p = 0.000$; $p < 0.05$) was observed between *E. coli* counts in water from the two sites with Site 8 recording a higher mean *E. coli* count of 3.68 MPN/100 mL ± SD compared to 3.04 MPN/100 mL ± SD at Site 7.

3.2 Physicochemical parameters during winter and spring sampling seasons

The mean values for the physicochemical parameters are shown in Table 3S. During the winter month, mean water temperatures ranged between 8.3°C and 9.4°C, turbidity ranged between 3.1 NTU and 131.4 NTU, pH ranged between 7.1 and 8.1, EC ranged between 236.5 µs/cm and 610.0 µs/cm, DO ranged between 6.7 mg/L and 10.4 mg/L, while TDS ranged between 197.6 and 520.3 mg/L. During the Spring month, mean temperatures, turbidity, pH, EC, DO and TDS ranged between 11.4°C and 15°C, 3.7 NTU and 37.2 NTU, 7.3 and 8.3, 239.5 µs/cm and 701.0 µs/cm, 4.0 mg/L and 8.9 mg/L, and 182.4 mg/L and 543.3 mg/L respectively. There was a change in most of the physicochemical properties of the water as it flowed through the various land uses around the tributaries. The level of significance of the variations in each of the physicochemical parameters is indicated in Table 1.

Table 1 Level of significance of the changes in physicochemical parameters during the entire study

Season	Land Use[a]	Physicochemical parameter[b]					
		Temperature	Turbidity	pH	EC	DO	TDS
Winter (July)	IS	0.424	*0.001*[c]	*0.009*[c]	*0.000*[c]	*0.001*[d]	*0.000*[c]
	RA	0.667	*0.004*[d]	*0.004*[c]	*0.001*[d]	*0.005*[c]	*0.000*[d]
	UP	0.930	0.219	*0.000*[c]	0.952	*0.001*[c]	0.930
	IA	1.000	0.256	0.066	0.619	0.564	0.632
	KJR	0.936	0.732	0.947	*0.002*[c]	0.073	*0.003*[c]
Spring (September)	IS	0.116	*0.000*[c]	*0.000*[c]	*0.000*[c]	*0.002*[d]	*0.000*[c]
	RA	0.372	*0.000*[d]	*0.007*[c]	*0.007*[d]	*0.010*[c]	*0.001*[d]
	UP	*0.047*[c]	0.899	*0.004*[c]	*0.000*[c]	*0.007*[c]	*0.000c*
	IA	0.519	0.094	*0.010*[d]	*0.002*[d]	*0.000*[d]	*0.002*[d]
	KJR	0.852	0.111	*0.019*[d]	*0.003*[c]	0.849	*0.002*[c]

[a]IS = Informal Settlement; RA = Residential Area; UP = Unconstructed Plots; IA = Industrial area; KJR = Klein Jukskei River

[b]Parameters with a statistically significant change ($p < 0.05$) are in italics. EC=Electrical Conductivity; DO = Dissolved Oxygen; TDS = Total Dissolved Solids

[c]Significant increase in the mean value of the given parameter

[d]Significant decrease in the mean value of the given parameter

Comparing the tributaries, the ST recorded a higher EC, TDS and pH and a lower DO in the winter month than the NRT. Only the EC ($p = 0.001$; $p < 0.05$), DO ($p = 0.032$; $p < 0.05$) and the TDS ($p = 0.001$; $p < 0.05$) were statistically significantly different. During the winter month, the NRT recorded higher water temperatures and turbidity than the ST, but none of them was statistically significant. In the spring month, the mean turbidity at NRT was statistically higher ($p = 0.037$; $p < 0.05$) than the ST while the pH was statistically higher ($p = 0.038$; $p < 0.05$) at the ST than at the NRT.

3.3 Seasonal variations in the microbial and physicochemical parameters

3.3.1 Microbial quality

There was an overall increase in the mean monthly *E. coli* count during the spring season compared to the winter season, although, this increase was not statistically significant ($p = 0.705$; $p > 0.05$). When considered individually, the NRT recorded a statistically significant higher mean monthly *E. coli* count during the spring compared to the winter season ($p = 0.004$; $p < 0.05$), while no statistical difference was observed between the winter and the spring season *E. coli* counts for the ST ($p = 0.708$; $p > 0.05$) and the main Klein Jukskei River ($p = 0.880$; $p > 0.05$).

