Cape Town's Stormwater Quality – A GIS-aided Case Study of the Zeekoe Catchment

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Highlights

- Stormwater harvesting (SWH) has been proposed and an alternative water source for Cape Town.
- However, it is believed that South Africa's stormwater is more polluted than other nations conducting SWH.
- This study found that for one catchment, the water quality is different and more polluted than that of the three countries implementing SWH.

Introduction

The current levels of water scarcity are expected to increase due to global warming and an ever-expanding human population. South Africa (SA) is already classified as a water-scarce nation, and the levels of scarcity are projected to increase due to population increase, development and climate change (Hedden *et al*., 2014; Fisher-Jeffes *et al*., 2017). It is thus imperative for the nation to harness alternative sources of water while conserving what is available.

Groundwater, treated sewage effluent, rainwater/stormwater harvesting, and desalination have all been proposed as a means of augmenting the current water supply, which is currently heavily biased towards surface water schemes (Armitage *et al*., 2014; Fisher-Jeffes *et al*., 2017; CoCT, 2019; Atkins *et al.*, 2021). While some South African cities are currently utilising groundwater, its use faces similar challenges as surface water, in that it needs to be replenished, which presently takes extended periods. Rapid (and often unplanned) urbanisation has had an adverse consequence for drainage in South African cities. The attendant increase in paved areas has increased the potential for flooding to occur due to increased stormwater runoff flow rates – whilst simultaneously reducing groundwater replenishment (Yao *et al*., 2016; Balwant *et al*., 2018). The traditional drainage system, such as the one used in the City of Cape Town, is designed to convey the stormwater, often of poor quality, *away* from settlements to the rivers and ultimately the ocean – imperilling the environment, particularly the tourist beaches, along the way. An appreciable volume of water could be recovered through stormwater harvesting (SWH), provided solutions can be found to the twin challenges of water quality and the need for massive storage due to Cape Town's Mediterranean-type climate with short wet winters and long hot, dry summers.

While other countries have trialled SWH, there is a belief that South Africa and indeed Cape Town's stormwater may be worse off than that of nations that have implemented urban SWH (Knight, 2017; Robertson et al., 2019). This belief stems from the presence of many informal areas located within South Africa's major cities, which still do not have access to formal and adequate sanitation infrastructure. However, a comprehensive study on the pollutant concentrations in the drainage systems found in South African cities is lacking.

This study sought to investigate Cape Town's stormwater quality by conducting a GIS-aided historical stormwater quality analysis of one of the city's largest catchments – the Zeekoe catchment. First, the median numerical values of nine (9) stormwater quality parameters were calculated from the CoCT historical stormwater quality database. The median values were then compared with the South African guidelines and median values from three nations that have implemented urban SWH (CRC, 2015; Yuan *et al*., 2016; Page *et al*., 2018).

Methodology

Study Area

The City of Cape Town (CoCT) is in the Western Cape Province of South Africa. Cape Town is Africa's 10th most populous city, with an estimated population of 4.4 million in 2019, with a 2% annual growth increase above the national average (COGTA, 2021). 20.5% of the population lives in informal housing with varying access to basic sanitation and waste removal services. This paper focuses on the Zeekoe Catchment located in the south-central part of the CoCT (Figure 1). The catchment covers 89 km^2 and has a relatively flat terrain with an average gradient of less than 3%. The land-use composition is 33% formal residential and vegetated areas, 16% agricultural, 6% informal residential and parks, while commercial areas make up the rest of the catchment. The mean annual precipitation (MAP) within the catchment ranges from 500 mm to 1100 mm (Okedi, 2019).

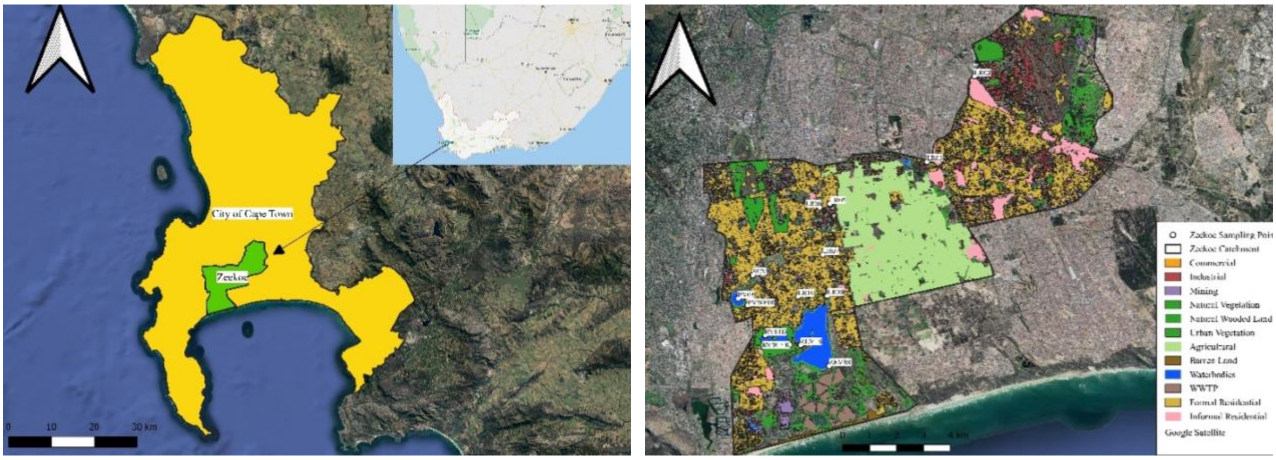

Figure 1. Maps showing 1) the location of the study area and 2) the location of the sampling sites and different land uses.

