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An Evaluation of the Cumulative Surface Water Pollution on Selected Areas within the Consolidated Main Reef Area, Roodepoort, South Africa

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ABSTRACT: Mining has long been at the center of the South African economy and has contributed to significant developments within the country. However, despite the large economic impact, surface water pollution due to mining is prevalent in most of the country's water catchments. Surface water in many areas of the central Roodepoort area in Johannesburg, South Africa, has also been impacted primarily by mining activities. The surface water quality for the Bosmontspruit, Russell's Stream, and the New Canada Dam was assessed in this study from October 2010 to March 2011. Physicochemical and biological characteristics of the water were determined for eight monitoring points, and the results obtained were compared with the in-stream water quality guidelines for the Klip River catchment and the South African Water Quality Guidelines. A trend noticed throughout the sampling period was the non-compliance to the set target water quality ranges (TWQRs) in the levels of total dissolved solids (TDS) and dissolved oxygen (DO). The results indicate that concentrations of iron, aluminum, nickel, manganese, and potassium were above the permissible limits across the Bosmontspruit and Russell's Stream. Excessive fecal coliforms and ammonium pollution were also detected in the Bosmontspruit. Additionally, during the monitoring period, it was noted that the water was being utilized for domestic purposes, and may pose health hazards due to poor water quality.

KEYWORDS: acid mine drainage, cumulative pollution, tailings, water pollution, water quality

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Introduction

The pollution of water resources associated with resource depletion, rising populations, industrialization, and urbanization, has resulted in worldwide dwindling of quality water sources.[1] South Africa depends on surface water for its rural and urban populations, and with the South African economy relying extensively on mining, water resources in South Africa are increasingly being subjected to pollution, including that by acid mine drainage.[1–5] Rivers are the main drains for their surrounding landscapes and the input of pollutants in a river depends on the surrounding landscape and associated activities.[6,7] Anywhere in a river catchment, activities are reflected in its waters and ecosystem, and when the river is located immediately below mine effluents, some industries and residential areas are often heavily polluted.[2,6]

The consolidated Main Reef area in Johannesburg, Gauteng, South Africa, is known for its prolific gold, coal, and uranium deposits, with mining activities being conducted in the area since the late 1800s.[8,9] The area is also commonly referred to as 'The Witwatersrand Basin.' The Witwatersrand Basin is made up of the Eastern (Springs-Nigel area), Central (Johannesburg area), and Western (Krugersdorp-Randfontein area) basins/regions. While most of the previous mining activities have ceased in the Central basin, new order mining rights to commence mining in the area on the basis of total resource extraction were recently awarded to companies including Central Rand Gold (Pty) Ltd., in 2008. With the recent reestablishment of mining within the Central Roodepoort region, there is a need to consider and examine the disruption of surface water systems due to surface and underground mining.

The impact of mining on South Africa's water resources has in the recent past received a great deal of publicity through various media.[10–14] Assessment of physicochemical parameters allows for the determination of the concentrations at the time of sampling, and there is always a great need to study the water quality of a catchment so as to have a real-time situational measurements. This study focused on assessing prevailing water quality of selected sampling areas of the Bosmontspruit, Russell's Stream, and the New Canada Dam. The Bosmontspruit flows under the western bypass and across Main Reef Road through the Stormill industrial complex, and finally deposits into the New Canada Dam; Russell's Stream also flows into the New Canada Dam.

The objective of this study was to assess the overall water quality of the Bosmontspruit, the New Canada Dam, and Russell's Stream, thus generating suitable surface water quality data for the identified sampling points. Another objective was to make a subsequent comparison of the results with the target water quality range (TWQR) as set out by the Department of Water Affairs. A further objective was to determine the relationship between the river flow and observed water quality parameters at selected surface water sampling points.

Materials and Methods

Location of sampling points. Eight water quality monitoring sites were selected for the monitoring studies in the study area. The location of the sampling points is indicated on the area map in Figure 1. Three of the eight water quality monitoring sites served as controls (SW01, SW04, and SW07) for various activities that could affect water quality. These sites were chosen upstream of any source of pollution. Due to the monitored river systems being historically polluted, however, the control sites were not expected to be pristine but to capture water quality changes that identified activities in the preceding surroundings could cause. Samples were taken monthly over a six-month period (October, 2010 to March, 2011). It would have been beneficial to conduct the study over a 12-month period and thus take into account the seasonal impacts; however, due to budget constraints, only the rainy season was assessed. The study area is situated in the summer rainfall region of South Africa and thus receives the most rainfall between October and April.[14] No more than one grouping of samples and one composite replicate was collected and analyzed per site due to budget constraints. The criteria used for the selection of the sites were based on the following[15,16]:

- Accessibility by road to enable water quality samples to be taken;
- Perennial flow of the streams, since the presence of flow was an important factor in determining water quality; and
- Proximity to pollution sites, e.g., active mine sites, tailings deposition sites, and industrial areas, since the aim of the study was to assess cumulative water pollution impacts.

