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Full Length Research Paper

Evaluation of portable water in five provinces of Zambia using a water pollution index

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Five provinces with different environmental characteristics were evaluated for water pollution with the aim of identifying the major sources and area(s) most affected. The results indicate that the water in Lusaka Province is significantly high in nitrate and sodium concentration compared to other provinces considered in this study. The results further reveal that ground water is most affected by nitrate and sodium. On the contrary, dissolved organic carbon (DOC) was found to be significantly higher in surface water but no particular province registered a higher amount compared to others. The results further reveal that the pollution is primarily a function of human activities, social amenities and industrial activities in the study areas.

Key words: Nitrate, sulphate, groundwater, Lusaka, ion exchange/cation-exchange chromatography.

INTRODUCTION

Surface and ground water resources are threatened by pollution from release of dissolved substances including inorganic ions and organic compounds such as oils, into rivers, wetlands and ground water from industrial activity in Zambia. Cement waste, molasses and bagasse, textile sediment sludge, petroleum, paint, pesticides, fungicides, human waste, fertilizers from farms/gardens, and lime sludge from industries in Lusaka, Kafue and the Copperbelt, all continue to find their way into water systems through direct discharge, seepage or overflow to ground and surface water courses (Chundama, 2008). To mitigate some of these problems, it is strongly recommended that there be adequate supervision on what type of sanitation is used in different areas depending on the geology and hydrology of the area; solid waste should be seen as a serious threat to water resources and the solid waste hierarchy of reduce-reuse-recycle should be followed up in solid waste management activities (Nakamboa, 2005).

Many studies cite groundwater quality data as evidence of sewer – related contamination (Baird and Cann, 2008; Marquita, 2010). Common indicators cited include bacteria, nitrate, ammonium and various organic compounds (Misstear and Bishop, 1997). Furthermore, potassium and boron are also considered to be amongst the substances indicative of contamination by sewage (Whitehead et al., 1999).

In areas without mains sewage system, runoff water from washing and flushing is conducted to pit latrines and sometimes absorber wells, and again flows into groundwater which is hence a source of pollution (Khazai and Riggi, 1999). Foster et al. (1993) argues that, in such a situation, about 90% of the water supply will end up as recharge to groundwater. Septic tank systems are frequently reported sources of localised groundwater pollution and in some cases regional groundwater problems have also been recognised in areas of high septic tank density resulting in degradation of groundwater. One common reason for degradation of the above is that the capacity of the soil to absorb effluent from the tank has exceeded the limit, and the waste added to the system moves upwards. Many other pathogens, such as typhoid, cholera, streptococci, salmonella, poliomyelitis, and protozoans are transmitted by septic tank systems (Chandra et al., 1997). This view is further supported by Foster et al. (1999) who contends that urban [or rural] residential districts without, or with incomplete, coverage of mains sewage system, seepage from unsewered sanitation sys-

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tems such as septic tanks, cesspits and latrines probably represents diffuse pollution sources. Ironically, Barret and Howard (2002) states that despite the importance of groundwater to urban and urbanising regions in Sub-Saharan Africa, there are few published studies of urban groundwater in this region, and a detailed scenario of the urban impacts on groundwater quality does not exist.

In Lusaka, there are three major types of sanitation services namely: water borne sewer system provided by Lusaka Water and Sewerage Company (LWSC); septic tanks; and pit latrines. The coverage of water borne sewer system is about 30% of the total area of which the LWSC supplies water [Environmental Council of Zambia and Zambia Environment Outlook Report 3 (ECZ and ZEOR3, 2008)]. With this meagre 30% coverage, and bearing in mind that an adult human being excretes around 4 kg of nitrogen per year (Barret and Howard, 2002), it is our contention that there is massive input of nitrogen into the soil, and eventually groundwater in Lusaka and other towns lacking adequate sanitation. Furthermore, urine stream is known to contain a substantial amount of nitrogen, about 8.5 and 2 mg/day of phosphorus (Green, 2003; Pickford, 1995) which is either potentially recoverable or a problem to treat. The fate of this nitrogen and phosphorus is usually in pit latrines and open ground or in stormy water runoff and subsequently combines with surface and groundwater. The consequences are obvious when it comes to health status of the general citizenry. In addition, the shallow geology and hydrogeological regime of Lusaka is of crucial importance when trying to predict the effect of urbanisation on groundwater. Furthermore, it is also important to acknowledge that nitrate contamination is the subject of extensive research because of its potential hazard resulting in mathaemoglobinemia (Fan and Steinberg, 1996), hypertrophy of the thyroid (van Maanen et al., 1994), and diabetes (Parslow et al., 1997). Zeb et al. (2011) argues that a regular monitoring of water bodies with required number of parameters in relation to water quality prevents the outbreak of diseases and occurrence of hazards.

Lusaka is built over a karstic dolomite aquifer and ground water accounts for 61% of the total water supply within Lusaka; ironically, there has been a registered increase in the amount of waste generated such that by 2006, it was estimated at 242,803 metric tons (ECZ and ZEOR3, 2008). The fate of this waste is usually in landfills, which consequently are sources of contamination for groundwater, and may result in disease-related problems, with associated risk to the environment (Magmedov and Yakovleva, 1997; Baird and Cann, 2008). This view is reinforced by Lerner et al. 1999) who contend that urban sources of nitrogen in groundwater include leaking sewers, leaking water mains, landfills and industrial chemical spillages. Even with a developed sewer system in the UK, Lerner et al. (1999) reported that sewers contribute about 13% of nitrogen loading, leaking water mains contribute about 36% and the remaining 50% of the nitrogen loading includes parks, gardens, landfills and industries. With an underdeveloped sewer system and the widespread use of illegal landfills in Lusaka and other Zambian towns, the nitrogen loadings and other pollutants from these sources can be assumed to be high and hence the need to do a comprehensive study not only in Lusaka but also in the various provinces. Zambia has an abundance of groundwater well distributed in many parts of the country of which the best known aquifer is nearly 25,000 km^2 in size extending from Lusaka to the Copperbelt region (ECZ and ZEOR3, 2008). Our premise is that unplanned urban development and especially development in recharge areas have resulted in increased pollution in this aquifer, which also happens to be the most populated. It is the source of groundwater for major cities and towns like Lusaka, Kabwe and Ndola.

In Zambia, most of the waste is disposed of in undesignated places, burnt, buried in the yard or recycled and there is no separation of the various types of waste. It can be argued that leachate from the waste has resulted into ammonium and other pollutants (Mocanu et al., 1997). And considering the fact that there is aged waste from old dumps and the on-going dumping or recent waste, it can be said with certainty that ground water is currently being affected by contamination from both modes, that is, from recent and aged waste leachate contamination.

The Kafue, one of the country's main rivers, is threatened by industrial activity and residue from agriculture run off. Pollutant accumulation within the Kafue ecosystem has been associated with various toxicological manifestations. The disappearance of Hippopotamus amphibious from the Kafue River in Chingola, the proliferation of water hyacinth and the bioaccumulation of heavy metals within wildlife liver tissue have been associated with pollutants in the Kafue River ecosystem (Choongo et al., 2005; Nakayama et al., 2010; von der Heyden and New, 2003).

No comprehensive research has been done in Zambia, covering a vast area, to accurately determine and compare the loadings of nitrogen and other pollutants in different areas and from different sources. The study's objective therefore was to carry out an evaluation of the portable water due to non-functioning social facilities, industries and general negative attitudes of the citizens to prudent management of their surroundings. The study further aimed at isolating areas of poor water quality and to sensitise stakeholders and interest groups and individuals on the state of the water quality in Zambia.

