Water Quality and Pollution Status using Principal Component Analysis of Lake Nsezi in Richards Bay, Kwazulu-Natal, South Africa

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Abstract

The water quality of Lake Nsezi in Richards Bay, South Africa was investigated for the possible influence of anthropogenic activities around the lake. Lake water was sampled for a period of one year from May 2014 to May 2015. Physicochemical and bacteriological analysis were compared to regulations of WHO, USEPA and DWAF WQG for aquatic environment and domestic use. Physicochemical parameters measured were within the recommended specifications as per WHO, USEPA and DWAF guidelines for aquatic environment and domestic use at the exception of TDS, Cl and few heavy metals such as Al, Cd, Cu, Fe and Mn. The average content levels for these parameters were: 530±167 mg/L (TDS), 135±92 mg/L (Cl), 0.079±0.11 mg/L (Al), 0.171±0.66 mg/L(Cd), 0.38 ± 0.50 mg/L (Fe), 13.6±15.33 mg/L (Pb).

Principal component biplots positively showed some strong and moderate metal loadings of 0.564 (Fe), 0.552 (Pb), 0.928 (Na), 0.893 (Mg), 0645 (Sr) and 0.772 (K) at a variety of sites. Bacteriological parameters content investigated were all above the WHO, USEPA and DWAF guidelines for domestic use for E. coli, heterotrophic plate counts and total coliform counts.

Keywords: Freshwater quality, Lake Nsezi, Principal component analysis, Heavy metals, Micro/bacteriological characteristics.

Introduction

Freshwater is an essential commodity for all living organisms on earth and also supports the functioning of various industries[39]. Hence water of good quality and quantity is important for industrial and agricultural developments, domestic use and supports poverty alleviation for communities[15,19]. One of the basic human rights is to have access to safe water[14]. As the World Health Organization (WHO), the United States Environmental Protection Agency (USEPA) and the South African National Water Act (SANWA) reiterate from the human rights charter saying, "everyone has the right to sufficient, safe, acceptable and physically accessible and affordable water for personal and domestic needs such as drinking and hygiene"[29,30,38]. Humans and nature should coexist in constructive harmony in achieving social and economic sustainable generations.

Water quality is a conception that illustrates a standard through which conformity is evaluated. In the midst of the ramification in the factors describing water quality, a straightforward definition of the quality of water becomes difficult, water quality is therefore described as a concept that discloses its fitness to sustain a variety of uses including domestic, agricultural, industrial, aquatic ecosystem processes and recreational opportunities. In the assessment of the quality of water, the most useful criteria relate to ecological health, its reaction to possible contaminants and the safety of drinking water[23,28,33].

Various factors contribute to the decline in available freshwater in a rapid occurrence of economic development that accelerates urbanization which in turn intensifies the growth in the global population that causes increased water demand from municipal services, for drinking, agricultural activities and industrial applications putting pressure on available freshwater resources. Global warming causes a rise in the average temperatures and a significant drop in precipitation rates causing severe droughts. However, a major cause of water shortage is the deterioration of the water quality as a result of anthropogenic activities which is detrimental to human health and the aquatic ecosystem. The affected water resources are therefore not suitable for drinking purposes and will seriously contribute to the reduction of the quantity of available freshwater[9,24].

Bigas[2] stated that at the end of the 20th century, a noticeable number of large dams and impoundments building projects were undertaken in the major cities of the world to cater for different human demands such as irrigation needs, electrical power generation, drinking water and flood control. Construction of dams creates, however, deep reservoirs that submerge a large amount of vegetation and biomass which withstand decomposition. The duration of storage in these reservoirs, accumulation and deposit of pollutants, water turbidity and temperature severely affect the quality of water in these impoundments prompting a real need for monitoring[3,7,17]. Lake Nsezi is located between Empangeni and Richards Bay, part of the uMhlathuze Municipality, KwaZulu-Natal province, South Africa. Lake Nsezi is enclosed by extended human settlements of the Nseleni and Mbonambi townships.

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The city of uMhlathuze Municipality has erected a water treatment plant next to the lake, since it serves as a major water resource in this part of the province for agricultural developments such as sugar cane plantations, forestry and small-scale farming, industrial activities including pulp and paper Mondi Kraft, Bayside and Hillside aluminium smelters, Foskor, The Richards Bay Coal Terminals (RBCT), Tronox mineral sands and Richards Bay Minerals (RBM).

Monitoring of Lake Nsezi's water originally started in 2000 and has been conducted by Mhlathuze Water Laboratory in Richards Bay addressing the following parameters: cyanide (CN), nitrogen (N), phosphates (PO_4), hardness, total dissolved solids (TDS) and dissolved oxygen (DO) as general water quality parameters; physicochemical parameters including temperature, colour, electrical conductivity and turbidity; metals including zinc, sodium, copper, cadmium, potassium, magnesium, lead, iron, manganese, calcium and aluminium; general water parameters including sulphate, fluoride, nitrate and chloride as well as bacteriological indicator *E.coli*[4].

The purpose of this study was to assess the water quality of Lake Nsezi through sampling of the lake water for physicochemical parameters, metals and bacteriological analysis. Results were compared to the South African Water Quality Guidelines for domestic and environmental uses[5,6]. Possible pollution sources were identified and the results of this study were compared to historical data in a quest to ascertain if there have been any improvements or decline in the quality of water of Lake Nsezi to inform decision making.

Material and Methods

Study area: Lake Nsezi (Figure 1) is a class H-hydrographic lake in Kwazulu-Natal, South Africa where the region font code is Africa/Middle East. The lake is located at an elevation of 1 m above sea level with coordinates 28º45'0" S and 31º58'60" E. The predicted storage capacity was found in the region of 834000 m^3, the average depth of 2.5 m, the length in the region of 5 km and the width of about 2 km. The lake is sourced by the Nseleni and Mposa rivers with a large settlement of Nseleni in the catchment area. The lake serves as the major storage reservoir in the municipality. The expansion of Empangeni and Richards bay has witnessed a remarkable increase in the abstraction rates of water from this lake in the past 23 years.

To address the demand from municipal users and industry, the appropriate yield capacity is controlled with an increased transfer of water from the uMhlathuze river. Lake Nsezi unveils an appealing appearance alongside a rich botanical display with African papyrus (*Cyperus papyrus*) dominating major parts of the lake, the lake is a shelter to crocodile, fish, hippopotami and a bountiful bird life[10,18,22].