Sampling and sample analysis. The following equipment was utilized for sample collection:

- Field sheets and sample labels;
- Flow meter;
- Cooler box with ice packs;

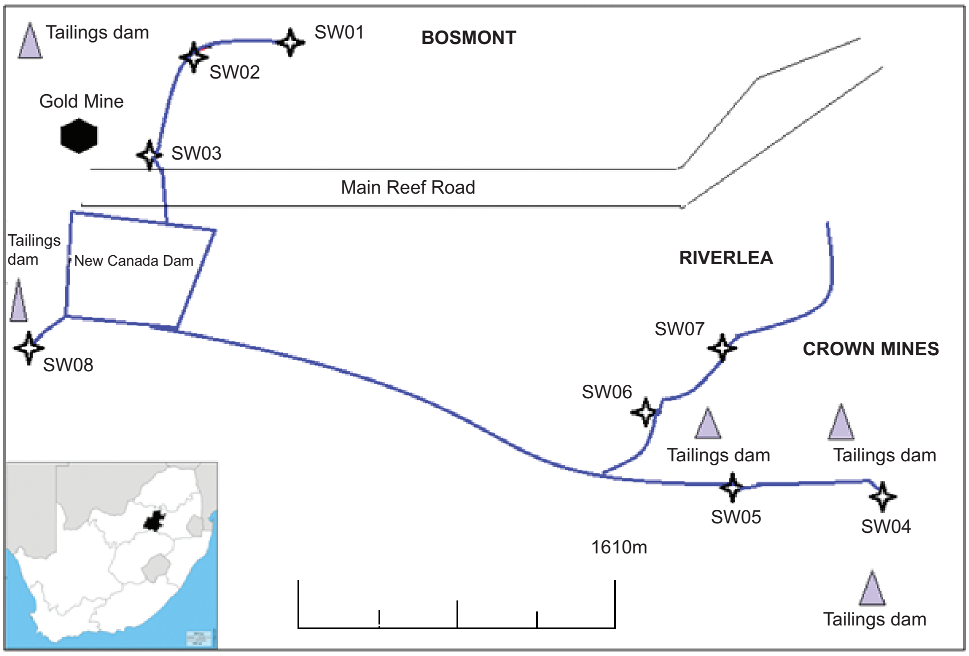

Figure 1. Sample locations.

- Powderless sterile gloves; and
- At each sampling point, the following sample bottles were utilized:
  a) 1 × 500 mL sterile glass bottles cooled at 4°C for fecal coliforms;
  b) 2 × 100 mL plastic bottles preserved to pH < 2 with nitric acid (1 mL at 40%) for metals; and
  c) 2 × 500 mL plastic bottles preserved to pH > 12 with sodium hydroxide cooled at 4°C for pH, electrical conductivity, total dissolved solids (TDS), alkalinity, chlorine, fluorine, nitrite, nitrate, sulphate, ammonia, and total cyanide.

At each sampling point, a field sheet was completed. The field sheets contained the following information:

- name and location of sampling point;
- date and time of sample location;
- any relevant, descriptive information, e.g., water level/flow, ambient conditions;
- sample appearance at time of collection, e.g., color, clarity, and odor; and
- results of any on-site analysis (dissolved oxygen (DO), conductivity, temperature, pH).

Sample treatment post-collection. Samples were taken from the shore or by wading, using the sample bottles described above. The researcher and/or assistant stood perpendicular to the flow facing upstream and completely submerged the sampling bottle into the stream. In order to prevent any unnecessary contamination during sampling, gloves were worn at all times and sample bottle caps were kept closed to ensure that samples are not contaminated further.

Immediately after collection, samples were stored in a cooler box with ice packs. The cooler boxes were securely strapped onto the back of the field vehicle in order to ensure that no breakages or spillages occur during transportation to the laboratory. All samples were taken to the laboratory for analysis on the same day of sampling in order to ensure the integrity of the sample.

Water samples were collected for the analysis of fecal coliforms and physicochemical water quality parameters. Selected physical and chemical parameters that are considered most relevant to the evaluation of effects on water quality by activities in the catchment were analyzed using standard methods. The DO, TDS, pH, and electrical conductivity were measured in situ using the relevant field meters (Mettler Toledo meters, UK).

River water flow. The river water flow measurements were taken and recorded at the same points of sampling as soon as the water samples were collected. The Global Water Flow probe (FP111, AMS Haden, South Africa) was used to determine the water velocity. The flow probe uses true velocity averaging and is coupled with a depth measure. One reading is taken per second and a continuous average is displayed; once the average reading becomes steady, the true average velocity in m/s of the stream is obtained. The depth was taken to determine the cross-sectional area of the river or stream so that flow could be determined. The cross-sectional area was determined as follows:

1) The width of the water body was measured using a tape measure;
2) The depth was taken at 1 m intervals from the shore until the opposite shore was reached;
3) The depth vs. the width intervals was plotted on a graph, and the area under the curve obtained was the cross-sectional area in square meters (m^2).

The average velocity (V) multiplied by the cross-sectional area (A) gave the river flow (Q) in m^3/s: $Q = V \times A$.