MATERIALS AND METHOD

The water samples were collected in September and October 2011, covering five of the ten provinces. The samples were collected in

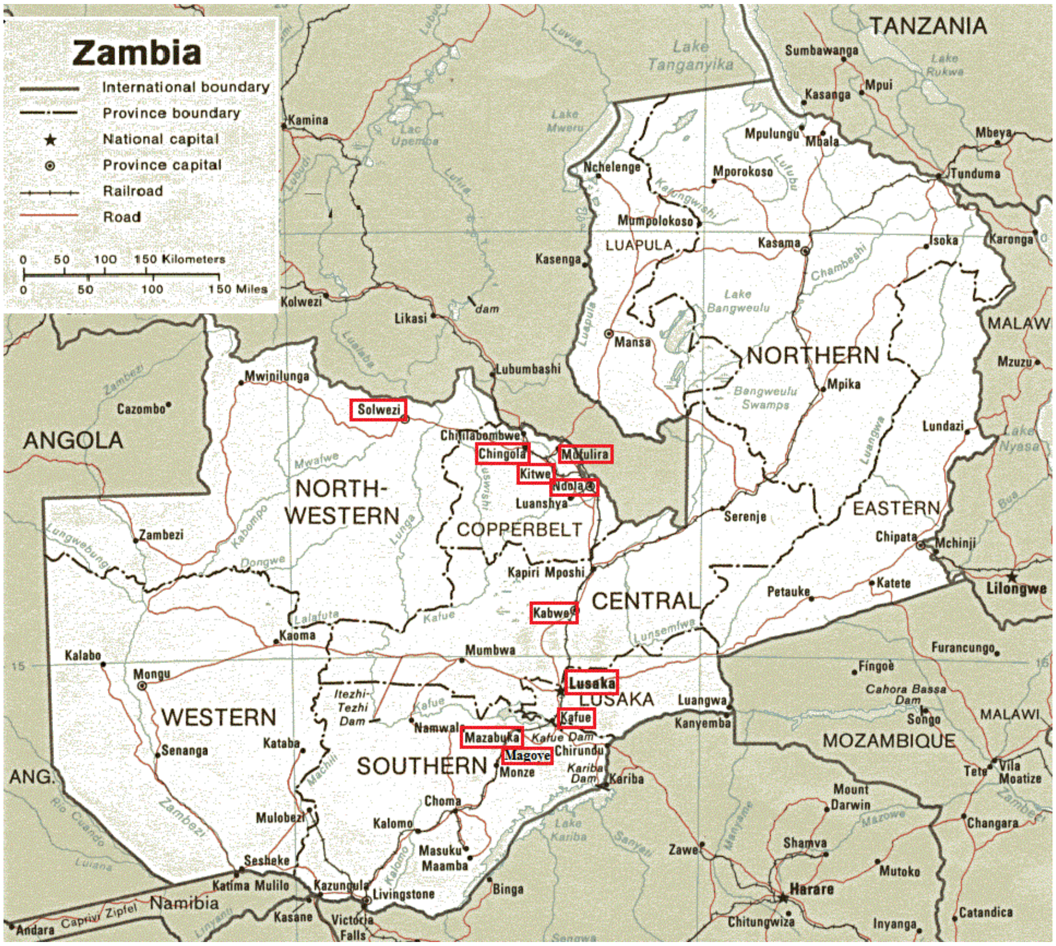

Figure 1. Map showing the ten locations where the 73 water samples were collected from. Source: Modified from Perry-Castañeda Library Map Collection (2001).

the driest period (dry season) to take care of diluting effect of rain water. Eight samples were from public water taps; 34 samples from rivers and/or streams; three samples from dams/water reservoirs; and 28 samples were from ground water sources such as wells and boreholes. Figure 1 shows the towns where the water samples were obtained.

Filtration of the samples was done through 0.45 µm filters to remove bacteria/suspended particles and to slow down sample degradation. A non-suppressed ion-exclusion/cation-exchange chromatography with conductimetric detection for the simultaneous determination of anions (SO_4^{2-}, Cl^- and NO_3^-) and cations (Na^+, K^+, NH_4^+, Mg^{2+} and Ca^{2+}) was performed on a polymethacrylate-based weakly acidic cation-exchange resin column and a mixed eluent consisting of succinic acid, tartaric acid and 18-crown-6 at pH 2.9; a Tosho IC – 2001 analyser was used. The separation mechanism was based on the ion-exclusion effect for the anions and the cation exchange effect for the cations. Under the optimised effluent conditions (26 mM succinic acid, 4 mM tartaric acid and 1 mM 18-crown-6 at 0.6mL/min), the simultaneous separation of the cations and cations was achieved in *ca*. 20 min. The other parameters: PO_4^{3-}, ClO^-, O_3, H_2O_2, CN^-, phenol, total hardness (TH), CH_2O, NO_2^-, B, SiO_2; pH; temperature; and dissolved organic carbon (DOC) were determined by diverse methods as shown in Table 1.

Creation of the water pollution index maps was achieved using ArcGIS version 9.3(ESRI Inc., USA). Further analysis of the data was done by factor analysis, T-test, spearman correlation and Tukey's honestly significant different (HSD) test following one-way analysis of variance (ANOVA). The statistical analyses were performed using SPSS statistical package version 17.0 (SPSS Inc., Chicago, III).

Part of the analysis involved use of the Nemerow–Sumitomo Water Pollution Index (*WPI*). In this study, 73 water samples from different locales around Zambia and 20 different parameters were analysed. However, the following parameters: CH_2O, TH, H_2O_2, O_3, ClO^-, pH and DOC were not included in the water pollution index (*WPI*) because there are no clear permissible values (*PVs)* in Zambia (or worldwide consensus on safe levels in drinking water) indicating the maximum or minimum permissible values.

The *WPI* was used to evaluate the pattern of portable water in the study areas. The function of this method was to standardize the concentrations ranges for the parameters such that the different concentrations ranges for each water parameter were rescaled by the equation to produce a relative value that lies within a comparable range (Nemerow and Sumitomo, 1970). The *WPI* is a function of relative values (C_i/L_i), where, C_i represents the concentration of parameter *i* and L_i represents the *PV* of parameter *i* defined by a regulation.

$$WPI = \text{a function of } (C_i/L_i)\text{'s} \quad (1)$$
$$= f(C_1/L_1,\ C_2/L_2,\ C_3/L_3 \ldots C_n/L_n) \qquad (i = 1, 2, 3 \ldots n)$$

Table 1. Analysed parameters and the methods/instruments used.

Analysed parameter	Method/Instrumentation)
Phosphate (PO_4^{3-})	Molybdenum blue
Hypochlorite ($C\ell O^-$)	N,N-diethyl-p-phenylenediamine sulphate
Ozone (O_3)	4-Aminoantipyrine with enzyme
Hydrogen Peroxide (H_2O_2)	4-Aminoantipyrine with enzyme
Cyanide (CN^-)	4-Pyridinecarboxylic acid
Phenol	4-Aminoantipyrine with enzyme
Total Hardness (TH)	Phthalein Complex
Formaldehyde (CH_2O)	N-methylbenzothiazolone hydrazone (MBTH)
Nitrate (NO_2^-)	Naphthylethylenediamine
Boron (B)	Azomethine H
Silica (SiO_2)	Molybdenum blue
pH and Temperature	As One 392R pH meter
Dissolved Organic Carbon (DOC)	Total Organic Carbon Analyser TOC-V CSN Shimadzu

Parameters 1 to 12 were determined by digital water analyser, DPM-MT.