Method

Monthly stormwater samples collected by the CoCT over five years from 2015-2020 from fourteen (14) locations in the catchment were collated in this study (Figure 1). The nine parameters used in this study are (1) ammonia, (2) pH, (3) dissolved oxygen (DO), (4) electrical conductivity (EC), (5) total suspended solids (TSS), (6) *Escherichia coli* (*E. Coli*), (7) total phosphorus (TP), (8) total nitrogen (TN) and (9) temperature.

Vector data and satellite images were used to map the land use and land cover (LULC) changes using the QGIS software. Eight (8) land-use types were identified: formal and informal residential, commercial, industrial, parks, agricultural, natural vegetation, and barren land. The stormwater sampling points shapefile was imported and overlaid on the LULC layer to link land use and stormwater quality.

The correlation between land use and stormwater quality parameters was analysed using a two-part statistical analysis: (1) descriptive statistics to assess stormwater quality and (2) correlation analysis between the water quality parameters and land use types. In the analysis, the water quality parameters were considered the dependent variables, and the land-use patterns the independent variables. The median values of the parameters were obtained and compared with the available SA water quality guidelines. The median was used as it is the recommended parameters as per DWAF (1996). Finally, a global comparison of the results with data from three studies in nations where SWH has been implemented and regulated was made.

Results and discussion

The study found that three of the eight parameters analysed in the study had median values deemed unacceptable by the SA water quality standards (Table 1). TSS was not evaluated as the guideline only gives a target range that relies on a known baseline to compare the change in TSS concentration, and none existed for this study. The correlation analysis revealed that residential areas strongly correlated to Ammonia, TN, and *E. Coli* (0.77, 0.73 and 0.88, respectively), indicating possible sewage spills/leaks in these areas. Informal areas had a stronger positive correlation to Ammonia, TN, TSS and *E. Coli* (0.97, 0.96, 0.74 and 1 respectively) due to the limited waste removal, street sweeping services and sanitation facilities. The high positive correlation to Ammonia and *E. Coli* (0.69 and 0.92) in parks is attributed to the use of fertiliser and animal excrement.

Table 1. Comparison of Zeekoe Catchments median values with the South African national water quality guidelines

Parameter	SA Quality Guideline (DWAF, 1996; Nel *et al.*, 2013)					Zeekoe (Median, n = 79)	Evaluation
	Natural	Good/ Target	Fair	Poor/ Risk	Unacceptable		
Ammonia (mg/L)	<0.015	0.015 – 0.058	0.058 – 0.1	0.1 -0.2	>0.2	0.2	Poor
TP (mg/L)	<0.005	0.005 – 0.025	0.025 – 0.125	0.125 – 0.25	>0.25	0.3	Unacceptable
TN (mg/L)	<0.25	0.25 - 1	1 - 4	4 – 10	>10	2.4	Fair
pH	8 – 6.5	9 – 8	10	>10		7.8	Natural
Temperature	-	5 – 30	-	-	-	18.4	Good/Target
***E. Coli* (/100mL)**	-	0 - 130	131 - 200	201 - 400	>400	2.20E+03	Unacceptable
DO (mg/L)	>8	8 - 6	6 - 4	4 - 2	<2	8.63	Natural

An evaluation of the parameters from this study and those from three countries that have implemented urban SWH shows marked differences in Ammonia (> 80%), TP (> 10 – 22.4%), TN (> 69.9 – 116%) and *E. Coli* parameters (Table 2). The difference is possibly due to informal settlements in the Zeekoe catchment, whereas none are mentioned in the other studies. The data in Table 2 thus suggests that the Zeekoe catchment is more polluted for the parameters analysed.

Table 2. Comparison of Zeekoe Catchments median values with median values from selected countries conducting SWH

Parameter	This Study	Gernjak *et al.*, (2016), W. Australia	% diff	Pitt *et al.*, (2004), USA	% diff	Boogaard *et al.*, (2014), Netherlands	% diff
	Catchment	Catchment		Catchment		Catchment	
Ammonia (mg/L)	0.2	0.1	80.3	0.4	-54.4	-	-
TP (mg/L)	0.3	-	-	0.3	22.4	0.3	10.2
TN (mg/L)	2.4	-	-	1.4	69.9	1.1	116
TSS (mg/L)	19	21.0	-9.5	58.0	-67.2	11	72.7
E. Coli (CFU/ 100mL)	2200	150	1367	1750	25.7	6700	-67.2
Conductivity (µS/cm)	80.0	755	-89.4	121	-33.9	-	-

Conclusions and future work

- According to SA standards, the Zeekoe catchment's median characteristics are generally good (4/7 parameters classified as fair or better).
- The Zeekoe catchment characteristics suggest that the SW is different and, for some parameters, more polluted than the SW from the three studies where SWH has been implemented.
- The authors note that the sole use of the median is flawed and that selecting different measures of statistical dispersion, such as the 95th percentile over the mean or median, will paint a different picture about the overall evaluation of the catchment. Consequently, it is recommended that all studies that seek to characterise stormwater quality should be presented with other supporting measures of dispersion such as the number of observations/data points, confidence intervals and standard deviations and, where possible, a repository of the raw data used in the analysis.
- More catchments need to be analysed, and statistical testing is required to definitively state whether there is a significant difference in the observed stormwater quality. The statistical testing is arduous due to the limited raw data in the public domain required to conduct statistical tests.

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