Fecal coliforms. The membrane filtration method[17] was used to determine the fecal coliforms in the sample. The m-FC agar was used as the growth media. A sample amount of 50 mL was filtered through a sterile membrane filter paper. The filter paper was placed onto the agar media, on plates, under sterile conditions and incubated at 44.5°C ± 1°C for ±3 hours. The number of fecal coliforms per 100 mL of sample from the identified characteristic colonies was used for quantification of the fecal coliforms.

Metal determination by ICP-OES. For the determination of the total dissolved metals, the method used was based on US EPA 200.8 and 200.7.[18] The aqueous samples (50 mL) were filtered through a 0.45 Im pore size filter (hydrophilic PVDF 0.45 Im filter, 33 mm diameter, Cat AS073345) and acidified immediately to pH 2 for preservation using concentrated HNO_3. The total dissolved metals in the acidified samples were analyzed after HNO_3 digestion using the Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES) (Agilent Technologies, 700 SERIES ICP-OES).[18] The samples were analyzed against respective elemental standards as prepared and/or diluted so that the concentrations would fall within the linear range of the instrument calibration.

Regression analysis. The regression analysis was used to assess the relationship between the flow and pollution of the river system. The dependent variable (y) selected for the purpose of the study was the determined water parameter concentration and was compared with the independent variable (x), which was river flow.

The use of the water quality guidelines. Water quality guidelines are usually derived to maintain the fitness of water for specific uses and to protect the health of the aquatic ecosystem.[19] The in-stream water quality guidelines for the Klip River catchment were developed by Rand Water due to their interest in the Klip River.[20] These guidelines were compiled by taking into cognizance the requirements of the three main users of raw water, i.e., aquatic ecosystem, potable water producers, and recreation. Other guidelines[19–22] and raw water quality guidelines[23] were also considered here, especially for variables not included in the in-stream water quality guidelines for the Klip River catchment.

The results for the sample water quality analyses are shown in Tables 1 to 3. The parameter measurements that exhibited non-compliance with the In-stream Water Quality Guidelines for the Klip River catchment as well as the TWQR[19,20,22] and the raw water quality guidelines[23] are highlighted in bold in the tables.

Results

SW01—Upstream control Bosmontspruit. A typical trend noticed throughout the sampling period for this site was the high levels of TDS (ranging above 157 to 500 mg/L) and the low levels of DO (ranging from 16.90% to 59.20%). The analyzed results for SW01 are shown in Table 1. None of the samples complied with the stipulated guidelines with regards to TDS and DO levels. SW01 displayed high levels of fecal coliforms in October (1.0×10^6 CFU/100 mL), January (7.0×10^4 CFU/100 mL), and February (4.5×10^4 CFU/100 mL). Non-compliance in the levels of nitrates was noted in January with concentrations at 15 mg/L and 17 mg/L in March. The water flow during this period was minimal, and the high amounts of debris dumped or washed into the watercourse resulted in restrictions to the water flow. Potassium levels showed elevated levels throughout the sampling period ranging from 4.15 to 8.20 mg/L. All other metal concentrations measured were below the set limits.

A regression analysis was performed on the river flow against all variables that exhibited non-compliance with the guidelines (statistical parameters are a unit less in all Tables). The correlation coefficient (CC) values were all negative with nitrate exhibiting a low CC value (0.1). This indicates that there is almost no relationship between flow and the selected parameter concentration. The coefficient of determination values indicate that river flow accounts for only 29% of the variability for TDS concentrations, 1% of the variability in nitrate concentration, 17% of the variability in fecal coliforms, no variability for DO concentration, and 9% variability in potassium concentration. The regression coefficient (RC) for TDS was −170.93, indicating that a 170.93 change in TDS per unit river flow occurs. The RC shows that, with every unit of river flow, the TDS value decreases by 170.93, which is significant as the relationship is inversely proportional. The RC for nitrate at SW01 is calculated at 1.72, indicating a directly proportional relationship between nitrate levels and river flow. There is an increase of 1.72 in nitrate levels per unit river flow. The levels of fecal coliforms, DO, and potassium all exhibit inversely proportional relationships to river flow. The most noticeable change in RC is that of fecal coliforms; for every unit of river flow, the fecal coliform levels decrease by 4.1×10^4. Apart from the levels of DO, the RC values indicate that increased river flow will result in a reduction in fecal coliform, TDS, and potassium levels. The RC value for nitrate indicates that the increased river flow at SW01 may result in increased nitrate levels from an upstream source. However, it must be noted that CCs do not support the above, and in order for the regression analysis to be accurate, the CC values must correspond to the RC values.