Then, the *WPI* for a specific water use *j* (WPI_j) is further expressed by the following equation:

$$WPI = \sum_{i=1}^{n} \sqrt{\frac{(C_i/L_{ij})^2_{max} + (C_i/L_{ij})^2_{ave}}{2}} \quad (2)$$

Where, C_i is the measured concentration of parameter *i*, L_{ij} is the *PV* for the parameter *i* determined for water use *j* (e.g. drinking or irrigation), and $(C_i/L_{ij})_{max}$ and $(C_i/L_{ij})_{ave}$ are maximum and average values of C_i/L_{ij} for water use *j*, respectively.

For the water parameters for which the higher value represents a higher level of pollutions, such as nitrate and heavy metals, the values of C_i/L_{ij} obtained from the field measurements can be directly calculated using the above equation, with a prerequisite. The prerequisite is that if the value of C_i/L_{ij} obtained from measurement is greater than 1.0, then the C_i/L_{ij} value must be standardized by applying the following equation:

$$(C_i/L_{ij})_{new} = 1.0 + x \log (C_i/L_{ij})_{ave} \quad (3)$$

Where, *x* is a constant value (as a standard value for a relative comparison, 5.0 is arbitrary employed for *x* value in the application of the index for the existing pollution).

For the parameters where the lower value represents a higher level of pollution, such as dissolved oxygen (DO), the C_i/L_{ij} values obtained from the field measurements must be standardized by using the following equation:

$$(C_i/L_{ij})_{new} = \frac{C_{im} - C_i}{C_{im} - L_{ij}} \quad (4)$$

Where, C_{im} is the saturation value for any parameter at room temperature.

For parameters for which the *PV* (L_{ij}) is defined by a range of numbers, such as for pH, where the *PV* ranges from 6 to 9, a standardized value C_i/L_{ij} is required, which is calculated by the following equation:

If $C_i \leq$ average L_{ij},

$$(C_i/L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{min} - (L_{ij})_{ave}} \quad (5)$$

If $C_i >$ average L_{ij},

$$(C_i/L_{ij})_{new} = \frac{C_i - (L_{ij})_{ave}}{(L_{ij})_{max} - (L_{ij})_{ave}} \quad (6)$$

Where, $(L_{ij})_{min}$ and $(L_{ij})_{max}$ are, respectively, the maximum and minimum values of L_{ij} (e.g., pH: min = 6, max = 9). The $(L_{ij})_{ave}$ is the average value of L_{ij} (e.g., pH: (6 + 9)/2 = 7.5).

Based on chemical loadings relative to their *PVs*, the results from the water samples were classified into four categories. The classification used in this study reflects the suitability of the water for human consumption because only *PVs* for drinking water were used. It did not cater for the suitability of the water for use on animal husbandry purposes or crops. In addition, the *WPI* did take into account of water contamination due to biological activities. So if the water meets the *PV* criteria, it may still need some form of treatment (e.g. chlorination and filtration) but at a far lower cost.

The *PVs* for this study are based on Zambia Bureau of Standards (ZBS)/Environmental Council of Zambia (ECZ) except for NH_4^+, Na^+ (WHO, 2006), and K^+, PO_4^{3-} (USEPA, 2009). Utilizing the *PVs* obtained from ZBS/ECZ, WHO and US-EPA, the *WPI* was classified into four categories expressing the portable water's suitability for human consumption; the categories are as shown below.

$0.0 \leq WPI \leq 1.0$ = clean water (meets the *PV* criteria)
$1.0 < WPI \leq 5.0$ = slightly polluted water
$5.0 < WPI \leq 10$ = moderately polluted water
$WPI > 10$ = highly polluted water.

RESULTS

The Copperbelt Province and North-western Provinces (CB/NW) were analysed as one entity because the latter did not have sufficient data to analyse separately. At face value, comparison of Tables 2 and 3 reveal that the Copperbelt region/North-western Province had the most

Table 2. The averages, maximum, minimum values and standard deviations of the twenty-two parameters in the three provinces and their corresponding *PVs*.

Parameter analysed	Copperbelt Province/North Western Province						Lusaka Province					
	PV (drinking)	PV (waste water)	Max.	Min.	SD	Average	PV (drinking)	PV (waste water)	Max.	Min.	SD	Average
pH		6 - 9	8.36	6.73	0.39	7.77		6-9	8.44	5.75	0.46	7.63
Temp			27.00	22.00	0.93	24.23			26.30	20.70	1.40	23.47
SO_4^{2-}	400.00	1500.00	1659.72	0.47	396.93	197.12	400.00	1500.00	105.33	0.47	24.74	29.48
Cl^-	250.00	800.00	598.24	0.09	138.22	61.23	250.00	800.00	72.92	0.63	17.10	19.15
NO_3^-	10.00	50.00	11.54	0.00	2.76	1.26	10.00	50.00	127.56	0.00	24.22	19.10
Na^+	200.00	nd	37.13	2.40	10.96	12.41	200.00	nd	108.77	0.53	25.68	35.18
NH_4^+	1.50	10.00	nd	nd	nd	nd	1.50	10.00	6.49	0.17	2.29	3.09
K^+	250.00	nd	51.32	0.01	9.97	6.84	250.00	nd	43.48	0.01	7.88	4.54
Mg^{2+}	150.00	500.00	341.96	0.40	71.48	43.38	150.00	500.00	71.36	0.21	15.92	32.06
Ca^{2+}	200.00	nd	93.21	4.45	25.57	54.21	200.00	nd	108.98	0.83	22.75	54.63
DOC	nd	nd	2.44	0.19	0.59	1.26	nd	nd	5.77	0.05	1.62	1.51
PO_4^{2-}	0.02	0.03	1.00	0.16	0.26	0.39	0.02	0.03	3.20	0.10	0.74	0.46
$C\ell O^-$	nd	nd	0.32	0.32	0.00	0.32	nd	nd	0.53	0.14	0.10	0.26
O_3	nd	nd	0.70	0.32	0.17	0.46	nd	nd	0.39	0.27	0.05	0.35
H_2O_2	nd	nd	0.25	0.25	0.00	0.25	nd	nd	0.22	0.11	0.04	0.18
CN^-	0.10	0.20	nd	nd	nd	nd	0.10	0.20	0.06	0.03	0.01	0.03
Phenol	0.00	0.20	2.18	0.77	0.39	1.36	0.00	0.20	1.03	0.21	0.30	0.52
TH	200.00	nd	2080.00	26.00	530.89	495.91	200.00	nd	410.00	68.00	79.50	188.39
CH_2O	nd	nd	nd	nd	nd	nd	md	nd	0.23	0.19	0.01	0.21
NO_2^-	1.00	2.00	0.28	0.02	0.08	0.06	1.00	2.00	1.92	0.02	0.44	0.24
B	nd	0.50	nd	nd	nd	nd	nd	0.50	1.57	0.72	0.37	1.23
SIO_2	nd	nd	nd	nd	nd	nd	nd	nd	41.20	3.30	7.37	15.17

nd, Not determined.