Lake water analyses: Physicochemical parameters including dissolved oxygen (DO), temperature, pH and electrical conductivity were measured *in situ* at each sampling site making use of portable meters (Figure 2 and tables 1 - 2). For each sampling season, water samples were collected in 2 L plastic bottles preserved with 3% sodium thiosulphate[20]. Collected samples were stored with ice packs in a cooler bag and delivered to Mhlathuze Water Laboratory in Richards Bay for analysis that included heavy metals, general water parameters and bacteriological parameters. Metals analysis was performed by Mhlathuze Water Laboratory making use of ICP-OES technique on a Perkin Elmer/Optima 8X-00 instrument using standard operating procedures (Table 2). The general water quality analysis was performed on each sample making use of an ion chromatography technique using a Dionex DX-100 instrument to include sulphate, chloride, fluoride and nitrate ions (Table 2).

Bacteriological analysis was performed on each water sample using the Colilert-18 method[1]. To assess the general health of the lake water, total coliform analysis was done while faecal coliform counts were performed to establish pathogenic indicators in the lake and to establish a possible formation of microbial colonies. Along with the overall bacteriological quality of the water, heterotrophic plate counts were performed. An enzyme substrate coliform method using Colilert-18[1] (Table 2) media was used, reagents were added to 1:10 diluted samples, thoroughly mixed and incubated at 35 ℃ ± 0.5 ℃ for 18 ± 4 h to produce a distinctive yellow colour for total coliform bacteria and fluorescent colour for *E. coli* to count as many as 2 x 10^6 heterotrophic bacteria/100 mL. Analyses of the lake water samples were done in duplicate making use of indicated techniques in accordance with the standard operating procedures (Table 2).

Table 1
Georeferencing coordinate system of the sampled sites.

Sampling point	Sampling location	Location coordinates (GPS)
1	Mposa river	E 32° 01' 10" S 28° 41' 09"
2	RBM abstraction point	E 32° 01' 55" S 28° 41' 36"
3	N_2 Bridge	E 32° 00' 51" S 28° 41' 45"
4	Downstream to N_2 Bridge	E 32° 00' 51" S 28° 41' 45"
5	Small stream into Lake Nsezi	E 32° 00' 20" S 28° 43' 22"
6	Abstraction point at Lake Nsezi	E 31° 58' 45" S 28° 44' 49"
7	Lake Nsezi discharge point	E 31° 57' 48" S 28° 46' 09"

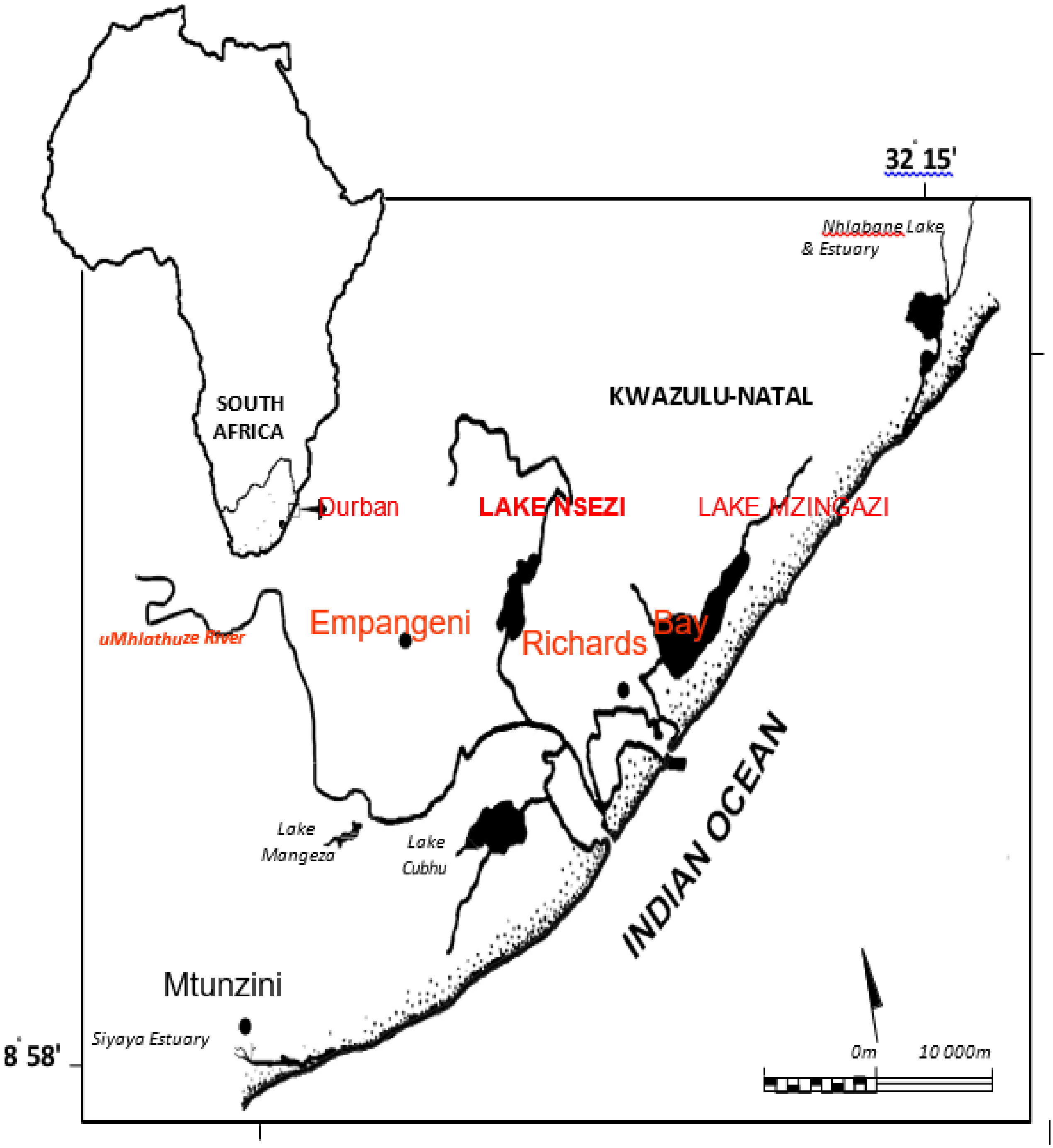

Figure 1: Lake Nsezi in the study area[16]

Table 2
Techniques used for chemical and bacteriological analyses of Lake Nsezi water.