SW02—In the vicinity of active mining on the Bosmontspruit. This sampling point was situated on the Bosmontspruit directly below the Central Rand Gold mine. SW02 and SW01 showed a similar trend in terms of non-compliance with regards to TDS, nitrate, and fecal coliforms, where both samples showed elevated levels of these parameters. Nitrate levels ranged from 0.5 mg/L to 9.65 mg/L and DO ranged from 10.90% to 24.80%. The levels of fecal coliforms exhibited non-compliance. In October they were 1.0×10^6 CFU/100 mL, 6.0×10^6 CFU/100 mL in January, and 4.0×10^6 CFU/100 mL in February. SW02 showed elevated levels of aluminum (ranging from 1.05 to 5.30 mg/L); the guidelines stipulate that levels greater than 0.5 mg/L are unacceptable for aluminum. Iron levels ranged from 6.85 to 7.30 mg/L during the period January to March; this was significantly elevated as the guideline dictates that levels greater than 1.5 mg/L for iron are unacceptable for in-stream water quality. There was also a marked increase in the nickel (0.17 mg/L) and potassium (8.15 mg/L) levels in March as compared to October through February, as shown in Table 1.

The most significant relationship at SW02 was that of DO and river flow. The CC was calculated as 0.8, which tends to be 1. This indicates that an increase in river flow was associated with a corresponding increase in DO at SW02. The coefficient of determination values indicates that river flow accounts for 63% of the variability in DO levels, which is significant as the faster flowing water increases the mixing of atmospheric oxygen, thus resulting in an increase in DO levels. The RC value of 8.96 indicated a directly proportional relationship between river flow and DO, and that there is an 8.96 increase in DO levels per unit of river flow. No other significant conclusions could be drawn from the regression analysis performed on the data for SW02.

SW03—Bosmontspruit under main reef road. SW03 was situated where the Bosmontspruit crosses under the Main Reef Road. The sampling point was in close proximity to a redundant tailings facility and mine pollution control dams. As was the case with SW01 and SW02, non-compliance is noted with respect to the levels of TDS, nitrate, and fecal coliforms. The TDS ranged from 219 to 1398 mg/L throughout the sampling period. Nitrate was 11.5 mg/L in February and 7.85 mg/L in January, while fecal coliforms were 8.3×10^4 CFU/100 mL in October and 4.4×10^4 CFU/100 mL in February. The DO ranged from 5.6% to 52% during the sample period, as shown in Table 1. During January, there was a significant drop in pH (3.16). At the actual time of sampling at SW03, it was noted that there was a pipe discharging water from the pollution control dams into the watercourse. The discharge was assumed to be illegal since all active mines in the Central Rand are required to operate closed

Table 1. Water quality on the Bosmontspruit as determined from October, 2010 to March, 2011 (units in mg/L unless otherwise stated).

VARIABLE	OCT	NOV	DEC	JAN	FEB	MAR	NON-COMPLIANCE LIMITS
SW01							
NO_3	0.50	0.50	4.35	**15.00**	3.95	**17.00**	>**7.00**
	6.90	7.80	7.49	7.73	7.38	7.35	<**6.00**; >**9.00**
EC (mS/m)	45.00	67.00	17.57	47.73	51.10	44.50	>**150.00**
NH_4	3.61	1.40	0.69	0.05	0.50	0.93	>**4.00**
Fecal coliforms (CFU/100 ml)	**1.0×10^6**	3.0×10^2	7.6×10^2	**7.0×10^4**	**4.6×10^5**	6.6×10^1	>**10,000**
DO (%)[19]	N/A	**16.90**	**33.50**	**50.40**	**59.20**	N/A	<**80.00**
K[21]	**5.91**	**5.81**	**5.90**	4.15	**5.35**	**8.20**	>**5.00**
Al	0.05	0.05	0.04	0.06	0.27	0.04	>**0.50**
Co[23]	0.05	0.05	0.03	0.03	0.03	0.03	>**0.25**
Fe	0.30	0.30	0.58	0.64	1.12	0.91	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	0.19	>**0.20**
Mn	0.07	0.08	0.18	0.21	0.34	0.69	>**4.00**
Ni[23]	0.06	0.06	0.06	0.06	0.06	0.06	>**0.10**
SW02							
NO_3	0.50	0.50	6.95	**8.80**	4.80	**9.65**	>**7.00**
pH	6.90	7.93	7.30	7.14	7.45	6.35	<**6.00**; >**9.00**
EC (mS/m)	51.00	52.83	15.60	55.70	52.50	59.50	>**150.00**
NH_4	2.09	1.80	0.08	3.05	0.46	1.10	>**4.00**
Fecal coliforms (CFU/100 ml)	**1.0×10^6**	3.0×10^2	6.0×10^2	**6.0×10^5**	**4.0×10^5**	5.0×10^1	>**10,000**
DO (%)[19]	N/A	**10.90**	**19.20**	**24.80**	**15.80**	N/A	<**80.00**
K[21]	**6.08**	4.06	2.90	4.45	4.95	**8.15**	>**5.00**
Al	0.06	0.05	0.04	**1.20**	**1.05**	**5.30**	>**0.50**
Co[23]	0.05	0.05	0.03	0.03	0.03	0.09	>**0.25**
Fe	0.30	1.19	1.10	**7.30**	**6.85**	**32.00**	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	0.19	>**0.20**
Mn	0.07	0.13	0.45	0.59	0.51	1.15	>**4.00**
Ni[23]	0.06	0.06	0.06	0.06	0.06	**0.17**	>**0.10**
SW03							
NO_3	0.40	0.50	5.05	6.65	**11.50**	**7.85**	>**7.00**
pH	6.70	7.67	7.46	**3.16**	7.54	6.85	<**6.00**; >**9.00**
EC (mS/m)	57.00	45.50	14.17	**173.97**	43.70	48.00	>**150.00**
NH_4	3.06	2.15	**6.20**	0.09	0.41	0.67	>**4.00**
Fecal coliforms (CFU/100 ml)	**8.3×10^4**	4.8×10^1	1.1×10^3	0.0	**4.4×10^4**	$2,45 \times 10^1$	>**10,000**
DO (%)[19]	N/A	**5.60**	**10.90**	**52.60**	**15.80**	N/A	<**80.00**
K[21]	9.59	2.31	3.00	4.35	3.75	**7.45**	>**5.00**
Al	0.16	0.05	**8.90**	**55.00**	**0.70**	**0.69**	>**0.50**
Co[23]	0.06	0.05	0.04	**1.70**	0.03	0.03	>**0.25**
Fe	0.54	1.21	**11.00**	**36.00**	**5.65**	**3.95**	>**1.50**
U[19]	0.20	0.20	0.19	**0.96**	0.19	0.19	>**0.20**
Mn	0.42	0.13	0.63	**6.75**	0.54	0.90	>**4.00**
Ni[23]	**0.32**	0.06	0.08	**3.75**	0.06	0.06	>**0.10**