Table 3. The averages, maximum, minimum values and standard deviations of the twenty-two parameters in the two provinces and their corresponding *PVs*.

Parameter analysed	Central Province						Southern Province					
	PV (Drinking)	PV (Waste Water)	Max	Min	SD	Average	PV (Drinking)	PV (Waste Water)	Max	Min	SD	Average
pH		6 - 9	7.74	7.63	0.06	7.69		6 - 9	8.13	7.63	0.21	7.93
Temp			21.30	20.80	0.25	21.05			20.90	20.50	0.16	20.70
SO_4^{2-}	400.00	1500.00	11.01	4.14	3.43	7.58	400.00	1500.00	62.08	21.50	17.80	46.39
Cl^-	250.00	800.00	2.78	0.70	1.04	1.74	250.00	800.00	12.44	2.57	4.12	6.91
NO_3^-	10.00	50.00	10.16	4.46	2.85	7.31	10.00	50.00	48.41	0.00	19.86	25.58
Na^+	200.00	nd	5.92	3.55	1.18	4.73	200.00	nd	81.02	10.64	28.79	47.10
NH_4^+	1.50	10.00	nd	nd	nd	nd	1.50	10.00	nd	nd	nd	nd
K^+	250.00		0.01	0.01	0.00	0.01	250.00		9.66	2.90	2.77	6.14
Mg^{2+}	150.00	500.00	50.23	45.65	2.29	47.94	150.00	500.00	49.08	16.93	13.34	34.68
Ca^{2+}	200.00	nd	66.65	43.62	11.51	55.14	200.00	nd	58.19	31.00	12.31	48.35
DOC	nd	nd	0.39	0.27	0.06	0.33	nd	nd	5.39	0.36	2.06	3.00
PO_4^{2-}	0.02	0.03	nd	nd	nd	nd	0.02	0.03	0.25	0.10	0.08	0.18
$C\ell O^-$	nd	nd	nd	nd	nd	nd	nd	nd	0.15	0.15	0.00	0.15
O_3	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd
H_2O_2	nd	nd	nd	nd	nd	nd	nd	nd	0.36	0.36	0.00	0.36
CN^-	0.10	0.20	nd	nd	nd	nd	0.10	0.20	nd	nd		nd
Phenol	0.00	0.20	nd	nd	nd	nd	0.00	0.20	0.44	0.21	0.12	0.33
TH	200.00	nd	94.00	66.00	14.00	80.00	200.00	nd	200.00	74.00	51.55	134.67
CH_2O	nd	nd	nd	nd	nd	nd	nd	nd	0.41	0.41	0.00	0.41
NO_2^-	1.00	2.00	nd	nd	nd	nd	1.00	2.00	6.00	0.02	2.99	3.01
B	nd	0.50	nd	nd	nd	nd	nd	0.50	nd	nd	nd	nd
SIO_2	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd	nd

nd, not determined.

parameters whose average concentrations exceeded the averages obtained from the other provinces. An in-depth discussion was done to determine if the observed mean differences for CB/NW were significantly different across the regions and to determine which parameter(s) was significantly higher compared to others. Furthermore, the result of the analysis of ground versus surface water pollution is reported in the subsequent sections.

Statistical treatment of the results

Results across all the provinces

A one-way between-groups analysis of variance was conducted to explore the impact of location on pollution as measured by different methods. There was a statistic-cally significant difference at the $p<0.05$ level in nitrate levels: F (3, 68) = 5.2, p = 0.02. Despite reaching statistical significance, the actual difference in mean scores between the locations was not very big. The effect size, calculated using eta squared, was 0.2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M = 19.5, SD=24.7) was significantly different from CB/NW (M = 1.21, SD = 2.78), Central Province (M = 7.31, SD = 4.03), Southern Province (M = 25.6, SD = 24.3).

Furthermore, there was a statistically significant difference at the $p<0.05$ level in sodium levels: F (3, 68) = 8.6, p = 0.00. The effect size, calculated using eta squa-red, was 0.3. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M= 36.7, SD=25.7) was significantly different from CB/NW (M = 12.0, SD = 11.2), Central Province (M = 4.7, SD = 1.7), Southern Province (M = 47.1, SD = 35.3). Furthermore it was found that Southern Province differed significantly from CB/NW.

In addition, there was a statistically significant difference at the $p < 0.05$ level in total hardness: F (3, 68) = 8.6, p = 0.00. The effect size, calculated using eta squared, was 0.2. Post-hoc comparisons using the Tukey HSD test indicated that the mean score for Lusaka (M = 187.9, SD = 80.9) was significantly different from CB/NW (M = 496.0, SD = 543.4). An independent-samples T-test was conducted to compare the pollution levels of ground and surface water. With reference to nitrate, there was a significant difference in mean scores for ground water (M=25.9, SD = 26.9) and surface water (M = 4.1, SD = 9.0); t (30.1) = 4.149, p = 0.000 (two tailed). The magnitude of the differences in the means was 21.8, and with reference to sodium, there was a significant difference between ground water (M = 39.3, SD = 28.6) and surface water (M = 18.6, SD = 17.8); t (42.6) =3.5, p = 0.01.

Furthermore, there was a significant difference in DOC levels between the water obtained from the ground (M = 0.90, SD = 1.2) and surface water (M = 1.8, SD = 1.5); t (67.5) = -3.0, p= 0.004.

Results for parameters obtained from Lusaka and Copperbelt Provinces *(phenol, NO_2^-, H_2O_2, O_3, ClO^-, PO_4^{3-})*

An independent-samples T-test was conducted to compare the pollution levels of the water obtained from the Lusaka and Copperbelt/North-western Provinces. With reference to phenol, there was a significant difference in scores for Lusaka (M=0.54, SD = 0.30) and Copperbelt / North-western Province (M =1.36, SD = 0.41); t (17) = -5.574, p= 0.000 (two tailed). The magnitude of the differences in the means was 0.81. The remaining parameters were not significantly different across the two provinces.

An independent-samples T-test was conducted to compare the pollution levels of the water obtained from the ground and surface water. With reference to the parameters listed above, there was no significant difference between ground and surface water.

Principal component analysis (PCA)

Principal component analysis (PCA) was performed only on the parameters that were analysed in all the five provinces (some parameters were not analysed in some provinces as shown in Tables 2 and 3). The results show that there was no ambiguity in the component matrix. After analysing the rotated matrix, it was even clearer that four components emerged. As shown in Table 5, component 1 (F1) was comprised of Cl^-, Mg, TH and K. Component 2 (F2) was constituted of NO_3^- and Na. The third component (F3) was made up of SO_4^{2-} and Ca^{2+}. DOC constituted the last component (F4). Table 4 shows that the four parameters explained 82.9% of the variance.

Correlations, as shown in Table 6, were observed between several parameters and the significant ones were between Na^+ and NO_3^- (r = 0.588); between K^+ and Cl^- (r = 0.573); between PO_4^{3-} and Ca^{2+} (r = 0.651) and between Mg^{2+} and Cl^- (r = 0.925) among others. In addition, location (province) was correlated positively with H_2O_2 and NO_2^- at 0.810 and 0.488, respectively. Water source (either obtained from the ground or rivers/streams) correlated significantly with DOC (r = 0.319). Using Tukey HSD test, PCA and the correlation coefficients, it was found that NO_3^- and Na^+ are indeed closely associated suggesting that they may have the same origin; the increase or decrease of either parameter will affect the other in a predictable manner. In addition, significant correlations of Cl^-, TH, K^+ and Mg^{2+} reinforces component 1 (F1) extracted by PCA. However component 3 (F3) was not supported by correlation coefficient; there was no evidence supporting a close relation that an increase or decrease of SO_4^{2-} leads to corresponding changes in levels of Ca^{2+} even though they fall under one component, F3. Furthermore, DOC analysis correlates significantly and positively with location, this finding confers addition insight to t-test results which showed that DOC levels

Table 4. Total variance explained.