Parameter	Technique	Method number	Instrument brand/model
pH	Electrochemical method	SM 4500 – H$^+$ B[1]	RE 300 ExStik II
Dissolved oxygen (DO)	Optical-probe method	SM 4500 – O H[1]	DO600 ExStik II
Temperature	Field method	SM 2550 B[1]	RE 300 ExStik II
Total dissolved solids (TDS)	Laboratory method	SM 2510 B[1]	EC510 ExStik II
Anions (F$^-$, Cl$^-$, NO$_3^-$, SO$_4^{2-}$)	Ion chromatography	SM 4110 B[1]	Dionex DX-100
Metals (Al, Ca, Cd, Fe, Mg, Pb, K, Na, Sr)	ICP- OES	SM 3120 B[1]	Perkin Elmer/Optima 8X- 00
E. coli; total coliform bacteria, heterotrophic bacteria	Colilert-18[1]	SM 9223 B[1]	EDEXX Colilert-18 Quanti-tray/2000

Sampling points

Figure 2: Lake Nsezi and the different sampling sites. 1- Mposa River; 2- RBM abstraction point; 3- N_2 Bridge; 4- N_2 Bridge downstream; 5- Small stream entering Lake Nsezi; 6- Mhlathuze Water abstraction point; 7-Lake Nsezi discharge point[3].

Table 3
The seasonal average values of Lake Nsezi analytical parameters for the sampling period 2014-2015.

Analytical parameter	Temp (°C)	DO (mg/L)	pH	TDS (mg/L)	NO_3^- (mg/L)	SO_4^{2-} (mg/L)	F^- (mg/L)	Cl^- (mg/L)	Al (mg/L)	Ba (mg/L)	B (mg/L)	Cd (mg/L)	Ca (mg/L)	Co (mg/L)	Cr (mg/L)	Cu (mg/L)
Autumn 2014	23.1	5.4	7.4	4.57	0.104	8.32	0.71	130.6	0.040	0.053	0.061	<7	18.04	<13	<6	<13
Winter 2014	19.4	4.27	7.7	5.73	0.262	10.49	0.41	141.23	0.047	0.061	0.104	5.71	19.30	<13	8	13
Spring 2014	24.9	3.86	7.5	5.58	0.243	9.73	0.45	136.74	0.08	0.073	0.093	BD	17.81	<13	<6	14
Summer 2015	25.9	3.17	7.2	4.29	0.325	12.38	0.40	103.94	0.092	0.117	0.098	0.94	16.03	<13	7	<13

Analytical parameter	Fe (mg/L)	Pb (mg/L)	Mn (mg/L)	Mg (mg/L)	Hg (mg/L)	Mo (mg/L)	Ni (mg/L)	K (mg/L)	Na (mg/L)	Sr (mg/L)	Ti (mg/L)	V (mg/L)	*E. coli*[2]	HPC[3]		TCB[4]
Autumn 2014	0.581	16.77	0.114	17.02	<0.5	<0.007	<0.021	5.48	91.37	0.140	<0.004	<0.003	3706	0.853 x10^6		11236
Winter 2014	0.363	7.28	0.102	23.79	<0.5	0.03	<0.021	8.66	118	0.151	0.014	0.007	74	0.299 x 10^6		1440
Spring 2014	0.237	31.80	0.196	19.37	<0.7	0.012	<0.021	8.03	129	0.155	0.018	0.008	54	1.358 x 10^6		13448
Summer 2015	0.475	0.50	0.223	15.30	<0.7	0.028	<0.021	6.33	106.3	0.158	0.023	0.006	15257	2.357 x 10^6		39322

[2] *E. coli* colonies counts/100 mL
[3] Heterotrophic plate counts/100 mL
[4] Total coliform bacteria counts/100 mL

Table 4
Surface water Quality Standards

Parameter	DWAF (a; b)*	WHO	US EPA
Aluminium (mg/L)	0.15; 0.005	0.2	0.2
Cadmium (mg/L)	0.0005; 0.00015	0.003	0.005
Copper (mg/L)	1; 0.0008	2	1.3
Iron (mg/L)	n/a	n/a	0.3
Manganese (mg/L)	0.015; 0.18	0.4	0.1
Lead (mg/L)	10; 0.0002	0.01	0.015
HPC (counts/mL)	n/a; 100	100	n/a
TDS (mg/L)	450; 435	n/a	500
Chloride (mg/L)	100; 0.0002	250	250

*a: Domestic use guideline, DWAF: Department of Water Affairs and Forestry (RSA)
*b: Aquatic environment guideline, WHO: World Health Organisation (United Nations)
n/a: No available guideline, USEPA: US Environmental Protection Agency (USA)

Table 5
Mean values of various parameters at seven sampling sites for the period of Autumn 2014.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Temperature (ºC)	21.9 ± 2.4	21.6± 2.2	23.6±6.6	23.1±5.6	23.3±2.92	26.4±6.6	22.1 ± 5.91
pH	7.0±0.2	7.8±0.3	7.6±0.3	7.7±0.63	6.9± 0.3	7.2 ±0.4	7.4± 0.54
TDS (mg/L)	564±35.16	621±56	534±86.5	637±318	274±74.1	239±158.6	570 ±184
DO (%)	25.66 ± 2.66	57.13±15.73	69.1±13.31	51.3±24.92	76.2±32.6	82.06±16.7	95.6± 80.9
HPC (counts/100mL)	$1.71x10^{4}\pm 7.6x10^{5}$	$8.5x10^{5}\pm 5.9x10^{5}$	$2.37x10^{4}\pm 8.5x10^{5}$	$1.04x10^{6}\pm 8.15x10^{5}$	$2.37x10^{4}\pm 8.5x10^{5}$	$1x10^{3}\pm 8.1x10^{5}$	$1x10^{3}\pm 8.2x10^{12}$
Cl^- (mg/L)	153±11.8	45.14± 45.2	150.08 ± 29	164.9±146.92	171.42±122.1	58.42±35.3	172.42 ± 10.8
Ca^{2+} (mg/L)	15.90±1.4	12.3±7.3	13.4±3.1	26.0±12.6	15.8±1.79	10.89±5.8	32.0 ± 4.91
K^+ (mg/L)	7.85±0.6	4.4± 2.4	4.92±5.4	6.82±6.10	9.21±5.6	2.89±2.3	2.89 ±61.3

Table 6
Mean values of various parameters at seven sampling sites for the period of Summer 2015.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
Temperature (ºC)	24.6± 2.4	26.1±1.8	26.5±3.0	26.9±5.59	25.8±2.92	27.4 ±3.0	24.4±5.91
pH	6.7±0.2	7.5±0.5	7.5±0.2	7.7±0.6	6.7±0.3	7.3 ±0.4	7.3±0.5
TDS (mg/L)	673±35.16	631±56	601±86.5	515±321.1	263 ±73.86	246±158.6	457±392.73
DO (%)	14.64±6.05	42±21.79	35.95±13.31	46.7±33.13	40.0±39.49	48.9±16.94	48.9±80.89
HPC (counts/100 mL)	$2.04x10^{6}\pm 7.7x10^{5}$	$1.93x10^{5}\pm 5.9x10^{5}$	$1.8x10^{5}\pm 8.5x10^{5}$	$24.3x10^{4} \pm 8.15x10^{5}$	$11.1x10^{4}\pm 1.64x10^{6}$	$1.51x10^{6}\pm 8.1x10^{5}$	$10.6x10^{6} \pm 8.2x10^{12}$
Cl^- (mg/L)	126.71±2.8	140.56±45.1	142.52±59.9	118±92.91	58.28±122.3	59.34±42.32	81.39±77.80
Ca^{2+} (mg/L)	19.80±1.4	15.40±3.3	15.30±3.0	13±12.6	13.6±1.71	4.41±5.8	29.4±4.91
K^+ (mg/L)	9.36 ±0.6	6.6±3.8	6.09±2.3	4.55±6.10	5.71±5.6	3.51±2.4	8.47±61.3