3.3.2 Physicochemical parameters

For the overall change in physicochemical parameters, there was an increase in mean monthly temperature, pH, EC and TDS during the spring season compared to the winter season. However, the increase was only statistically significant for temperature ($p = 0.000$; $p <0.05$) and EC ($p = 0.011$; $p <0.05$). On the other hand, there was an overall decrease in the mean monthly turbidity and DO, with the decrease being statistically significant only for the DO ($p = 0.000$; $p < 0.05$). Individually, a statistically significant increase in temperature ($p = 0.000$; $p < 0.05$) was observed during the spring season compared to the winter season for the ST. The pH, EC, and TDS also showed increases while there was a decrease in the mean turbidity and DO, none of which was statistically significant. For the NRT, statistically significant increases were observed for mean monthly temperature ($p = 0.000$; $p < 0.05$), EC ($p = 0.001$; $p < 0.05$) and TDS ($p = 0.000$; $p < 0.05$) while there was a statistically significant decrease in the mean monthly DO concentration ($p = 0.001$; $p < 0.05$). Mean monthly turbidity and pH showed statistically insignificant decreases in the spring month compared to the winter month for the NRT. Regarding the main river stretch, statistically significant increases were observed in the mean monthly temperature ($p = 0.001$; $p < 0.05$) and pH ($p = 0.018$; $p < 0.05$) while a statistically significant decrease was observed for DO ($p = 0.001$; $p < 0.05$) during spring compared to winter. For this main river stretch, turbidity and TDS decreased in spring compared to winter, though in a statistically insignificant manner.

3.4 Correlation between measured water parameters

3.4.1 Correlation between *E. coli* counts and physicochemical parameters

There was an overall positive correlation between the mean *E. coli* count and turbidity ($r_s = 0.424$; $p = 0.000$), pH ($r_s = 0.384$; $p = 0.002$) and TDS ($r_s = 0.660$; $p = 0.000$). The overall mean *E. coli* count was negatively correlated to DO (r_s = -0.322; p = 0.010). The correlation between the mean *E. coli* count and the physicochemical parameters for the individual river stretches are shown in Table 2.

Table 2 Correlation between the mean *E. coli* count and the physicochemical parameters for the individual river stretches

		Physicochemical parameters					
River stretch	**Correlation**	**Temperature**	**Turbidity**	**pH**	**EC**	**DO**	**TDS**
ST	r_s	-0.008	0.888	0.480	0.868	-0.801	0.901
	p	0.969	*0.000*	*0.018*	*0.000*	*0.000*	*0.000*
	N	24	24	24	24	24	24
NRT	r_s	0.229	0.564	0.207	0.507	-0.222	0.521
	p	0.282	*0.004*	0.331	*0.012*	0.298	*0.009*
	N	24	24	24	24	24	24
Klein Jukskei	r_s	-0.046	0.460	-0.339	0.628	-0.200	0.631
River	p	0.867	0.073	0.200	*0.009*	0.457	*0.009*
	N	16	16	16	16	16	16

r_s = Spearman's rank correlation coefficient; p = significance; N= Number of samples.
Figures in italics are the p - values for which correlation was significant ($p < 0.05$).

3.4.1 Correlation between the various physicochemical parameters

The overall correlation between the different physicochemical parameters is shown in Table 4S (Supplementary material). There was a positive correlation between the following pairs of physicochemical parameters: temperature/pH, pH/DO, EC/turbidity, EC/TDS and TDS/turbidity. Negative correlations were observed for the following pair of parameters: pH/turbidity, DO/temperature, DO/turbidity, DO/EC and DO/TDS. The correlation between the different physicochemical parameters for the individual river stretches is shown in Table 5S (Supplementary material). For the ST, positive correlations were observed between pH and turbidity, EC, TDS; between EC and turbidity, TDS; between TDS and turbidity. A negative correlation was found between DO/turbidity, DO/EC, and TDS/DO. The following parameter pairs showed a positive correlation for the NRT: EC/temperature, DO/pH, TDS/temperature, TDS/pH, TDS/EC; while DO/temperature and DO/EC showed negative correlations. In the main river stretch (Klein Jukskei River), pH/temperature and TDS/EC showed positive correlations while turbidity/temperature, pH/turbidity, and temperature/DO all showed negative correlations.

3.5 Correlation between water parameters and the different land uses

The correlation coefficients and the levels of significance for the association between the various land uses and all the water parameters are shown in Table 3.

Table 3 Correlation coefficients and the levels of significance for the association between the various land uses and all the water parameters