Component	Initial Eigen values			Extraction sums of squared loadings			Rotation sums of squared loadings
	Total	% Variance	Cumulative %	Total	% Variance	Cumulative %	Total
1	3.41	37.84	37.84	3.41	37.84	37.84	3.34
2	1.67	18.57	56.41	1.67	18.57	56.41	1.65
3	1.23	13.63	70.04	1.23	13.63	70.04	1.53
4	1.16	12.89	82.93	1.16	12.89	82.93	1.19
5	.82	9.09	92.02				
6	.34	3.81	95.83				
7	.31	3.49	99.32				
8	.05	.53	99.85				
9	.01	.15	100.00				

Table 5. Pattern and structure matrix.

Component	Pattern matrix				Component	Structure matrix			
	1	2	3	4		1	2	3	4
Cl^-	0.976				Mg	0.967			
Mg^{2+}	0.961				Cl	0.937			
TH	0.873				TH	0.911			
K^+	0.756				K	0.776			
NO_3^-		0.903			NO_3^-		0.889		
Na^+		0.868			Na		0.882		
SO_4^{2-}			0.827		SO_4^{2-}			0.831	
Ca^{2+}			0.737		Ca			0.739	
DOC				0.959	DOC				0.957

were significantly high in surface water compared to ground water. However, there are several other parameters which correlated significantly but no rational explanation was given for their correlations because they were not supported by other analyses methods and they also proved not to be statistically significant in other regions compared to others; they did not either prove higher when compared to ground and surface water.

The water pollution index (WPI)

The findings of the Zambian water quality using the *WPI* are summarised in Tables 7, 8 and 9. The results are arranged in ascending order with water samples that met the benchmark (0.0 ≤*WPI* ≤1.0) to the water samples that were highly polluted (*WPI*> 10).

It is apparent from the *WPI* tables, that the Zambian water is compromised in one way or another, apart from the nitrate issue. The *WPI* reveals that out of all the water collected from Lusaka Province, 39.1% were not compromised (the water was safe for household consumption with reference to the analysed parameters); out of the water samples collected from the Copperbelt/North-western Provinces, 20.9% were safe for household consumption and 28.6% of the samples collected from Central and Southern Provinces were not polluted. Further analysis of the water shows that water treatment is reasonably effective in Mufulira as the water derived from the tap CB22T is suitable for human consumption despite its source being the highly polluted Kafue River (CB40R). However, the other water sample obtained directly from the mine ground aquifer and supplied to the former mine residential area proved to be unsuitable for human consumption, despite whatever treatment procedure is performed on the water, as shown by sample CB20T and according to the *WPI* of 1.63, is moderately polluted. The Lusaka city (Figure 2) and Copperbelt region (Figure 3) data is further presented on maps, using ArcGIS, showing spatial distribution of water quality across the two regions. There was a general tendency of the groundwater to degrade on the outskirts (commonly referred to as the peri-urban) of the Lusaka city boundary; most of the unplanned settlements in Lusaka are also built on the outskirtsof the city. As for surface water, it was expected that more pollutants would be observed towards the north east as it is generally the flow of all surface water in Lusaka, but there is no genera

Table 6. Pearson correlation of the pollution data.

	SO_4^{2-}	Cl^-	NO_3^-	Na^+	K^{2+}	Mg^{2+}	Ca^{2+}	DOC	PO_4^{3-}	ClO^-	O_3	H_2O_2	PNL	TH	NO_2^-	SiO_2	Location
Cl^-	-0.108	1															
NO_3^-	-0.106	-0.015	1														
Na^+	-0.063	0.190	**0.588****	1													
K^{2+}	0.174	**0.573****	-0.050	0.248*	1												
Mg^{2+}	0.156	**0.925****	0.048	0.179	**0.658****	1											
Ca^{2+}	0.243	0.092	0.036	0.026	0.040	0.204	1										
DOC	-0.058	-0.022	-0.230	0.074	0.212	0.006	0.174	1									
PO_4^{3-}	-0.113	0.033	0.027	0.356	**0.509****	-0.049	**0.651****	0.461*	1								
ClO^-	0.132	0.241	-0.089	0.062	-0.065	-0.268	0.088	-0.263	-0.003	1							
O_3	-0.242	-0.124	-0.460	-0.426	-0.001	-0.650	-0.750	-0.111	-0.651	0.490	1						
H_2O_2	0.287	-0.191	0.436	0.482	**0.852***	0.024	0.118	**0.825***	-0.941	-0.114	-10.000**	1					
PNL	0.045	0.113	-0.563**	-0.549*	-0.197	-0.593*	-0.038	-0.366	0.409	**0.887****	**10.000****	0.121	1				
TH	0.435**	**0.813****	-0.124	0.046	**0.609****	**0.892****	0.320*	-0.014	0.063	0.155	-0.040	-0.148	0.162	1			
NO_2^-	-0.018	-0.056	0.197	0.163	-0.031	-0.022	0.045	**0.679****	-0.745*	-0.281	-10.000**	0.920	-0.507	-0.054	1		
SiO_2	-0.292	-0.234	-0.129	-0.012	-0.083	-0.204	-0.318	0.052	0.022	0.029	-0.038	-0.849	-0.293	-0.163	-0.256	1	
Location	0.148	0.072	-0.189	-0.237*	0.049	0.063	-0.065	0.038	-0.136	-0.152	0.437	**0.810***	0.049	0.146	**0.488****	-	1
Water source	0.086	0.112	-0.511**	-0.412**	0.097	-0.077	0.154	**0.319****	0.299	0.137	0.437	-0.153	0.374	0.194	-0.145	-0.030	0.298*

**Correlation is significant at the 0.01 level (2-tailed). *Correlation is significant at the 0.05 level (2-tailed).

Observable trend. However, there is a general observable trend that the surface water which meets *WPI* clean water criteria is at or near the centre (e.g. LSK16R) of the city and but also intermingled with some of the worst polluted groundwater (e.g. LSK68G).

DISCUSSION

The water in Lusaka city revealed mixed results, that is, both acceptable chemical loadings and unacceptably high chemical loadings (to pollution levels) with nitrate being more widespread and predominant in high-density residential areas, like sites; LSK2R, LSK8R, LSK13T, LSK14G, LSK48G, LSK49T, LSK54G, LSK55G, LSK57G, LSK59G and LSK63G among others. The locations that revealed high levels of nitrates in tap water derive their water from boreholes and wells. A similar trend is observed in Magoye (site MG71G and MG74G), a typical rural area with a very low population density and no industrial activities; the sampled water was extracted from a borehole. The source of nitrate is mostly from decaying organic matter, sewage, fertilizers, manure, and nitrate in the soil or natural deposits, animal waste and septic tanks. The areas which tested for high nitrate have also been a source of perpetual cholera outbreaks; relentless cholera outbreaks have been reported over the past years with the first reported cases being in 1977 (Sasaki et al., 2009; WHO, 2011).