Statistical analysis: Statistical analysis was undertaken by making use of principal component analysis (PCA). Data screening by PCA draws particular attention to the influence of the pollution causing responsible components from a multivariate data set. It is an effective technique for the description of many variables and their relationships within an analytical system[31]. The method applies a linear relationship to convert the initial variables (X) towards a reduced number of new principal components according to the equation (1):

$$X = t_1p_1 + t_2p_2 + \ldots + t_np_n + E \quad (1)$$

where t_n and p_n are respectively score values and loading values respectively and E is the residual matrix. The loadings and scores can be represented on a PCA bi-plot that allows concurrent analysis of variable relationships and sample properties[11]. The statistical data processing was performed by making use of Microsoft excel XLSTAT 2022.1.2.12345 (ADDINSOFT, Inc., USA, 2022).

Results and Discussion

The georeferencing of the sampling points is shown in table 1. Thirty one analytical parameters were recorded for each sampling site for the entire sampling period (2014-2015): temperature, pH, total dissolved solids (TDS), dissolved oxygen (DO), nitrate (NO_3^-), sulphate (SO_4^{2-}), fluoride (F^-), chloride (Cl^-), aluminium (Al), barium (Ba), boron (B), cadmium (Cd), calcium (Ca), cobalt (Co), chromium (Cr), copper (Cu), iron (Fe), lead (Pb), magnesium (Mg), mercury (Hg), manganese (Mn), molybdenum (Mo), nickel (Ni), potassium (K), sodium (Na), strontium (Sr), titanium (Ti), vanadium (V), *Escherichia coli* (*E. coli*), heterotrophic bacteria and total coliform bacteria.

Comparing the different parameter concentrations between autumn 2014 and summer 2015 sampling period (Tables 5-6), HPC concentration increased with a factor of 50 moving from site 1 to 2 in autumn 2014 and dropped with a factor of 0.1 in summer 2015; Cl^- (as Cl) concentration increased with a factor of 4 moving from site 2 to 7 in autumn 2014 and dropped with a factor of 0.6 in summer 2015; TDS levels increased with a factor of 2 moving from site 5 to 7 in autumn 2014 and dropped with a factor of 1.7 in summer 2015.

Table 7
Metals content (mg/L) for samples collected during Autumn 2014 sampling and corresponding pH values for each sampling site.

Parameter	Site 1	Site 2	Site 3	Site 4	Site 5	Site 6	Site 7
pH	7.0	7.8	7.6	7.7	6.9	7.2	7.4
Al	0.019	0.002	0.019	0.019	0.023	0.178	0.178
Cd	0.0069	0.0069	0.0069	0.0069	0.0069	0.0069	0.0028
Cu	0.0128	0.0128	0.0128	0.0129	0.0129	0.0128	0.0129
Fe	0.025	0.0364	0.739	2.625	0.025	0.252	0.036
Mn	0.024	0.024	0.039	0.166	0.025	0.166	0.489
Pb	0.0159	0.0159	0.035	0.0159	0.0159	0.0013	0.0013

Table 8
Statistics summary of parameters in the data set.

Variable	Observations	Obs. with missing data	Obs. without missing data	Minimum	Maximum	Mean	Std. deviation
E. coli (counts/100mL)	35	0	35	1,000	6867,000	380,257	1197,483
F(mg/L)	35	0	35	0,150	2,190	0,563	0,445
DO%	35	0	35	11,000	114,000	55,506	24,123
N (mg/L)	35	0	35	0,079	5,270	0,410	0,937
Temp (^{o}C)	35	0	35	17,100	28,900	23,646	2,895
Al (mg/L)	35	0	35	0,002	0,412	0,079	0,112
SO_4^{2-}(mg/L)	35	0	35	0,890	88,320	12,335	14,600
Fe (mg/L)	35	0	35	0,025	2,630	0,380	0,498
Pb (mg/L)	35	0	35	0,000	60,400	13,600	15,331
HPC (counts/100mL)	35	0	35	1000,000	10600000,000	1260085,714	1802807,522
B (mg/L)	35	0	35	0,025	0,128	0,084	0,032
K (mg/L)	35	0	35	2,270	10,200	6,381	2,585
N (mg/L)	35	0	35	35,700	162,000	103,535	42,627
TDS (mg/L)	35	0	35	214,000	728,000	529,714	166,548
Cd (mg/L)	35	0	35	-0,003	2,800	0,171	0,656
Cl (mg/L)	35	0	35	3,760	598,000	135,205	92,214
Mg (mg/L)	35	0	35	8,220	29,700	17,997	6,189
Ca (mg/L)	35	0	35	4,410	33,000	17,993	6,700
Sr (mg/L)	35	0	35	0,074	0,241	0,148	0,042
TCB (counts/100mL)	35	0	35	236,000	220295,000	16284,543	36602,181

Table 9
Score loadings of the Principal Components Analysis of the 20 analytical parameters on the first six Principal components (PCs).

Parameter	PC1	PC2	PC3	PC4	PC5	PC6
E. coli	0,212	-0,278	0,346	0,200	0,696	0,156
F	-0,252	-0,069	0,464	0,615	-0,497	0,071
DO%	-0,300	-0,435	0,667	0,154	-0,125	-0,060
N	-0,485	-0,015	-0,076	0,289	-0,096	0,113
Temp(°C)	-0,463	0,013	-0,012	0,100	0,372	-0,344
Al	-0,517	0,388	0,290	0,022	0,020	-0,396
SO_4^{2-}	-0,409	-0,055	-0,127	0,528	-0,247	0,270
Fe	-0,102	0,354	-0,083	-0,434	-0,106	0,564
Pb	0,203	-0,153	0,207	0,391	0,552	0,403
HPC	-0,165	0,896	0,267	0,117	0,124	0,138
B	0,797	0,261	-0,033	0,276	-0,007	-0,337
K	0,772	0,275	-0,307	0,241	0,115	-0,108
Na	0,928	-0,012	0,001	0,123	-0,024	-0,204
TDS	0,843	0,016	0,051	0,115	-0,001	0,068
Cd	-0,154	-0,373	0,448	-0,369	0,191	0,027
Cl	0,249	-0,178	-0,313	-0,016	-0,035	0,405
Mg	0,893	-0,123	0,253	-0,035	-0,236	0,063
Ca	0,275	0,058	0,630	-0,400	-0,105	-0,099
Sr	0,645	0,079	0,456	-0,086	-0,226	0,216
TCB	-0,104	0,862	0,327	0,051	0,137	0,148
Eigenvalue	5,347	2,459	2,178	1,639	1,475	1,313
Variability (%)	26,736	12,294	10,890	8,196	7,374	6,563
Cumulative %	26,736	39,030	49,921	58,117	65,491	72,054

Moving from site 2 to 7 Ca^{2+} concentration increased with a factor of 3 in autumn 2014 and decreased with a factor of 2 in summer 2015.