Sampling Month	Parameter	Informal Settlement		Cosmos City (Residential Area)		Unconstructed Plots		Industrial Area (Kya Sand)		Main River	
		r_s	p	r_s	p	r_s	p	r_s	p	r_s	p
Winter (July)	*E. coli*	0.875**	0.000	-0.869**	0.000	0.678**	0.000	-0.386	0.062	0.491*	0.015
	Temperature	-0.274	0.511	0.000	1.000	-0.218	0.604	0.055	0.897	0.000	1.000
	Turbidity	0.873**	0.005	-0.873**	0.005	0.873**	0.005	-0.655	0.078	0.327	0.429
	pH	0.878**	0.004	0.768*	0.026	0.873**	0.005	0.764*	0.027	0.000	1.000
	EC	0.873**	0.005	-0.878**	0.004	0.000	1.000	0.218	0.604	0.878**	0.004
	DO	-0.873**	0.005	0.873**	0.005	0.873**	0.005	-0.274	0.511	-0.655	0.078
	TDS	0.873**	0.005	-0.873**	0.005	0.000	1.000	0.218	0.604	0.873**	0.005
Spring (September)	*E. coli*	0.896**	0.000	-0.871**	0.000	0.735**	0.000	0.760**	0.000	0.771**	0.000
	Temperature	0.442	0.273	0.442	0.273	0.663	0.073	-0.442	0.273	-0.218	0.604
	Turbidity	0.873**	0.005	-0.873**	0.005	0.220	0.601	0.549	0.159	0.165	0.697
	pH	0.873**	0.005	0.873**	0.005	0.873**	0.005	-0.873**	0.005	-0.823*	0.012
	EC	0.873**	0.005	-0.546	0.162	0.546	0.162	-0.436	0.280	0.873**	0.005
	DO	-0.873**	0.005	0.873**	0.005	0.873**	0.005	-0.873**	0.005	-0.109	0.797
	TDS	0.878**	0.004	-0.546	0.162	0.878**	0.004	-0.439	0.276	0.546	0.162

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).

No correlation was observed between the temperature, and any of the different land uses during both sampling months. During the Winter month (July), for the ST, the Informal Settlement was positively correlated with the mean *E. coli* concentration, Turbidity, pH, EC and TDS but negative correlated to DO. The same trend was observed during the Spring month (September). For both seasons, the Residential Area (Cosmos City) was positively correlated to the pH and DO but negatively correlated with all the other parameters. For the NRT, the Unconstructed Plot was positively correlated to the *E. coli* concentration, pH and DO. Also, this site was positively correlated to the turbidity in the winter season but not in the spring season; it was positively correlated to TDS in the spring season but not in the winter season. Contrary to the unconstructed plot, the Industrial Area was only correlated (positively) with pH in the winter season while in the Spring season, it was positively correlated to *E. coli* concentration but negatively correlated to DO and pH. Finally, the main river stretch sampled was positive correlated to the *E. coli* concentration, EC and TDS (winter) and *E. coli* and EC (summer), but negatively correlated with pH in summer.

4 Discussion

The South African guidelines for recreational water recommends that no *E. coli* be detected in any given 100 mL of water meant for domestic use (DWAF, 1996a) and indicates that ≥ 130 Colony Forming Units (CFU)/100 mL (*E. coli*) would represent a health risk associated with freshwater resources meant for recreational purposes (DWAF, 1996b). The results obtained in the present study for both months indicate that the two tributaries flowing into the Klein Jukskei River are of poor microbial quality and not suitable for household use. Water samples from both tributaries recorded an overall higher mean *E. coli* count than those recommended for drinking purposes. Also, the findings of the current study indicate that different land uses have different impacts on the microbial and physicochemical properties of a given water catchment and that the tributaries of the Klein Jukskei River are also of poor physicochemical quality. Furthermore, the informal settlement and the industrial area are amongst the main contributors to the poor microbial and physicochemical quality of the tributaries. As such, identifying the impact of these land uses is a major step in identifying areas of priority regarding the management and protection of water resources.

4.1 Mean *E. coli* count during entire study

4.1.1 Sandspruit tributary (ST)

Site 1, the source of the ST recorded the lowest mean *E. coli* count (<1 MPN/100 mL) for this tributary. As the water flowed through the informal settlement (Zandspruit), there was a statistically significant increase in the mean *E. coli* concentration. This spike in *E. coli* in the surface water indicates the negative impact the informal settlement had on the tributary. Zandspruit consists of an estimated 14 500 shacks inhabited by approximately 80 000 residents. This informal settlement lacks adequate access to clean water, sewage and refuse removal services (Dawson et al., 2013). Due to the absence of appropriate sanitary infrastructure, residents of this informal settlement dispose of their household, as well as excretory waste in the tributary or on its banks with a resulting negative impact on the tributary's water, especially during rainfall. However, given that the current study was conducted in the dry months in South Africa indicates that the observed pollution was probably because of direct waste deposition into the water bodies, thus highlighting the immediate impact of the land uses on the quality of the water catchment. This negative impact was further supported by the strong positive correlation ($p = 0.000$) between the informal settlement and the *E. coli* concentration. The impact of informal settlements on the microbial quality of water resources has previously been reported in the region (Abia et al., 2015). In a study conducted in the same Gauteng Province, it was observed that sites downstream of an informal settlement (Alexandria) recorded *E.* coli counts which were at least two orders of magnitude higher than those measured at three upstream locations (Matowanyika, 2010).