Analysis of the data shows that nitrate pollution is a major problem in Lusaka city in contrast to the CB/NW and Central Provinces, where none of the samples tested for nitrates beyond what is naturally expected. The low levels of nitrates prevailing in the CB/NW and Central Provinces can be attributed to the well organised and planned settlements which are serviced by sewer pipelines. This fact is quite opposite to Lusaka which is comprised of a large number of unplanned settlements (shanty townships, slums etc.), which are not serviced by a sewer system and garbage collection by the city council is way beyond their capacity.

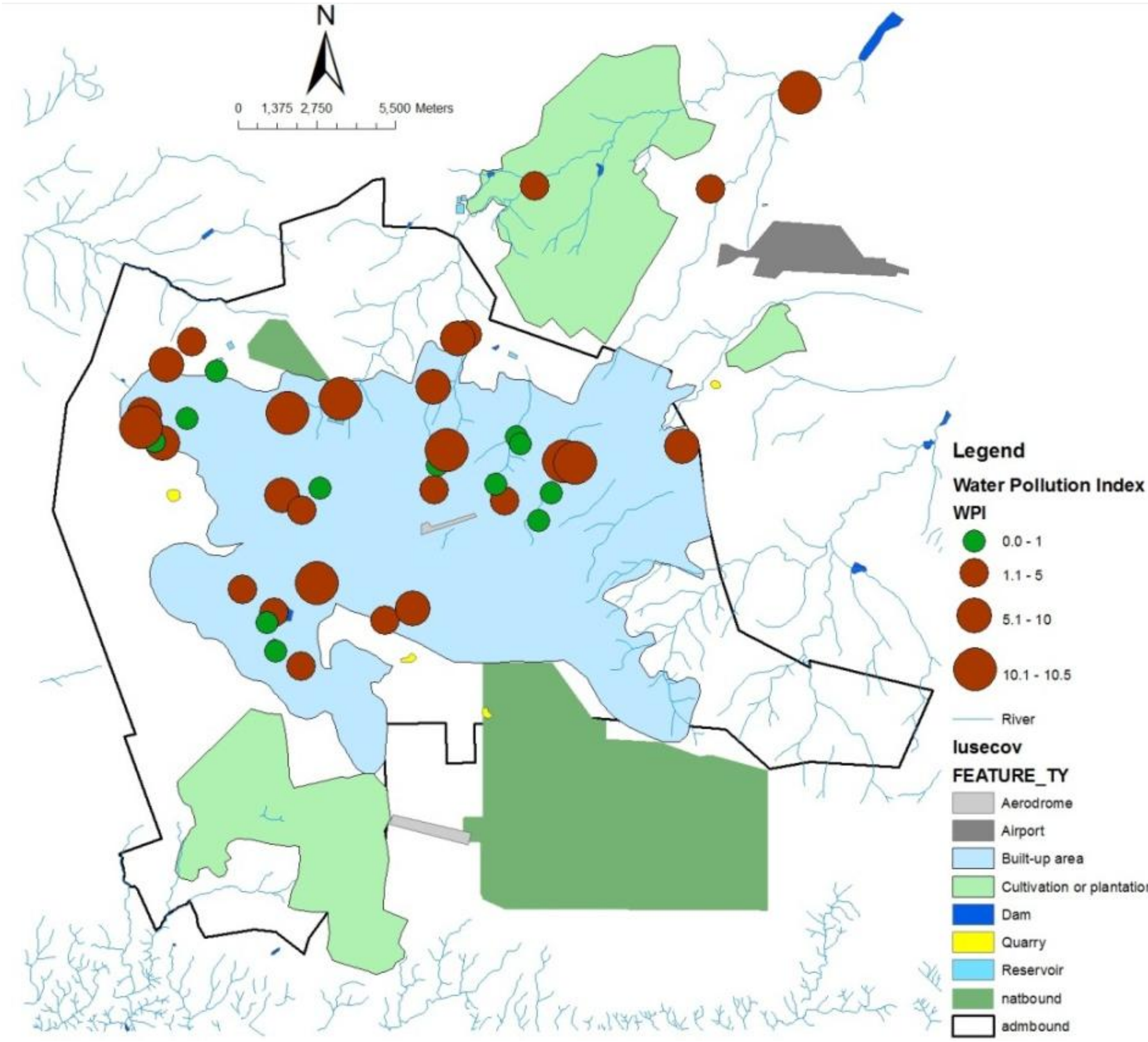

Figure 2. Lusaka city Data using the water pollution index.

This has resulted in many illegal/backyard dumpsites. The situation in Lusaka is also found in most rural areas like Magoye, where there has never existed any sewer system (except for *in-situ* sanitation), or any garbage collection system.

The high sulphate content (Table 2) is restricted to the Copperbelt region especially, near the effluent water discharged from the copper mines in Chingola and Mufulira towns. The mining activities are a probable explanation of the high levels of sulphates in the drinking water (e.g. site CB20T). The water in the Butondo River (CB21R, receiving drainage water from the mines) equally revealed high sulphate, an indication of how negatively the mine has affected the environment. "Zambia: MCM Acid Spillage" (2008) reports that Mopani Copper Mines (MCM) in Mufulira has disclosed that part of its ground water table has been contaminated following an acid spillage into the main domestic water supply system that pumps water to households in former mine townships.

Part of the tap water used in Lusaka is obtained from the Kafue River at Kafue town. Nevertheless, groundwater abstraction in the city has increased because of the construction of public and private boreholes. LWSC has approximately 50 boreholes around the city which draw water from the Lusaka and Cheta aquifers. For surface water derived from the Kafue River, there is a conventional treatment facility at the Ioland Water Treatment Plant. As for LWSC groundwater obtained from public boreholes, there are simple on-site chlorination facilities at borehole sites (LWSC, Personal Communication,

Table 7. Water quality in Lusaka Province using the water pollution index.

Code	Site name	WPI
LSK47G	Chainama Lusaka General Hospital	0.19
LSK16R	Roma/Garden Township Stream	0.24
LSK1D	Mutendere Dam	0.29
ND43R	Kafubu Upstream	0.32
LSK15T	Matero Petroda Station Tap Water (LWSC)	0.44
LSK56G	Mutendere Near Chainama Golf Club Well Water	0.44
LSK4R	Mumana Pleasure Resort (stream)	0.46
LSK51G	UNZA Tap Water - Groundwater	0.51
LSK65G	Zeko Camp Borehole	0.87
LSK17D	Blue Water Dam	1.05
LSK7R	Mutendere/Maplot midstream	1.36
LSK52G	Femag Garden John Laing Tap Water from the Ground	1.56
LSK58G	Entrance of Chunga - Ground Water	1.60
LSK50G	Vera Chiluba Basic School Tap from tap ground	2.17
LSK14G	John Laing Tap (ground water)	2.19
LSK9R	Ngombe Basic school Stream	2.31
LSK8R	Malimba Ngwerere Stream	2.43
LSK57G	Chunga, Africa Methodist Episcopal Church Ground Water Borehole	2.60
LSK49T	Libala Basic School Tap from the Ground	2.75
LSK63G	Ndeke Village	3.09
LSK13T	Chawama Compound Tap Water (LWSC)	3.15
LSK54G	Gospel Outreach Tap Water-ground	3.19
LSK53G	Kanyama Ground Water-Borehole-Filling Station	3.56
LSK68G	Thornpark Construction Centre Borehole	3.68
LSK60G	Avondale River Side Street Tap Water from the Ground	4.19
LSK10G	New N'gombe Basic Tap (underground)	4.50
LSK55G	Zingalume Police Tap Water from the Ground	4.72
LSK67G	Villa Elizabetha	4.73
LSK62G	George Compound Borehole	5.02
LSK64G	Chisengalumbwe Basic School	5.25
LSK61G	Ngome tap Water from Ground Aquifer	5.56
LSK59G	Twikatane Area Ground Water	5.65
ND46R	Kafubu Downstream	7.24
LSK3R	Mutendere River upstream	7.41
LSK48G	Kamwala Remand Prison Borehole Water	8.34
LSK72G	Zingalume borehole water	8.60
LSK2R	Chipata/Marapodi at Garden Park (stream)	9.05
LSK66G	NRDC Borehole Tap	9.22
LSK6R	Ngwerere Stream (near Kasisi)	9.28
LSK12R	Lumumba/Great North Road Junction (stream)	10.19
LSK70D	Goma lakes	10.47
ND31R	Kafubu River	10.93
ND45T	Laka Petroleum Filling Station Tap Water - Ndola	11.26