No note indicates.[24]

Table 2. Water quality on the Russell's Stream as determined from October, 2010 to March, 2011 (units in mg/L unless otherwise stated).

VARIABLE	OCT	NOV	DEC	JAN	FEB	MAR	NON-COMPLIANCE LIMITS
SW04							
Total alkalinity[23]	**17.00**	30.50	54.50	69.00	66.00	**10.00**	<**20.00**
NO_3	**7.70**	5.00	4.75	**1.50**	5.15	**5.55**	>**7.00**
pH	**5.60**	**4.83**	6.93	6.67	6.36	**4.30**	<**6.00**; >**9.00**
EC (mS/m)	43.00	76.80	23.30	74.60	63.20	130.00	>**150.00**
NH_4	1.87	3.70	3.50	1.01	1.75	**71.50**	>**4.00**
Fecal coliforms (CFU/100 ml)	1.1×10^1	0.0	1.1×10^3	**1.7×10^4**	4.5×10^2	0.0	>**10,000**
DO (%)[19]	N/A	**60.90**	**49.60**	**25.00**	**49.40**	N/A	<**80.00**
K[21]	3.62	3.36	4.00	**7.05**	4.10	**13.00**	>**5.00**
Al	0.14	0.40	0.04	0.41	**1.35**	**39.00**	>**0.50**
Co[23]	0.17	0.23	0.20	**0.29**	**0.34**	**1.00**	>**0.25**
Fe	0.30	**13.75**	**2.30**	**19.00**	**26.00**	**73.00**	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	**0.73**	>**0.20**
Mn	1.01	1.74	1.20	**4.15**	**4.30**	**6.10**	>**4.00**
Ni[23]	**0.38**	**0.55**	**0.27**	**0.50**	**0.69**	**1.90**	>**0.10**
SW05							
Total alkalinity[23]	22	20.00	47.00	**10.00**	**14.00**	**11.00**	<**20.00**
NO_3	**7.8**	4.05	5.05	1.85	3.90	6.75	>**7.00**
pH	**5.9**	**4.83**	6.51	6.45	**5.44**	**4.35**	<**6.00**; >**9.00**
EC (mS/m)	30	84.13	21.63	76.33	52.63	130.00	>**150.00**
NH_4	2.02	**4.45**	3.50	**6.25**	2.70	**90.00**	>**4.00**
Fecal coliforms (CFU/100 ml)	0	0.00	1.00	515.00	0.50	0.00	>**10,000**
DO (%)[19]	N/A	**60.90**	**67.10**	**36.60**	**53.70**	N/A	<**80.00**
K[21]	3.24	4.03	3.70	**7.15**	2.95	**15.00**	>**5.00**
Al	0.38	0.40	0.04	**1.10**	**1.70**	**35.00**	>**0.50**
Co[23]	0.12	**0.27**	0.25	**0.39**	**0.33**	**1.20**	>**0.25**
Fe	0.30	**17.30**	**5.40**	**20.00**	**23.50**	**81.50**	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	**0.73**	>**0.20**
Mn	0.86	2.59	1.50	**6.20**	**5.05**	**8.20**	>**4.00**
Ni[23]	**0.25**	**0.60**	**0.37**	**0.61**	**0.54**	**2.10**	>**0.10**
SW06							
Total alkalinity[23]	63.00	132.00	165.00	180.00	120.00	210.00	<**20.00**
NO_3	**14.80**	6.15	5.20	5.45	4.30	0.40	>**7.00**
pH	7.10	8.18	7.73	7.91	6.77	7.75	<**6.00**; >**9.00**
EC (mS/m)	30.00	50.70	17.60	48.30	49.63	58.50	>**150.00**
NH_4	0.75	0.45	2.40	0.22	0.31	0.11	>**4.00**
Fecal coliforms (CFU/100 ml)	**3.9×10^5**	4.9×10^1	3.3×10^2	7.0×10^2	4.2×10^3	8.3×10^3	>**10,000**
DO (%)[19]	N/A	88.30	**71.20**	**54.20**	**53.70**	N/A	<**80.00**
K[21]	4.57	2.35	4.00	4.30	4.10	**8.60**	>**5.00**
Al	0.05	0.05	0.04	0.26	0.42	0.42	>**0.50**
Co[23]	0.05	0.05	0.03	0.03	0.03	0.03	>**0.25**
Fe	0.30	0.30	0.25	0.66	1.10	0.89	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	0.19	>**0.20**