K^+ content increased with a factor of 2 moving from site 2 to 5 in autumn 2014 and decreased with a factor of 1 in summer 2015 and DO concentration increased with a factor of 1.6 moving from site 5 to 7 in autumn 2014 and decreased with a factor of 1.2 in summer 2015. Increased Ca^{2+} content at site 7 (Tables 5-6) may be attributed to natural weathering of the rocks that are rich in calcite and dolomite.

Snails' presence spotted at sampling site 7 may also be an indicator of a high-density calcium carbonate, a necessary compound in shell building for shelled fauna[26]. The decrease in concentration levels is noted because of rainy summer months dilution. Table 3 gives the seasonal averages for all the sampling sites of all the parameters analysed in the study.

Biological analysis of the lake water samples for the entire sampling period (2014 to 2015) indicated in general an elevated bacterial activity with all the indicators *E. coli*, total coliform counts and heterotrophic plate counts (HPC) at all the sampling sites (Tables 3-6).[5,6,38]

Lake Nsezi water temperatures were above 15 °C at all the sampling sites (Tables 3 and 6) which created a breeding ground for bacterial growth and municipal secondary sewage effluent discharge into the lake added to the bacteria loadings. To this the absence of proper sanitation facilities at recreation sites is added, pushing communities to make use of the forest for toilet compelling rain to wash the defecation into the lake[13,21,31].

Heavy metal concentrations indicated an increased trend. Al concentration increased by factors of 8 and 10 moving from sampling sites 5 to 6 and sites 2 to 3; Fe concentration increased by factors of 1.5, 4 and 20 moving from sampling sites 1 to 2, sites 3 to 4 and sites 2 to 3; Mn concentration increased with factors 1.6, 4.3 and 20 moving from sampling sites 2 to 3, sites 3 to 4 and sites 5 to 7 while Pb concentration increased by a factor of 2.2 moving from sampling sites 2 to 3 (Table 7). Although the concentrations of Cd and Cu remained constant throughout, recorded levels (Table 7) are still exceeding standards (Table 4).[5,6,30,34,35-37]

The elevated content in Cd, Cu and Mn in Lake Nsezi is attributed to heavy metals accumulation properties into the depth of lakes because of agricultural, domestic and industrial waste disposal into the lake[8]; increased Pb content in this area is attributed mainly by Pb dust emissions by gasoline powered vehicles and agricultural machinery, street runoff and lead-acid battery industrial waste[25]. High Al content in the lake environment is attributed to anthropogenic deposition from Hillside and Bay Side Aluminium smelter emissions, waste disposal from Mondi

Kraft where aluminium sulphate additive is part of pulp and paper process as well as waste disposal contamination from Mhlathuze water treatment plant where aluminium sulphate is part of the process[4,12].

Increased Fe content in sites 3 and 4 (Table 7) may be associated with agricultural runoff from excess fertilizer additives in the course of soil preparation and pesticides application especially on forest plantations in the study area[27,32].

Lake Nsezi data set was built by making use of 20 analytical parameters per sampling site from autumn 2014 to autumn 2015 to a total of 700 values with measured parameters considered as variables and sampling sites as objects (Table 8).

Figure 3 is a bar plot of the score loadings illustrating each variable's evident contribution to the building of the Principal Components (PCs). The factor loading can be classified as weak, moderate and strong with reference to absolute loading values of 0.50-0.30, 0.75-0.50 and > 0.75 respectively[11,12]. The first Principal Component (PC1) describing 27% of total variance (Figure 3 and Table 9) indicates strong and moderate positive metal loadings for Lake Nsezi water (0.928-0.645); PC2 describing 39% variance indicates strong positive bacteriological parameter loadings (0.896-0.862) and poorly positive metal loadings (0.388-0.054) (Table 9); PC3 describing 50% total variance indicates moderate to poor metal loadings (0.630-0.001) (Table 9); PC4 describing 58% variance indicates a moderate positive general water parameter loadings (0.615-0.528) (Table 9) while PC5 at 66% variance and PC6 at 72% variance indicate a moderate metal loadings 0.552 and 0.564 respectively (Table 9).

In figures 4 and 5, the Principal Components biplots shows that in both visible axes, 39.03% of total variance is described with 26.74% explained on axis 1 and 12.29% explained on axis 2. The strong driving variables graphically represented here are inclusive of general water parameters, physicochemical parameters, metals and bacteriological population per sampling site.

Most of the metals have separated in quadrants 1 and 4 with TDS in one direction; Na, Mg, K, Sr, Fe and Pb are related to the strong and moderate metal loadings in PC1, PC5 and PC6 (Table 9) with a conglomerate of sampling sites closer to the metal vectors and on the right side of the origin signalling the higher metal concentrations in the vectors. Dissolved oxygen (DO) and HPCs indicate a negative relationship (Figures 4 and 5) in a sense that heterotrophic bacteria need oxygen and make use of DO for some of their life processes at different sampling sites.