LSK, Lusaka city; ND, Ndola city; G, groundwater; T, tap water; R, river water; D, dam/water reservoir.

Table 8. Water quality in Copperbelt and North-western Province using the Water pollution Index.

Code	Site name	WPI
CB30R	Malembeka Stream into Kafue (1st site)	0.02
SL73G	Solwezi well water	0.08
CB23R	Boating Club Dam (Mufulira)	0.16
CB28R	Chingola/Chililabobwe Road Kafue River	0.20
CB22T	Tap Water - Mufulira Town Centre (Mulonga Water)	0.22
CB19R	Kafue River Mufulira/Kitwe Road	0.25
CB24R	Kafue River, Nkana East Waterworks	0.47
CB25R	River Near Sabina	0.62
CB26R	Before Tailings Damp (Butondo Stream)	0.67
CB20T	Mine Water Mulonga Tap (Entebbe)	1.63
CB27R	Tailings Damp Effluent)	2.10
CB21R	West Shaft Effluent Water	2.54
CB29R	Chingola Mine Effluent	4.77
CB34R	Ndola Kitwe Dual Carriage Kafue River	10.00
CB39R	Kawama stream - Mufulira	10.17
CB36R	Chingola River Upstream	10.55
CB33R	Butondo Stream at Road Near Butondo High	10.58
CB32R	West Mine Shaft - Butondo Stream (at Bridge)	10.70
CB40R	Kafue Water Treatment Plant - Mulonga WSC	10.77
CB44R	Kasuswa Stream (at Mufulira/Kitwe Road)	10.92
CB37R	Tailings Damp (TD 11)	11.09
CB38G	Eagle High School Tap Water (Groundwater)	11.17
CB35R	Malembeka Stream into Kafue (2nd site)	11.57

CB, Copperbelt; SL, Solwezi town; G, groundwater; T, tap water; R, river water.

Table 9. Water quality in central and southern province using the Water pollution index.

Code	Site name	WPI
KB41T	Kabwe City Council Tap Water (Lukanga WSC)	0.33
KB42T	Jack and Jill School - Lukanga WSC	0.75
MG74G	Magoye borehole water- school	2.34
KF11R	Kafue River at Motor Bridge	5.07
MZ69T	Mazabuka Tap water	8.04
KF18R	Train Bridge (Kafue River)	8.85
MG71G	Magoye borehole water - main compound	9.21

KB, Kabwe town; KF, Kafue town; MG, Magoye town; MZ, Mazabuka town; G, groundwater; T, tap water; R, river water.

January 11, 2013). And for private boreholes, the onus is on the individual to treat or not to. Inevitably these uncontrolled, unmonitored and untreated shallow and deeper boreholes can pose serious health hazard

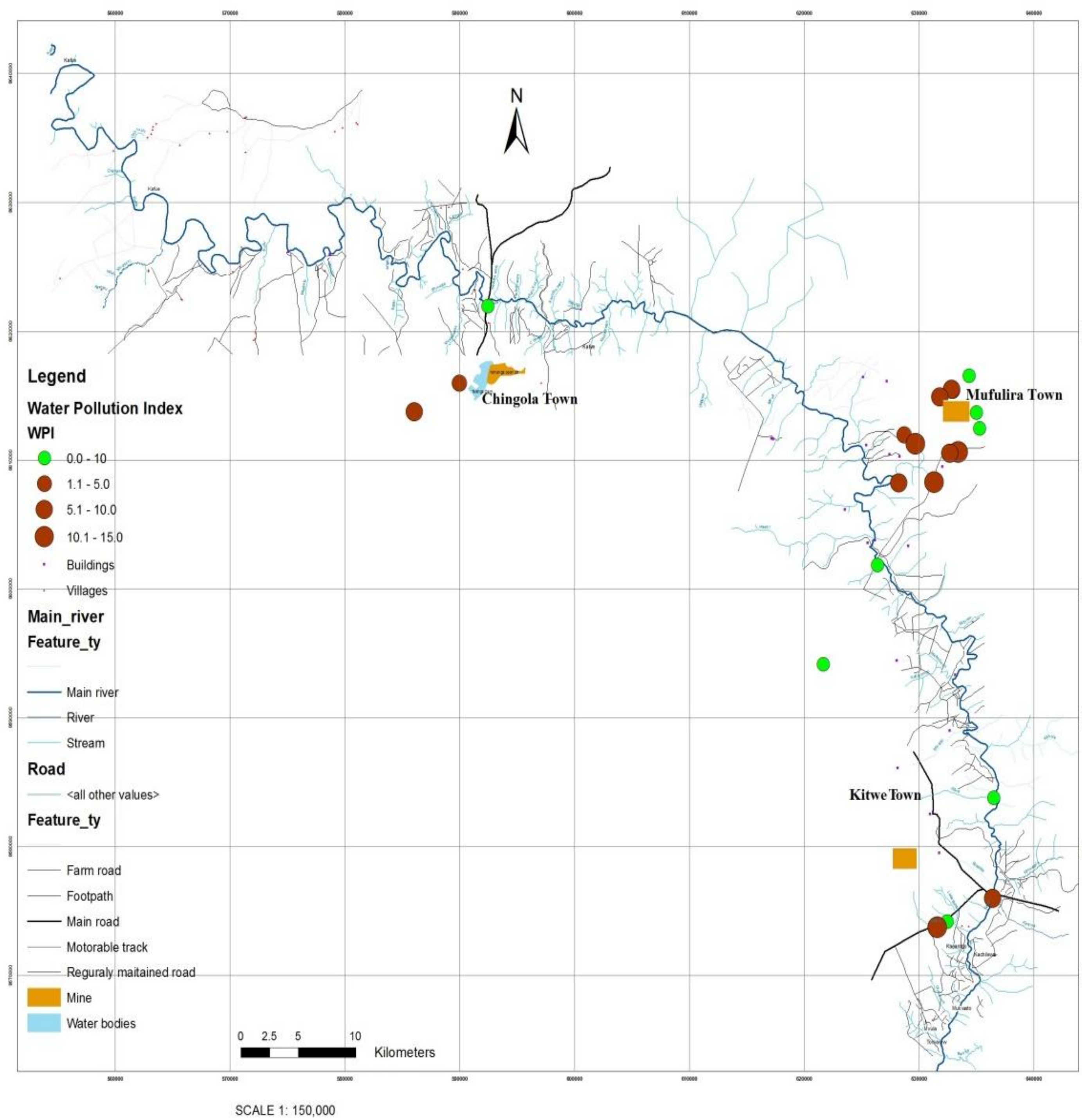

Figure 3. Copperbelt region Water Pollution Index.