Cosmo City is a well-known functioning suburb and is a rapidly growing residential area described as a mixed-use, integrated housing development area (Palmer Development Group, 2011). The residential area covers about 9.90 km² of land and has a population of over 44 295 people with about 14 783 (1493.84 per km²) households (2011 census). The area is well managed, with in-house water supply and safe sanitation facilities (Palmer Development Group, 2011). Over the study period, it was observed that there was a statistically significant drop in the mean *E. coli* counts (from the high values recorded at Site 2) as the tributary flowed pass Cosmos City. One important factor could have accounted for the drop in the *E. coli* count downstream after the tributary had flowed through the Cosmos City. The main reason could be due to the wetland through which the tributary flowed. As the tributary flows pass through Cosmos City, its channel widens, meanders more and has an increased presence of vegetation. These probably favoured settling of the *E. coli* into the bed sediments or the *E. coli* being trapped and filtered by the plants in the water, resulting in a lower mean count downstream from sampling Site 2, as demonstrated by a strong negative correlation (p = 0.000) between Cosmos City and the *E. coli* count. Wetlands have been shown to actively and efficiently remove microorganisms from surface water bodies (Hench et al., 2003; Jia et al., 2016). Despite the significant drop in the mean *E. coli* count at Site 3, the quality was still not safe for drinking or recreation. However, this site is used for religious (baptisms) and recreational (swimming) purposes, meaning that the river still represents a health risk for the users of the water at this point. Exposure to such water has been demonstrated to result in the possibility of contracting gastrointestinal illnesses and other waterborne diseases (Howard et al., 2006).

4.1.2 North Ridingspruit tributary (NRT)

Like the ST, the source (Site 4) of the NRT recorded the lowest mean *E. coli* count for this tributary. Unexpectedly, there was a statistically significant increase in mean *E. coli* count at Site 5 after the tributary flowed through an area of unconstructed plots. Also, this area was positively correlated (p = 0.000) to the *E. coli* concentration. However, although unconstructed, there are some recreational resorts uphill on both sides of the unconstructed plots while the tributary flows in the valley down. Some of the recreational activities at these resorts include horse riding, and as such there existed small scale horse ranches in these holdings. The increase in mean *E. coli* at this point count could, therefore, have been of animal origin. Also, given that the area was not habited, it could have served as a safe place for other wild animals that could access the water at that point. *E. coli* is well-known to colonise the intestinal tract of both diseased and healthy warm-blooded animals and birds (Barnett Foster, 2013; Ghanbarpour and Daneshdoost, 2012; Hammerum and Heuer, 2009; Oporto et al., 2008).

Kya Sand is known as one of Johannesburg's biggest industrial areas, with a wide variety of industries including food processing industries. Although there was a statistical drop in the mean *E. coli* count as the tributary flowed through the industrial area during the winter month (July), a significant increase was observed during the spring month (September). This increase could be due to a recent discharge of waste by the industries into the tributary in September as seen in Fig. 1. The dynamics in the association of this land use with the water quality in the NRT was further supported by the lack of a significant correlation with the *E. coli* concentration during the winter month (p = 0.062) and a positive correlation (p = 0.000) during the summer month. The discharge of waste into the tributary, especially from the food processing industries, could lead to an increase in nutrients within the water channel, thereby favouring the growth of *E. coli*. Industries have been reported to negatively affect water quality by the direct discharge of untreated or poorly treated waste into water courses (Awomeso et al., 2010; Kanu and Achie, 2011). Another marked characteristic of the Kya Sand industrial area is the development of an informal settlement in the area. This settlement is inhabited by people who work in the factories and by some others that make a living from picking recyclable solid wastes from the industries. The informal settlement also lacks sanitary facilities, and the tributaries are therefore used as a dumping site for their waste. As such, it was common to see numerous instances of open defecation in the area during the sampling period, a practice that is well known to negatively impact the quality of waterbodies (Matowanyika, 2010).

4.1.3 Klein Jukskei River

There was a significant statistical difference between the up and the downstream sites on the main Klein Jukskei River during both seasons (winter and spring), indicating the contribution of the tributaries to the poor quality of the water of the main river. Cold and dry weather characterise the winter season in most parts of South Africa. These weather conditions affect the volume of water that flows in most catchments and some even dry out completely. Similarly, the Spring month does not experience rainfall, but is rather characterised by dry, windy weathers. As such, the quality of the river could have been minimally influenced by runoff indicating that the tributaries probably played a significant role in the deteriorating water quality as it flowed from Site 7 to Site 8. However, some parts of South Africa, including Gauteng, do experience occasional rainfall events in winter. This was the case during the sampling rounds in the current study. Although the sources of the tributaries always recorded the lowest *E. coli* counts during the sampling rounds, a spike was observed at each source following a rainfall event, in the last sampling week in winter, on the eve of the sampling day. Previous studies have highlighted the increase in microbial loads in water catchments following rainfall events (Chen and Chang, 2014; Coulliette and Noble, 2008).

4.2 Physicochemical parameters and correlation with the abundance of *E. coli*

The WHO stipulates that, although microbial pollutants from faecal sources pose the greatest majority of health problems associated with drinking water, some naturally occurring physicochemical parameters, as well as those induced by human activities, could pose significant problems (WHO, 1997). In addition to the WHO water quality guidelines, South Africa has a set of country specific requirements for different water types (UNEP GEMS/Water Programme, 2008).