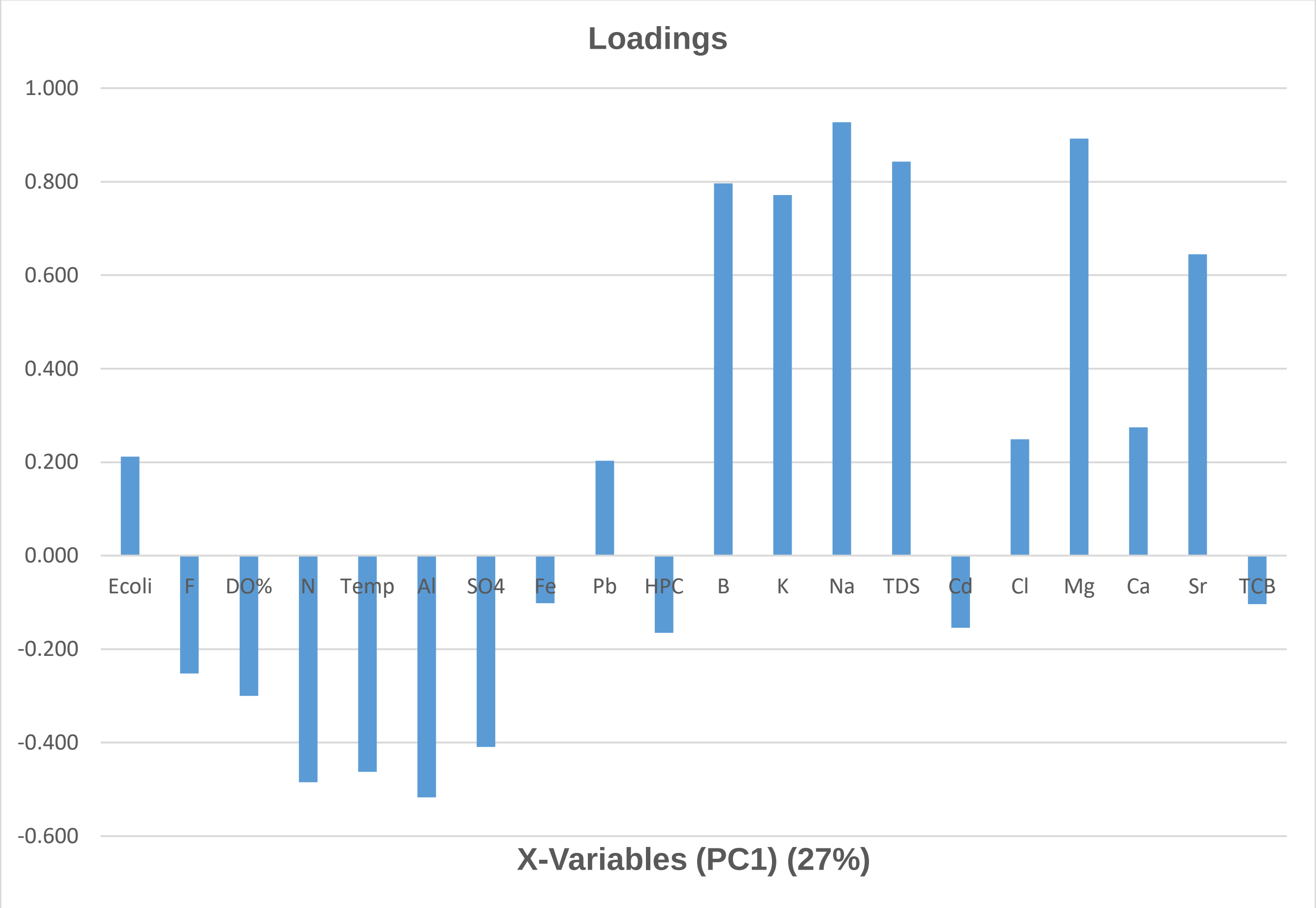

Figure 3: PCA score loadings of variables on the first Principal Component (PC1) at 27% cumulative variability

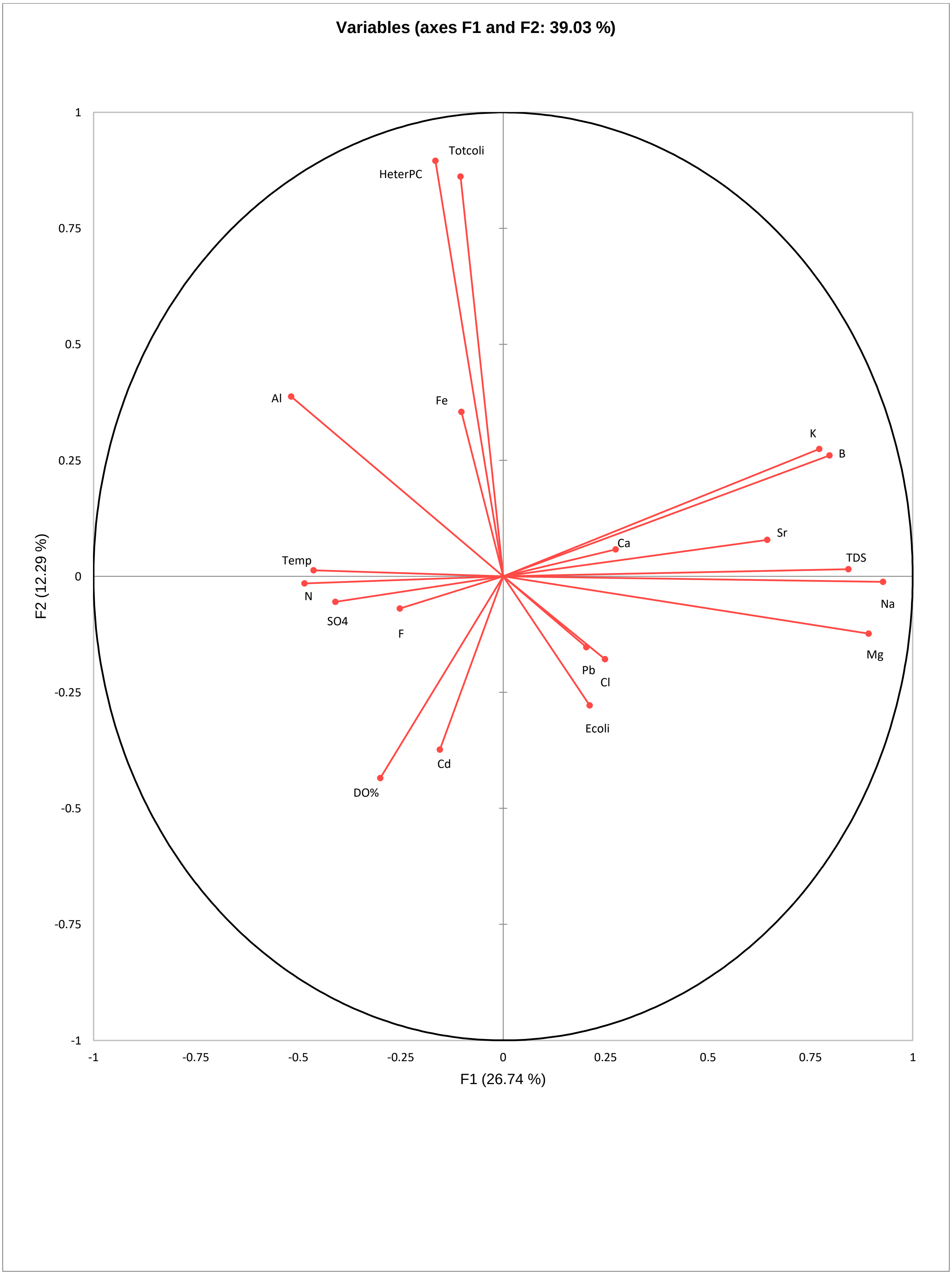

Figure 4: PCA biplot of active strongest variables separation for the sampling period 2014-2015