Nitrate concentrations are similar in urban and rural areas and frequently exceed the drinking water limits set by the Zambia bureau of standards and environment council of Zambia. There is unequivocal evidence of pollution by sewer system as this problem was more predominant in the sites with a rudimentary sewer system, both urban and rural. Rural areas may have an addition loading from fertilizer application from the nearby farms but there is no strong evidence linking the two. For example site SL73G, found in a typical farming area did not test for nitrates beyond what is expected in nature.

It can be deduced from the locations sampled that the main source of nitrate is from human excrement (pit latrines) and biomass decay (garbage). This fact is further supported by the presence of ammonia, and nitrite (intermediate products in the nitrogen cycle) in both the rural (MZ69T, MG71G and MG74G) water and Lusaka city water.

Groundwater protection is best achieved by defining "standards of practice" which, for example would exclude certain types of development and land use activity in areas specified as hygrogeologically sensitive. Recent hydrogeological and hydrochemical studies at the University of Toronto confirm that urbanization represents a serious threat to local groundwater quality (Howard, 1997). Due to its vulnerability, groundwater use may be restrictted to certain areas where geology is favourable or where the supply infrastructure has not been installed, or it may only be certain types of users. In Birmingham, UK, virtually all of the public supply is surface water, with groundwater restricted to industries (Howard, 1997), but this is not the case in Zambian (and many other developing countries) where, for example, 58% (130,000 m^3/d) of water supplied by LWSC is from ground sources, excluding the sources from satellite systems and private boreholes estimated at 80,000 m^3/d (ECZ.ZEOR3, 2008). Data from the Zambian Ministry of Health (MoH) indicates that diarrhoea was one of the cause of hospital visitation, an average of 75 persons per 1,000 population from 2006 to 2008, ranking only third from malaria and respiratory infections (Ministry of Health and European Development Fund, 2010). Ironically, one of the interventions by the MoH, acting with other stakeholders, is to advocate sinking of more boreholes on top of the existing ones and promote the use of pit latrines. However, it is important to note that when groundwater is used as a source of drinking water, it is vital that sanitation methods and garbage collection and its disposal are of the highest efficiency to eliminate threats to human safety (Khalid et al., 2011; Zaadnoordijk et al., 2004), which is not the case in Zambia and numerous other developing countries. A risk assessment into the potential for sewer-related pollution should be carried when locating a new borehole site, especially if this is within or close to an urban area (Misstear and Bishop, 1997).

Some of the factors associated with environmental problems in Zambia is that there are no clear promulgated standards for the minimum or maximum groundwater depths, making evaluation of drainage situation difficult and although for some chemicals, quality standards are present, but the picture is not complete (for example DOC, TOC, pH, $C\ell O^-$, TH, B and PO_4^{3-}). Currently, there is no systematic priority list available on which pollutants are most serious in Zambia and what should be emphasized at household, industry and/or government level. Furthermore, there is a lack of an integral approach, by this we mean, ground water, stormwater, surface water, sewers and drinking water supply, all represents different dimensions of the same water system within a given locality. Nonetheless, these activities have been studied and planned separately. Hardly is the issue of groundwater given the gravity that it deserves and how it relates to human settlements and town planning. It was the purpose of this study to highlight some of the important water related aspects that would be worth giving a serious consideration.

One parameter worth noting is the amount of water TH in Lusaka city and Copperbelt region; it is important to note that guidelines for hardness are based on aesthetic, rather than health concerns. "Safe Drinking Water Foundation" (2006) has stated that levels greater than 200 ppm are considered poor but can be tolerated and levels in excess of 500 ppm are normally considered unacceptable. Of the Lusaka water samples, 33% were beyond 200 ppm, but all were below 500 ppm. This is in contrast to the Copperbelt region water (especially near the mining towns), where 13.6% of the samples' TH concentrations were greater than 200ppm; 31.8% with concentrations well beyond 500 ppm. The other sites assessed from miscellaneous regions around Zambia revealed normal TH with occasional undetectable levels of TH below 20 ppm.

The other parameters (ClO^-, H_2O_2, CH_2O, pH, DOC, O_3 and SiO_2), even though lack agreed upon standards, tested positive in some of the water samples and hence it would be appropriated to embark on research to establish the effects on human health from such chemicals as is common in the Zambian water. For instance, SiO_2 was detectable in all the samples tested from Lusaka city and 38% of all the samples tested positive for ClO^-; further discussion was not done for lack of Zambian *PV* standards to warrant an in-depth discussion. Another parameter highly considered in public discourse but with widely varying standards is pH; the ZBS/ECZ has not set any guidelines for drinking water. By and large, the pH values were within range of 6.5 to 8.5 (USEPA standards) except for one sample (LSK13T) from Chawama compound in the capital city of Zambia, Lusaka, which was slightly acidic at 5.75. However, it is important to use the unregulated contaminant monitoring program where data is collected for contaminants that were present in water samples, but do not have health-based standards set under the safe drinking water regulations. If safety of water is to be sustained, surface and groundwater protection process must be an integral part of the ministry in charge of environmental issues (Ministry of Tourism, Environment and Natural Resources in case of Zambia).

Conclusion

After analysing water from the five Zambian Provinces with different characteristics, it is indisputable that the pollution is anthropogenic in nature and is a consequence of mining on the Copperbelt, as revealed by TH levels, and the rampart unplanned residential areas in Lusaka Province as revealed by PCA, Tukey HSD test and correlation coefficients which show NO_3^- and Na^+ to be significantly higher in Lusaka compared to other regions. These parameters, among others, are a typical signature of human induced (human excrement) pollution. Furthermore, the levels of NO_3^- and Na^+ in ground water were significantly higher than in surface water. On the other hand, DOC levels were significantly higher in surface water compared to ground water and were not specific to any province. The users of the water in Zambia should pay particular attention when using ground water because of NO_3^- and Na^+ (that is, especially for Lusaka and Southern Provinces) and DOC pollution when using surface water irrespective of province. The residents of the Copperbelt Province should however be cautious of sulphate, phenolic compounds and excessive water TH especially when using the water obtained from the mine ground aquifers.

It is clear from this study that living in Lusaka (or any location heavily dependent on in-situ sanitation and backyard dumpsites like Magoye town) is particularly hazardous, given the high prevalence of nitrate pollution in tap water derived from the ground aquifers. Due to many people obtaining their drinking water from ground sources, it is important to set regulatory standards for more parameters and to monitor supplies regularly to ensure that potential health risk to humans are avoided. In Zambia, it is a popular advice (through private and public media and MoH) to tell the general public to either chlorinate and/or boil their drinking water, but merely boiling water will increase rather than decrease the contaminant concentrations. It is correct to argue that by boiling their drinking water, most Zambians are exposed to elevated pollutant concentrations than what was elucidated in this study. This study, therefore, suggests that water especially in Lusaka should not be boiled as a way of disinfecting it, but rather chlorinate because boil-ing will not remove the nitrates and other pollutants but instead increase their concentration.

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