Table 2. (*Continued*)

VARIABLE	OCT	NOV	DEC	JAN	FEB	MAR	NON-COMPLIANCE LIMITS
Mn	0.07	0.07	0.06	0.61	1.65	0.78	>**4.00**
Ni[23]	0.06	0.06	0.06	0.06	0.07	0.06	>**0.10**
SW07							
Total alkalinity[23]	68.00	106.00	145.00	92.00	75.00	140.00	<**20.00**
NO_3	**10.20**	**8.80**	3.80	5.70	6.40	3.20	>**7.00**
pH	6.70	7.58	7.88	7.80	6.20	6.15	<**6.00**; >**9.00**
EC (mS/m)	32.00	62.13	17.03	49.00	62.53	96.00	>**150.00**
NH_4	0.47	1.05	1.90	0.80	2.85	**39.08**	>**4.00**
Fecal coliforms (CFU/100 ml)	**2.4×10^5**	3.0×10^2	2.1×10^2	8.2×10^3	8.3×10^3	3.5×10^2	>**10,000**
DO (%)[19]	N/A	**70.00**	**51.80**	**41.80**	**49.40**	N/A	<**80.00**
K[21]	4.59	2.38	3.60	4.35	4.60	**9.05**	>**5.00**
Al	0.06	0.05	0.04	0.37	0.38	0.04	>**0.50**
Co[23]	0.05	0.05	0.03	0.03	0.03	0.03	>**0.25**
Fe	0.30	0.30	0.25	0.69	0.95	0.42	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	0.19	>**0.20**
Mn	0.07	0.07	0.06	0.82	1.80	0.59	>**4.00**
Ni[23]	0.07	0.06	0.06	0.06	0.07	0.06	>**0.10**

[1] = 23.
[2] = 19.
[3] = 21.
No note indicates.[24]

Table 3. Water quality in the New Canada Dam as determined from October, 2010 to March, 2011 (units in mg/L unless otherwise stated).

VARIABLE	OCT	NOV	DEC	JAN	FEB	MAR	NON-COMPLIANCE LIMIT
SW08							
TDS	**397.00**	**744.33**	**377.33**	**489.67**	**424.67**	**526.00**	>**55.00**
Total alkalinity[23]	**19.00**	35.50	23.50	23.00	**14.00**	**12.00**	<**20.00**
NO_3	**2.90**	0.50	**2.95**	0.40	0.40	1.20	>**7.00**
pH	**10.10**	6.85	7.14	6.40	6.88	6.25	<**6.00**; >**9.00**
EC	0.60	99.87	24.67	70.67	68.20	63.00	>**150.00**
NH_4	**4.73**	**5.60**	2.85	**9.40**	**4.15**	2.05	>**4.00**
Fecal coliforms (CFU/100ml)	5.00	2.00	0.00	0.00	77.50	0.00	>**10,000**
DO (%)[19]	N/A	**71.40**	**65.10**	**62.60**	**69.10**	N/A	<**80.00**
K[21]	**9.07**	3.84	4.40	6.10	4.80	**8.25**	>**5.00**
Al	0.09	0.05	0.10	0.07	0.04	0.04	>**0.50**
Co[23]	**0.30**	0.05	0.10	0.09	0.08	0.09	>**0.25**
Fe	0.30	1.42	**4.40**	**4.05**	**5.05**	**6.85**	>**1.50**
U[19]	0.20	0.20	0.19	0.19	0.19	0.19	>**0.20**
Mn	**5.30**	1.56	2.00	3.30	3.90	3.85	>**4.00**
Ni[23]	**0.57**	0.06	**0.13**	**0.17**	**0.15**	**0.12**	>**0.10**

No note indicates.[24]

water circuits so as to minimize overall water consumption. Aluminum (55 mg/L), electrical conductivity (173.97 mS/m), cobalt (1.7 mg/L), iron (36 mg/L), manganese (6.75 mg/L), nickel (3.75 mg/L), and uranium (0.96 mg/L) were all above the respective guideline limits during January. The results are shown in Table 1. There was no river flow from November 2010 through to February 2011. The levels of metal contaminants stabilized in February. However, aluminum (0.70 mg/L) and iron levels still remained elevated (5.65 mg/L).