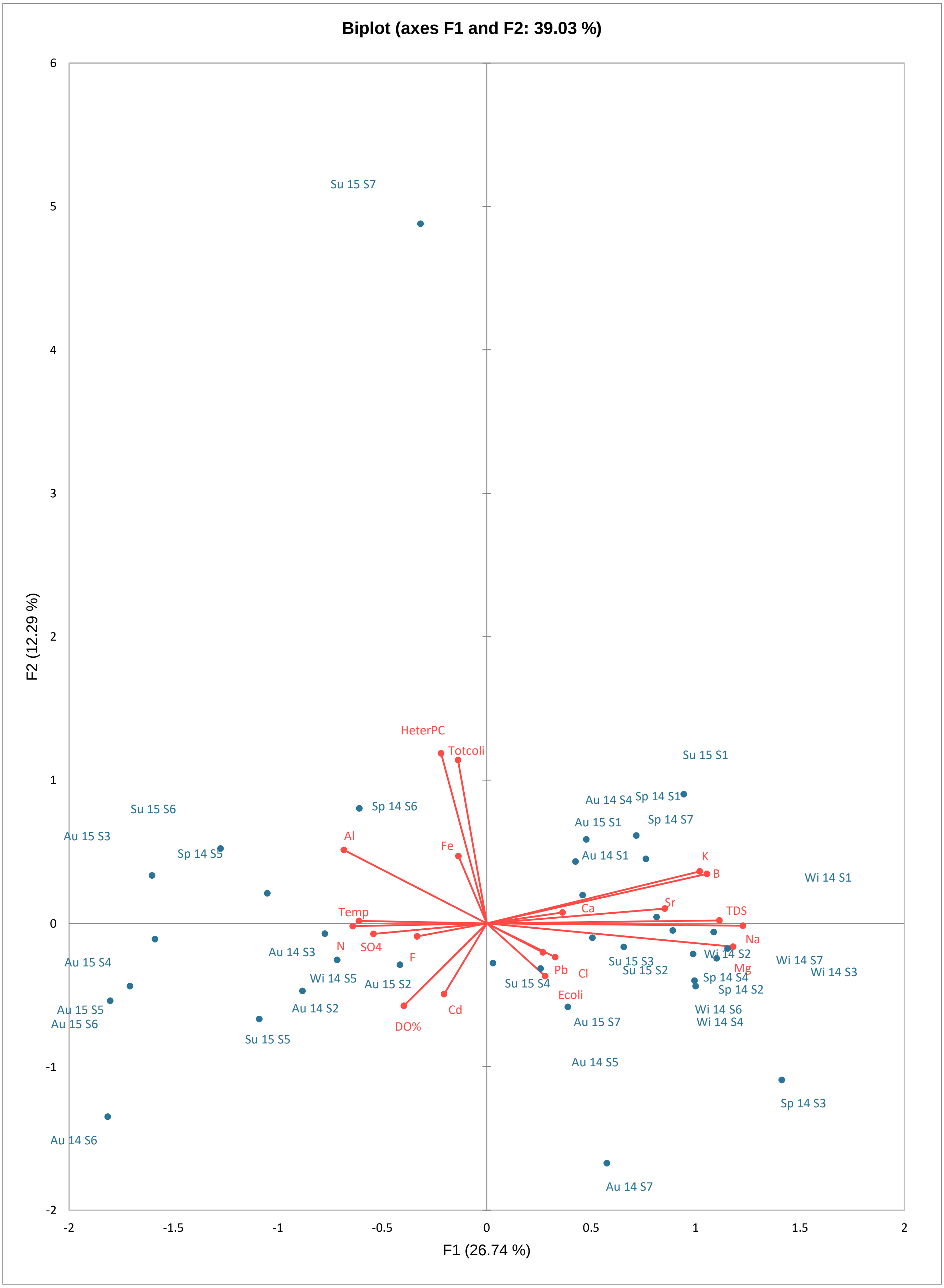

Figure 5: PCA biplot of active strongest variables emanating in season and sampling site separation for the sampling period 2014-2015

This will be a possibility that as the HPCs content increases, there may be a depletion in DO concentration. Another inverse correlation is also noted between TDS and temperature as TDS indicates in part the amount of organic materials dissolved in water and surviving on the DO content of the lake water, when the temperatures are high the DO concentrations decrease and the TDS concentrations will also drop.

Conclusion

In this area there is a high traffic of pedestrians crossing in and out of Nseleni township at Mposa River bridge. Cattle grazing at the banks of the lake is observed and secondary sewage effluent from Nseleni township is discharged into the lake, municipal, agricultural and industrial surface runoff land into the lake.

Sites 3, 4, 6 and 7 are in the proximity of the giant aluminium smelter as well as a pulp and paper mill that uses aluminium derivatives. All explain the occurrence of aluminium, cadmium, copper, manganese as well as lead. The method used as tested in this study proves its predictive potential as a credible means for routine monitoring to inform decision making.

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References

1. Bairds R.B., Eaton A.D. and Rice E.W., Standard Methods for the Examination of Water and Wastewater, American Public Health Association, 23rd edition Washington DC, USA, 1546 **(2017)**

2. Bigas H., The global water crisis: Addressing an urgent security issue, Papers for the Inter Action Council, Hamilton, Canada: UNU-INWEH **(2012)**

3. Cimanga L., Evaluation of the water quality of Lake Nsezi in Kwazulu-Natal, South Africa, Environmental Science, MSc, University of South Africa **(2018)**

4. Chitonge H., Urbanisation and the Water Challenge in Africa: Mapping out orders of Water Scarcity, *African Studies*, **79(2)**, 192-211 **(2020)**

5. Department of Water Affairs and Forestry (DWAF), South African Water Quality Guidelines: Aquatic ecosystems, Second edition, 1-161 **(1996 a)**

6. Department of Water Affairs and Forestry (DWAF), South African Water Quality Guidelines: Domestic use, Second edition, 1-190 **(1996 b)**

7. Dinesh K.S., Impact of dams on River Water Quality, *International Journal of Current Advanced Research*, **4(7)**, 176-181 **(2015)**

8. Erdogan K., Sevket K., Mehmet I.D., Arzu D., Ismail S., Savas Y., Gülnihal Ö., Levent A., Okan Y., Nuh K. and Hibrahim Ö., The effects of seasonal Heavy Metal pollution of Ladik Lake on Pike Fish (Exos Lucius), *Biological Rhythm Research*, **52(6)**, 821-845 **(2021)**