For drinking water, the South African water quality guidelines recommend EC values between 0 and 70 µs/cm (DWAF, 1996a). Based on these guidelines, all the sampling points in the current study were not compliant with the South African recommendations for drinking water. Electrical conductivity is a measure of the total concentration of dissolved ions in water and increases as the concentration of dissolved pollutants increases (Prathumratana et al., 2008). It has also been shown that areas that experience higher evaporation than precipitation tend to have high EC values in their surface waters (UNEP GEMS/Water Programme, 2008). This could, therefore, explain the high levels of EC recorded in the current study (including at the sources) given that South Africa is a semi-arid region characterised by little amounts of rainfall and considering that sampling was mostly done in the dry months. However, the significant spikes in EC values as the water went through the informal settlement (during both seasons) indicate that this land use was the leading source of pollution in the ST. This is further supported by the fact that the EC was positively correlated with the informal settlement (p = 0.005) and significantly dropped as the tributary flowed through Cosmos City (with a negative correlation; p = 0.004) that had well-constructed sanitary facilities. In the NRT, although there was an increase in EC values as the tributary flowed pass the plots, the increase was not as high as that observed with the informal settlement on the ST. The increase is EC seen in this second tributary (NRT) could be due to weathering from surrounding surfaces (UNEP GEMS/Water Programme, 2008). There was a positive correlation between the EC and the abundance of *E. coli* in both tributaries and the main river stretch. A similar positive correlation between EC and *E. coli* had previously been reported in other studies (Pereira et al., 2011). No significant correlation was observed between the unconstructed plots and the EC for both seasons (Table 3).

Although it may be difficult to establish a direct relationship between the pH of drinking water and its impact on human health, the South African drinking water quality guidelines recommend a pH range between 6 and 9 (DWAF, 1996a). Based on this range, all the sampling sites recorded mean pH values ranging between 7.1 and 8.3 (Table 3S) which were all in conformity with the set standards. Most bacteria are known to thrive better around neutral pH of 7 (Fricker et al., 2010). As such, the pH ranges obtained in the current study for both tributaries favoured the survival of *E. coli* as demonstrated by the positive correlation between pH and *E. coli* counts. A similar relationship had previously been reported in a study conducted in the Apies River, South Africa (Abia et al., 2015).

The target water quality range for turbidity of any water meant for domestic use in the South African water quality guidelines has been set at 0 – 1 NTU (DWAF, 1996a). In the current study, all the sampling sites largely exceeded the recommended South African set guidelines. The mean turbidity values recorded at the sites ranged between 3.1 NTU and 131.4 NTU (Table 3S). Again, Site 2 (after informal settlement) had the highest occurring turbidity value after Site 5 (after unconstructed plots). The high mean turbidity value obtained at Site 5 was due to runoff following a rainfall event on the eve of the sampling day. The discharge of waste from the industrial area also caused a spike in the turbidity values at Site 6 (Fig. 1). Water of high turbidity may be objectionable for consumption, may interfere with treatment options thereby increasing water treatment cost, and most importantly may have public health implications due to the association of pathogenic microorganisms in turbid waters (DWAF, 1996a; Igbinosa and Okoh, 2009; UNEP GEMS/Water Programme, 2008). The possible microbial health risk associated with turbid water was supported by the positive correlation between turbidity and mean *E. coli* counts for both tributaries. Although several studies have reported different degrees of correlation between *E. coli* and turbidity (Cho et al., 2010), it can be said that visual observation of water for cloudiness (turbidity) could serve as a guide to community members of the possible quality of the water (Schwartz, 2000).

The TDS is an indication of the total concentration of various dissolved inorganic salts in water. These salts may naturally originate from decomposing plants or dissolution from surrounding soils and rocks and as such could be dependent on the geological characteristics of the landscape through which a water body flows (DWAF, 1996a). However, high levels of these salts may also arise due to human pollution (Prathumratana et al., 2008). These elevated concentrations may have adverse osmoregulation effects on aquatic lives (Igbinosa and Okoh, 2009) or in humans such as laxative effects especially in cardiac and hypertensive patients, blood intoxication (toxaemia) in pregnant women and kidney malfunctioning (DWAF, 1996a). As such, the South African water quality guidelines stipulate that TDS in water meant for domestic use should fall within the range of 0 – 450 mg/L. All the sampling sites (but for Site 2 below the informal settlement, which exceeded the limits during both seasons) met the set requirements. This again highlights the negative impact of the informal settlement on the water quality of the ST. Given that EC and TDS are both measures of the concentration of dissolved solids in water, a similar positive correlation was observed between the mean *E. coli* counts and TDS. Again, EC and TDS were positive correlated with the informal settlement during both seasons, strengthening the evidence that the informal settlement was a major contributor to poor surface water quality.