The CC values indicate that the most significant relationships existed between river flow and fecal coliforms and potassium, respectively. The fecal coliform CC is calculated at 0.87, which is the same situation with potassium and river flow, with a CC of 0.78. The coefficient of determination value indicates that river flow accounts for 75% of the variability for fecal coliform levels and 61% of the variability for potassium levels. Both RC values for potassium and fecal coliforms indicate directly proportional relationships to river flow. The CC values for pH, conductivity, and alkalinity was 0 (zero), which indicates the absence of a predictive relationship between these parameters and river flow.

SW04—Upstream control Russell's Stream. SW04 was the upstream control sampling point for Russell's Stream. The surrounding landscape for SW04 is that of a redundant tailings dam which has a high erosion potential. TDS levels ranged from 286.33 to 1228.00 mg/L through the sampling period, and DO ranged from 25.00% to 60.90%. Fecal coliforms exceeded the guideline in January at levels 1.7×10^4 CFU/100 mL. The pH levels at SW04 were lower than the acceptable range in the TWQR of less than 6. The pH readings obtained were 5.60 in October, 4.83 in November, and 4.30 in March.

Nickel and iron levels were consistently high at SW04. During the first quarter of 2011, there was a significant increase in manganese levels ranging from 4.15 to 6.10 mg/L (the acceptable range is less than 4 mg/L). A spike in uranium levels was noted during March, 2011 (0.73 mg/L) as per analysis results shown in Table 2. There does not seem to be any immediate link between flow and contamination, as the increased flow levels did not correspond to an increase or decrease in contaminants.

A coefficient of determination value of 0.75 indicates that river flow accounts for 75% variability in DO levels. The negative RC value indicates an inversely proportional relationship and further indicates that for every unit increase in river flow, there is a 21.83 decrease in DO. This may indicate that the water entering SW04 limits the levels of DO, and could mean that the incoming water was highly polluted by organic matter, resulting in a high biological oxygen demand. The value of the CC for nitrate, iron, nickel, cobalt, and manganese were close to 0 (zero), indicating the absence of a predictive relationship between river flow and the water parameter concentrations.

SW05—In-stream water quality point for Russell's Stream. SW05 is the in-stream water quality sampling point for the Russell's Stream. The TDS levels ranged from 333 to 1384 mg/L and exhibited non-compliance with the standard throughout the sampling period. The DO levels ranged from 36.30% to 60.90%. Additionally, the Russell's Stream had a high amount of metal pollution and the water pH conditions were more towards the acidic range. Fecal coliform levels were within the range of the relevant compliance index. It is also worth noting that there is an informal settlement alongside the stream that utilize the water for domestic purposes.

The most significant relationship that existed at SW05 was between manganese and river flow. The CC value of 0.84 indicates that an increase in river flow corresponds to an increase in the levels of manganese, thus indicating a directly proportional relationship. The coefficient of determination value of 0.7 shows that river flow accounts for 70% of the variability in manganese levels. The RC value of 1.17 indicates that for every unit of increase in river flow, there is a 1.17 unit increase of manganese levels. This situation does not exist upstream at SW04. Therefore, the elevated manganese levels may be attributed to the washing down and subsequent runoff that is generated as well as the illegal processing of the redundant tailings facilities in the vicinity of SW05. No other significant statistical relationships existed at SW05.

SW06—In-stream water quality point for Russell's Stream tributary. SW06 serves as the in-stream sampling point for the Russell's Stream tributary that is in the vicinity of a redundant tailings facility and significant illegal mining activities. The levels of TDS and DO were found to be above the guideline limit, as shown in Table 2. Fecal coliforms only displayed non-compliance in October, with a value of 3.9×10^5 CFU/100 mL. In general, the water quality was particularly good in this area, meeting most of the set water quality standards as shown in Table 2.

The regression analysis at SW06 showed that no significant relationship existed between river flow and all the water parameter concentration.

SW07—Control point for Russell's Stream tributary. Similar to SW06, the levels of TDS and DO at SW07 were higher than the set guidelines. Elevated levels of nitrate were noted in October (10.2 mg/L) and November (8.80 mg/L). Low DO levels were measured at this sampling point, and it would be expected that an increased biological oxygen demand would be found.[4] March showed a spike in both potassium levels (9.05 mg/L) and ammonium levels (39.08 mg/L), as shown in Table 2. It was noted that there was a significant amount of illegal dumping in the vicinity of SW07, and the material dumped into the watercourse ranged from domestic, mining, and construction wastes. This material could very well explain the increases in the levels of TDS. The trend at SW07 mimics that of SW06 with respect to TDS, DO, and fecal coliforms. In addition, no significant metal pollution was noted and contains no acid mine generating potential, since the level of iron is at 0%.

As with the case at SW06, the regression analysis indicated that no significant relationship exists between river flow and water parameters concentration. This is largely due to the values obtained for the CC, which are all negative. Only nitrate exhibited a positive value, but it is still not significant. The flow at SW07 was also restricted due to a large amount of debris that obstructs the flow. Therefore, there is a significant fluctuation in flow; thus, the absence of a predictable relationship was expected. The CC for nitrate tends to incline towards 0 (zero), indicating that no predictive relationship exists.