9. Hejdukova P. and Kurekova L., Water Scarcity: Regional analyses in the Czech Republic from 2014 to 2018, *Oeconomia Copernicana*, **11(1)**, 161-181 **(2020)**

10. Heyneke A.W., City of uMhlathuze Hard at Work, Annual review, 2008-2009 **(2008)**

11. Ioele G., Deluca M., Grande F., Durante G., Trozzo R., Crupi C. and Ragno G., Assessment of Surface Water Quality using Multivariate Analysis: Case study of Crati River, Italy, *Water*, **12(8)**, 2214 **(2020)**

12. Jayaseelan Vijayashree Priyadharsini and Arumugam Paramasivam, Stem cells and cell derived exosomal biomarkers as promising therapeutic components for temporomandibular joint disorders, *Res. J. Biotech*., **17(10)**, 162-170 **(2022)**

13. Jyothylakshmi K., Nandakumar S. and Sanalkumar M.G., Bacterial Pollution Indicators associated in tissues of an Estuarine fish *Magul Cephalus* from Astamudi Lake, a RAMSA site (India), *Sustainability, Agricutural, Food and Environmental Research*, **4(9),** 516-525 **(2021)**

14. Kiefer I., Van De Linde L., Alder –Michaelson H., Neumeyer H., Khalfan A., Roaf V., Morley D., O'Cornenell M., Johnson C., Montgomery I. and Charri J.B., Legal resources for the Right to water and Sanitation, Centre on housing rights and evictions, 30 **(2008)**

15. Li S.H., Hong L., Jin B.X., Zou J.S. and Perg S.Y., Spatiotemporal Patterns of Impervious Surface Area and Water Quality Response in the Fuxian Lake Watershed, *Journal of Environmental Public Health*, **2020**, 1-12 **(2020)**

16. Mackay C.F. and Cyrus D.P., Available information on macroinvertebrates of the Mhlathuze coastal lakes: setting the ecological reserve (lake water requirements), *Southern African Journal of Aquatic Sciences*, **26(2)**, 85-98 **(2001)**

17. Millington N. and Scheba S., Day Zero and the Infrastructures of Climate Change: Water Governance, Inequalities and Infrastructural Politics in Cape Town's Water Crisis, *International Journal of Urban and Regional Research*, **45(1)**, 116-132 **(2020)**

18. Moss D., Bioregional planning in the city of uMhlathuze, Contract Document for the City of uMhlathuze **(2005)**

19. Mthobisi I.S., A study of the impact of anthropogenic activities in the crocodile River, Mpumalanga, South Africa, Environmental Science, MSc, University of South Africa, 123 **(2014)**

20. Murray A.L., Kumpel E., Peletz R., Kush R.S. and Lantangne D.S., The effect of Sodium Thiosulphate dichlorination on fecal indicator bacteria enumeration: Laboratory and field data, *Journal of Water and Health*, **16(1)**, 70-77 **(2018)**

21. Niyoyitungiye L., Giri A. and Ndayisenga M., Assessment of Coliform Bacteria Contamination in Lake Tanganyika as

Bioindicators of Recreational and Drinking Water Quality, *South Asian Journal of Research in Microbiology*, **6(3)**, 9-16 **(2020)**

22. Nowele S., Environmental Management Framework (EMF) for the Richards Bay port expansion area and Industrial development zone area, Department of Agriculture and Environmental Affairs, Pietermaritzburg: Government Printer **(2010)**

23. Puri P.J., Yenkie M.K.N., Sangal S.P., Grandare D.B., Sarote G.B. and Dhanonkar D.B., Surface water (lakes) Quality Assessment in Nagpur City (India) based on water quality index (WQI), *Rasayan Journal of Chemistry*, **4**, 43-48 **(2011)**

24. Qureshi W.A., International Law and Efforts to Mitigate Freshwater Scarcity, Oregon Review of International Law, 21st edition, **22**, 109-146 **(2021)**

25. Rees N. and Fuller R., The Toxicity Truth: Children Exposure to Lead Pollution Undermines a Generation of Future Potential, UNICEF, Washington DC **(2020)**

26. Sazon R.R. and Migo V.P., Metal concentrations in Sediments of the Alinsaog River, Santa Cruz, Zambales, Central Luzon, Philippines, *Journal of Health and Pollution*, **10(27)**, 200914 **(2020)**

27. Singh B.P., Choudhury M., Samantha P., Gaur M. and Kumar M., Ecological Risk Assessment of Heavy Metals in Adjoining Sediment of River Ecosystem, *Sustainability*, **13**, 10330 **(2021)**

28. Smol J.P., Pollution of Lakes and Rivers: A Paleo environmental Perspective 2nd edition, Blackwell, Malden USA, 396pp **(2008)**

29. South African National Water Act (SANWA), Act no. 36 of 1998, Government Gazette, 101 **(1998)**

30. US EPA, National Primary Drinking Water Regulations. EPA 816-F-09-004, US Environmental Protection Agency, Washington, DC **(2001)**

31. Vadde K.K., Wang J., Yuan T., McCarthy A.J. and Sekar R., Assessment of Water Quality and Identification of Pollution Risk Locations in Tiao River (Taihu Watershed), China, *Water*, **10**, 183 **(2018)**

32. Viana L.F., Crispim B.A., Sposito J.V.C., De Melo M.P., Francisco L.F.V., De Nascimento V.A. and Barufatti A., High iron content in river waters: environmental risks for aquatic biota and human health, *Ambiante & Ăgua- An Interdisciplinary Journal of Applied Science*, **16(5),** e2751**(2021)**

33. Votruba A.M. and Corman J.R., Definitions of Water Quality: A survey of Lake- Users of Water Quality-Compromised Lakes, *Water*, **12(8)**, 2114 **(2020)**

34. World Health Organization background document for development of Guidelines for drinking, water Quality: Total dissolved solids, WHO, Geneva **(2003)**

35. World Health Organization Guidelines for drinking, water quality, WHO, Geneva **(2008)**

36. World Health Organization Guidelines for drinking, water quality, WHO, Geneva **(2011)**

37. World Health Organization Heterotrophic Plate Counts and Drinking, water safety, WHO, Geneva **(2003)**

38. World Health Organization Housing and Health Guidelines, WHO, Geneva **(2018)**

39. Yang X., Cui H., Liu X., Wu Q. and Zhang H., Water Pollution Characteristics and Analysis of Chaohu Lake basin by using Different assessment methods, *Environmental Science and Pollution Research*, **27**, 18168-18181 **(2020)**.

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