Mean DO values during the entire sampling period ranged between 4.0 mg/L and 10.4 mg/L (Table 3S). Although no health-based guidelines have been recommended for DO by the WHO (WHO, 2011), DO is an essential water parameter required for the survival of aquatic life (Tunc et al., 2013).

A decrease in DO concentration in environmental water bodies may favour the breakdown of nitrates into nitrites which have adverse health effects such as methaemoglobinaemia, especially in infants if consumed (DWAF, 1996a; Tunc et al., 2013; WHO, 2011). It is suggested that the DO in drinking water should be around 6 mg/L (Igbinosa and Okoh, 2009) while the US Environmental Protection Agency (USEPA) suggests minimum DO concentrations between 5 mg/L and 9.5 mg/L for aquatic biota, depending on their life stage and the water temperature (ARMCANZ and ANZECC, 2000). Again, based on these suggestions, although most sites were within the set limits, Site 2 and Site 6 recorded DO values below 5 mg/L implying some form of pollution had occurred, especially at Site 6 as seen in Fig. 1. A negative correlation was observed between DO and mean *E. coli* counts in the ST. Specifically, a negative correlation was observed between the informal settlement and the DO during both seasons. This could have been as a result of human waste pollution from the informal settlement that favoured the rapid growth of the *E. coli* thus leading to the depletion of DO. This negative correlation corroborates findings of Pennington et al., (2001) who observed that as DO decreased in a river, the number of heterotrophic plate count bacteria increased. This is further supported by a positive correlation between the cosmos city and the DO and a drop in the *E. coli* concentration as the water flowed through the residential area. However, no correlation was found between DO and *E. coli* counts in the NRT. The decrease in DO in this tributary could have been due to the higher temperatures experienced by the tributary compared to the ST. Temperature and DO have been shown to have a strong negative relationship (Tiefenthaler et al., 2009).

The mean water temperatures measured during the entire study ranged between 8.3 °C and 9.5 °C in winter and between 11.4 °C and 15.1 °C in spring. These values were all below the 25 °C recommended limit of the South African domestic water quality and were also lower than those recorded in a study conducted in a rural South African community (Igbinosa and Okoh, 2009). The temperature of every aquatic environment is an important physical parameter that directly or indirectly influences other water parameters such as DO (ARMCANZ and ANZECC, 2000). Drastic reductions in the concentration of DO in water as a result of high-temperature increase may lead to the dead of fishes (Kumar and Puri, 2012) while temperatures drop below 5 °C may result in the eggs of some water-breeding insects from hatching (ARMCANZ and ANZECC, 2000). Temperature has been found to be one of the factors influencing the growth and survival of microorganisms in the aquatic environment. However, in the current study, there was no correlation between temperature and the abundance of *E. coli* for the various water stretches. These results contradict the findings of Abia et al. (2015) who reported a positive correlation between water temperature and *E. coli* abundance. This difference could be because, in the current study, there was a slight variation in the temperature within the same season due to fewer sampling rounds compared to the study of Abia et al. (2015). Also, no significant correlation was observed between temperature and any of the land uses, indicating that these land uses did not have an influence on the temperature of the tributaries.

4.3 Seasonal variations in the microbial and physicochemical parameters

The impact of seasonality on the microbial and physicochemical quality of aquatic environments has been reported by several other studies (Cheng et al., 2013; Shabalala et al., 2013; Uzoukwu et al., 2004). Most of these studies have reported a decrease in water quality during the rainy seasons compared to the dry season as a result of increased runoff following rainfall events. The current study was, however, conducted between July and September neither of which is a wet month in South Africa. As such, the difference in seasons was based on a statistically high temperature recorded in Spring (September) compared to Winter (July). Higher temperatures in spring favoured the growth of *E. coli* in this season compared to the winter season although the increase in the overall mean monthly *E. coli* count was not statistically significant. When considered individually, though, the NRT had a statistically higher mean *E. coli* count in spring than in winter whereas the increase in the ST was not statistically significant. Given that there was minimal rain during these seasons and as such no runoff, this is a reliable indication that the changes in the water quality observed in the current study were all as a result of the influence of the various land uses around the tributaries. Also, as earlier mentioned, a rise in water temperature results in higher dissolution of salts in the water and a decrease in DO (ANZECC & ARMCANZ, 2000). This is supported by the fact that the statistically significant higher spring temperatures were accompanied by a statistically significant increase in EC and TDS and a decrease in DO in the NRT. Similar trends were observed for the ST although there were not statistically significant. Overall, there was a statistically significant increase in EC and a statistically significant decrease in DO during the entire study period.