SW08—New Canada Dam sampling point. SW08 was the sampling on the New Canada Dam and was the final decant point for the Bosmontspruit and Russell's Stream. As with all the other sampling points, the levels of TDS and DO showed non-compliance to the guidelines. Levels of fecal coliforms showed compliance throughout the sampling period and complied with the guideline, as per Table 3. During October, the pH levels were elevated (10.10) and cobalt (0.3 mg/L), manganese (5.3 mg/L), nickel (0.57 mg/L), and potassium (9.07 mg/L) levels were all outside the permissible levels. The levels of nickel were above the permissible limit of 0.1 mg/L, except in November. The levels of iron in the New Canada Dam were consistently high, ranging between 0.30 and 6.85 mg/L. SW08 also had high alkalinity or ammonium levels. Water from the New Canada Dam is utilized by the surrounding communities for human and live stock consumption as well as for watering crops despite the levels of metal pollution.

The most significant relationship existed between DO and river flow. The coefficient of determination value of 0.80 for DO indicates that river flow accounts for 80% of the variability in DO levels, which is significant. The RC value of −0.47 indicates that for every unit increase of river flow, there is a 0.47 unit decrease in DO levels. This may indicate that water entering New Canada Dam reduces the amount of DO present. The CC values for TDS, nitrate, cobalt and manganese were close to 0 (zero), indicating a non-predictable relationship.

Discussion

It was evident from this study that water in the catchment was of poor quality with reference to the set guidelines and purposes.[19,22,23] Anthropogenic activities in the catchment ranged from mining, industries, and human settlements—all activities which are known to contribute to poor surface water quality elsewhere. With gold mining continuing in the Central basin, acid mine drainage will remain a continued source of pollution to the watercourses in this area. The Klip River In-stream Water Quality guidelines were found to be of significant value in describing the general water quality of the study area. The present and future state of South Africa's fresh water resources is fundamentally important if the continued existence of both the resource and the populations reliant on the resource are to be ensured.[4]

The concentrations of the metals (iron, aluminum, and nickel), TDS, and DO in the study area were often out of the permissible levels as set by the water quality standards. The excessive fecal coliform levels as detected at the sampling points in the Bosmontspruit can be attributed to the discharge of raw sewage and illegal settlements as noted during sampling. There was significant evidence of raw sewage being discharged upstream in the Bosmontspruit (SW01); this contributed to high fecal coliforms and potassium levels, and low DO levels. The metal levels at SW01 were all within the set guideline limits, which was in contrast with SW02 and SW03, where the metals iron, aluminum, and nickel were occasionally found above the set limit. The impacts of mining in the Bosmontspruit surrounding area and runoff from tailings facilities could be attributed to the metal contaminants' increase at SW02 and SW03 as compared to SW01; these were consistent with pollution from gold mine tailings runoff.[24] The sampling point SW02 was located directly below the Central Rand Gold Mine, while SW03 was located further down the Bosmontspruit.

The water in the Russell's Stream (SW04 and SW05) was found to have mostly elevated levels of iron, aluminum, cobalt, nickel, and manganese. These metals have been shown in previous studies to originate from gold mine tailings from historic and prevailing mining activities.[11,25,26] Illegal processing of the redundant tailings facilities in the vicinity of SW04 and SW05 was observed, thus the elevated metal levels could be attributed to the washing down and subsequent runoff that is generated from illegal mining activities. At SW06 and SW07, all the trace metals tested for were within the set quality guidelines while NO_3, DO, fecal coliforms, and NH_4 were found to be above the set limits at some sampling point and time. The water quality at these sampling points, therefore, showed that the water was most likely impacted by human settlement activities other than mining. The poor water quality in the New Canada Dam could be attributed to poor quality of water coming into the dam from the Bosmontspruit and Russell's Stream, and input by runoff from the catchment. To this end, the TDS was always exceptionally high. Nickel, DO, NH_4, and iron were also constantly above the set limits.

A regression analysis performed determined that little to no relationship could be established between flow and water quality parameter concentration. Long periods of monitoring will be required if conclusive data is to be obtained in this regard. Although the regression analysis did not yield the expected results, a review of the CC and RC provided a perspective to determine theoretical proportionality of the data set.

There is significant evidence going forward to look at the area in more detail from a number of different key environmental perspectives and expand the study further.

Author Contributions

Conceived and designed the experiments: DNM. Analyzed the data: DNM, MT. Wrote the first draft of the manuscript: DNM. Contributed to the writing of the manuscript: DNM. Agree with manuscript results and conclusions: DNM, MT. Jointly developed the structure and arguments for the paper: DNM, MT. Made critical revisions and approved final version: DNM, MT. All authors reviewed and approved of the final manuscript.

DISCLOSURES AND ETHICS

As a requirement of publication the authors have provided signed confirmation of their compliance with ethical and legal obligations including but not limited to compliance with ICMJE authorship and competing interests guidelines, that the article is neither under consideration for publication nor published elsewhere, of their compliance with legal and ethical guidelines concerning human and animal research participants (if applicable), and that permission has been obtained for reproduction of any copyrighted material. This article was subject to blind, independent, expert peer review. The reviewers reported no competing interests.

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