5 Conclusion

The overall aim of this study was to evaluate the impact of different land uses on the microbial and physicochemical quality of surface waters, using two main tributaries of the Klein Jukskei River as case study, to identify the areas where management was needed. From the results, it is concluded that both the ST and the NRT are of poor microbial as well as poor physicochemical quality and are not suitable for domestic use. Most of the physicochemical parameters as well as the microbial counts did not conform to the South African guidelines for drinking water quality. The informal settlement had the greatest negative impact on the water quality compared to the other land uses. As such, it is recommended that adequate water supply and sanitation facilities be put in place at the informal settlement to prevent pollution of water bodies by such land use. Also, effluents from industrial discharges should be monitored to ensure that they conform to national water quality guidelines. Furthermore, given that there was an improvement in the water quality after the ST flowed through the Cosmos City wetland, it would be beneficial for countries without adequate access to safe pipe-borne water, to protect their wetlands as they play a significant role in the natural purification of the water.

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Supplementary material

Table 1S Location and description of sampling sites

Catchment Stretch	Sampling Site	Latitude	Longitude	Site Description
Sandspruit Tributary	Site 1	-26.06916667	27.91444444	Source of the Sandspruit tributary (ST), above the informal settlement
	Site 2	-26.04527778	27.91611111	Below the informal settlement, above residential area
	Site 3	-26.01111111	27.93027778	Below the residential area
North Ridingspruit Tributary	Site 4	-26.06083333	27.93361111	Source of the North Ridingspruit tributary (NRT)
	Site 5	-26.03750000	27.94638889	Above the industrial area
	Site 6	-26.03055556	27.95333333	Below the industrial area
Klein Jukskei River	Site 7	-26.01472222	27.97111111	Above confluence of tributaries with Klein Jukskei River
	Site 8	-25.98611111	27.96333333	Below confluence of tributaries with Klein Jukskei River

Table 2S *E. coli* data, Geometric mean and standard deviations of *E. coli* counts per site per site during entire study

July	R1*			R2			R3			R4					
	1**	2	3	1	2	3	1	2	3	1	2	3	n	Geometric mean	Standard Deviation
Site 1	0.61	0.61	1.00	0.61	1.00	1.00	1.00	1.00	1.00	1.83	2.02	1.96	12	1.04	0.51
Site 2	5.38	5.38	5.38	5.59	5.74	5.69	5.46	5.71	5.51	5.96	5.86	5.59	12	5.60	0.19
Site 3	3.38	3.38	3.38	5.01	5.01	4.96	5.35	5.16	5.41	4.67	4.44	4.64	12	4.50	0.77
Site 4	1.00	0.30	1.00	1.00	1.00	1.00	1.04	0.88	1.16	2.71	2.86	2.89	12	1.18	0.88
Site 5	3.38	3.30	3.38	2.30	2.30	2.30	2.61	2.87	2.61	3.56	3.46	3.62	12	2.93	0.53
Site 6	2.13	2.08	2.13	2.76	2.56	2.71	1.00	1.00	1.00	3.91	3.93	3.83	12	2.17	1.09
Site 7	3.38	3.38	3.38	2.91	3.24	3.10	2.30	1.00	2.60	3.43	3.02	3.34	12	2.80	0.70
Site 8	3.38	3.38	3.38	3.78	3.79	3.76	3.86	3.71	3.79	4.12	4.28	4.17	12	3.77	0.30
September															
Site 1	0.30	1.00	0.30	1.00	1.00	1.00	0.30	1.00	1.00	1.00	1.00	1.00	12	0.74	0.32
Site 2	5.99	5.99	6.02	6.11	5.89	5.99	5.99	6.02	5.89	5.99	5.91	5.96	12	5.98	0.06
Site 3	3.66	3.71	3.78	4.38	4.25	4.49	3.95	3.79	4.04	3.85	3.66	3.86	12	3.94	0.28
Site 4	0.61	0.72	1.09	2.84	2.91	2.89	1.76	1.59	1.52	1.23	1.08	1.13	12	1.43	0.83
Site 5	3.61	3.60	3.52	3.13	3.08	3.13	2.61	2.48	2.61	2.93	2.87	3.03	12	3.03	0.38
Site 6	3.38	3.38	3.38	5.38	5.19	5.15	5.49	5.45	5.54	5.68	5.68	5.68	12	4.85	0.96
Site 7	3.02	3.10	3.18	2.30	2.30	2.91	3.17	3.24	3.18	3.57	3.38	3.51	12	3.04	0.41
Site 8	3.89	3.74	3.91	3.92	3.86	3.81	3.50	3.45	3.29	3.72	3.63	3.54	12	3.68	0.21

*R1-R4 = Sampling rounds in each month

**1-3 = Replicate samples from each site

Table 3S Mean values of the physicochemical parameters measured during the entire study

Season	Stretch*	Sites	Temperature (°C)	Turbidity (NTU)	pH	EC (μs/cm)	DO (mg/L)	TDS (mg/L)
Winter (July)	**A**	1	8.9	3.1	7.1	243.3	9.7	202.8
		2	8.5	40.8	7.8	610.0	6.7	520.3
		3	8.3	11.7	7.9	526.5	9.1	450.0
	B	4	9.4	15.4	7.3	258.8	8.8	218.3
		5	9.3	131.4	7.6	260.3	10.0	220.1
		6	9.3	24.5	7.7	283.0	9.9	239.1
	C	7	9.5	8.8	8.1	236.5	10.4	197.6
		8	9.4	11.1	8.1	296.3	10.1	245.0
Spring (September)	A	1	11.4	5.3	7.6	270.5	8.8	205.9
		2	13.6	35.6	7.8	701.0	4.9	543.3
		3	14.5	13.8	7.9	607.0	8.1	470.8
	B	4	12.2	28.0	7.3	304.3	7.1	231.5
		5	15.0	26.4	8.0	492.3	8.9	375.8
		6	14.3	37.2	7.4	418.8	4.0	319.0
	C	7	15.1	3.7	8.3	239.5	8.9	182.4
		8	15.0	4.6	8.2	302.3	8.9	229.1

* A = Sandspruit tributary; B = North Ridingspruit tributary; C= Klein Jukskei River (Main river)

EC=Electrical Conductivity; DO = Dissolved Oxygen; TDS = Total Dissolved Solids

Table 4S Overall correlation between physicochemical parameters

		Temperature	Turbidity	pH	EC	DO	TDS
Temperature	r_s	1.000					
	p						
	N	64					
Turbidity	r_s	-0.122	1.000				
	p	0.337					
	N	64	64				
pH	r_s	**0.325****	**-0.280***	1.000			
	p	***0.009***	***0.025***				
	N	64	64	64			
EC	r_s	0.194	**0.478****	0.069	1.000		
	p	0.126	***0.000***	0.589			
	N	64	64	64	64		
DO	r_s	**-0.394****	**-0.424****	**0.272***	**-0.613****	1.000	
	p	***0.001***	***0.000***	***0.030***	***0.000***		
	N	64	64	64	64	64	
TDS	r_s	0.094	**0.524****	0.030	**0.981****	**-0.543****	1.000
	p	0.461	***0.000***	0.817	***0.000***	***0.000***	
	N	64	64	64	64	64	64

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Table 5S Correlation between the individual physicochemical parameters for the different river stretches

Catchment stretch	Parameter	Correlation	Physicochemical parameters					
			Temp	Turbidity	pH	EC	DO	TDS
Sandspruit tributary	**Turbidity**	r_s	0.171					
		p	0.424					
		N	24					
	pH	r_s	0.322	0.562**	1.000			
		p	0.125	**0.004**				
		N	24	24	24			
	EC	r_s	0.389	0.902**	0.590**	1.000		
		p	0.060	**0.000**	**0.002**			
		N	24	24	24	24		
	DO	r_s	-.339	-.858**	-.322	-.910**	1.000	
		p	0.105	**0.000**	0.125	**0.000**		
		N	24	24	24	24	24	
	TDS	r_s	0.219	0.896**	0.513*	0.952**	-0.872**	1.000
		p	0.304	0.000	0.010	0.000	0.000	
		N	24	24	24	24	24	24
North Ridingspruit tributary	**Turbidity**	r_s	-0.122	1.000				
		p	0.569					
		N	24	24				
	pH	r_s	0.098	0.142	1.000			
		p	0.650	0.508				
		N	24	24	24			
	EC	r_s	0.722**	0.082	0.314	1.000		
		p	**0.000**	0.704	0.136			
		N	24	24	24	24		
	DO	r_s	-0.592**	.019	.580**	-.353	1.000	
		p	**0.002**	0.931	**0.003**	0.091		
		N	24	24	24	24	24	
	TDS	r_s	0.703**	0.102	0.408*	0.973**	-0.254	1.000
		p	**0.000**	0.635	**0.048**	**0.000**	0.231	
		N	24	24	24	24	24	24

Catchment stretch	Parameter	Correlation	Physicochemical parameters					
			Temp	**Turbidity**	**pH**	**EC**	**DO**	**TDS**
Klein Jukskei River	**Turbidity**	r_s	-0.604*	1.000				
		p	**0.013**					
		N	16	16				
	pH	r_s	0.687**	0-.836**	1.000			
		p	**0.003**	**0.000**				
		N	16	16	16			
	EC	r_s	-0.013	0.221	-0.229	1.000		
		p	0.961	0.410	0.393			
		N	16	16	16	16		
	DO	r_s	-0.766**	0.162	-0.383	-0.214	1.000	
		p	**0.001**	0.548	0.143	0.426		
		N	16	16	16	16	16	
	TDS	r_s	-.327	.395	-.491	.924**	.109	1.000
		p	0.216	0.130	0.053	**0.000**	0.687	
		N	16	16	16	16	16	16

*. Correlation is significant at the 0.05 level (2-tailed).

**. Correlation is significant at the 0.01 level (2-tailed).