Spatial Vulnerability of Surface Water to Chemical Contamination in the Ngwerere River Peri-Urban Watershed, Lusaka, Zambia

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Concerns about water pollution from commercial agriculture, demographic changes, urbanisation, industry, and anthropogenic activities in the Ngwerere River peri-urban watershed (NPW) were the drivers of this study. This study focused on the spatial vulnerability of surface water to chemical pollution. The aim was to implement a rapid integrated ecosystem assessment system to analyse the predisposition of surface water to chemical pollution. The specific objectives were to evaluate water quality (WQ) parameters as indicators of chemical pollution in the Ngwerere River, determine the spatial vulnerability of water to chemical pollution, and establish linkages between chemical pollution and sources within the NPW. In this study, the ecosystems approach, was followed to assess pH, salinity, total dissolved solids (TDS), chemical oxygen demand (COD), Na+, and total suspended solids (TSS)to determine WQ for the functional integrity of some ecosystem services. The results show that pH ranged from 7–8 and COD from 4–36 mg L-1 O2. The results for other parameters were as follows: 60–163 mg L-1, 258–567 mg L-1, 22–60 mg L-1, and 2–710 mg L-1 for salinity, TDS, Na+, and TSS, respectively. The means were 7.62 $\pm$ 0.05 mg L-1, 118.50 $\pm$ 4.07 mg L-1, 437.91 $\pm$ 14.35 mg L-1, 17.45 $\pm$ 2.04 mg L-1 O2, 45.46 $\pm$ 1.53 mg L-1, and 192.79 $\pm$ 46.90 mg L-1 for pH, salinity, TDS, COD, Na+, and TSS, respectively. With the exception of COD and Na+, which exceeded the relevant environmental standards, all measured parameters were within acceptable ranges, indicating the functional integrity of the ecosystem. Furthermore, the trends in concentration for all WQ parameters were indicative of chemical pollution. Three watershed positions, upstream catchment (USC), midstream catchment (MSC), and downstream catchment (DSC), were assessed for vulnerability to chemical pollution. USC and MSC were more vulnerable based on all parameters, excluding TSS, which had higher concentrations at DSC. Linkages were established between chemical pollution in the river and pollution sources. With the exception of TSS, all parameter concentrations were high in USC and MSC due to their proximity to point source and non-point source pollution. In contrast, high concentrations of TSS were observed in DSC due to the accumulation of loading. Further work should be conducted to establish the ecosystem services present in NPW. Thus, assessments will need be refined and focused on specific environmental concerns for NPW.

Keywords:chemical pollution, ecosystems, freshwater, water quality, Ngwerere River peri-urban watershed

Introduction

Further deterioration of freshwater quality due to pollution is a major challenge humanity will face in the 21st century (UNEP, 2016). Consequently, we must strike a delicate balance between meeting increasing demand for water, food, and energy without causing irreparable damage to freshwater ecosystems. According to the United Nations Environment Programme (UNEP (2016)), deterioration of freshwater ecosystems has primarily been driven by human population growth, economic activity, land use, and climate change. These driving factors continue to exert pressure on the quality and quantity of freshwater resources. As a result, deteriorating freshwater quality is a global concern as it threatens to destabilize water use, freshwater ecosystem integrity, and the biodiversity of these ecosystems.

Freshwater is a critical natural resource as it is vital for the delivery of ecological goods and services, such as domestic water, food production, energy, industrial processing, transportation, waste disposal, and human health(Gleick, 1993; Malmqvist & Rundle, 2002). According to Shaklomanov (1993), the total global water resources are an estimated 1386 million km3, over 96% of which is saline, and just 4% is freshwater. Of these freshwater resources, 68% is captured in ice and glaciers, and the remaining 30% is restricted to the ground. Freshwater sources, such as rivers and lakes, only account for 93100 km3, which is approximately 0.0067% of the world's total water. Nevertheless, rivers and lakes are major sources of water for humans as well as wildlife. Of all the water in the hydrosphere, surface water and other freshwater resources are further categorised as follows: atmospheric water 0.22%, biological water 0.22%, rivers 0.46%, swamps and marshes 2.53%, and soil moisture 3.52% (Shaklomanov, 1993). The focus of this study is freshwater river resources at watershed scale.

Degradation of river ecosystems has been extensive in developed countries such that it is now necessary to either protect what remains or restore degraded systems. In contrast, in developing countries, destruction of river ecosystems is currently peaking, but it may present an immediate threat (Dudgeon, 1999). According to Dudgeon (1999), information on the impacts of human activities on river ecosystems in developing countries is scarce. There are critical knowledge gaps concerning the impacts of many pollutants, and there is insufficient data for this in developing countries, most of which are likely to become vulnerable in the near future. Additionally, fewer studies have been undertaken to predict changes in the status and ecology of river water systems.

With the global population projected to increase by 2–8 billion by 2023, pressure on river systems is expected to increase dramatically (Malmqvist & Rundle, 2002; Rijsberman et al., 2006). Unsustainable land use and management practices within a watershed may be the underlying cause of resource degradation within the watershed. This could have primary implications for the socio-economic well being of resource users and the environment (Fock & Cao, 2016). The terms 'basin', 'watershed', and 'catchment' are often used interchangeably (World Bank, 2001). However, for the purpose of this study, the term 'catchment' is used to refer to the segmentation of the NPW into 'subwatersheds'. River ecosystems are characterized by temporal variations in flow regimes due to spatial differences, the occurrence of maximum precipitation, evapotranspiration, and ice melting (Dettinger & Diaz, 2000). Therefore, the focus of this study is toassess water quality parameters that could be indicative of an optimal freshwater ecosystem in a peri-urban watershed.

In the context of Sub-Saharan Africa (SSA), the outlook on freshwater resources is no different, if not worse. For instance, findings from a study by Conway et al. (2009) highlighted significant temporal variation of up to 14% and 51% for rainfall and river flows, respectively, in SSA. A prospective study of Africa indicated that rapid urbanization is the paramount threat to the ecosystem (Clancy, 2008). Furthermore, according to the United Nations Population Fund (UNFPA) (2007), Africa's annual urban population growth has been the highest in the world recently, at a rate exceeding 4% per annum. Africa's urban population is expected to grow from 294 to 724 million by 2030. Several authors, including Mokwunye et al. (1996), Bridge (2001), Marcotullio (2003), Rijsberman et al. (2006), Cities Alliance/ICLEI/UNEP (2007), Simon (2008), Bhatta and Doppler (2010), Kasa et al. (2017), and Schwärzel et al. (2014), have elucidated the connection between the population, urbanization, and environmental degradation. According to Clancy (2008), in the current decade and the future, high annual urban growth will continue in Africa as well as across the world. This suggests that there will be a major strain on water resources and disruption of river ecosystems will accelerate. For example, unsustainable groundwater exploitation has decreased water table levels and increased degradation such that, in Africa, there has been a shift in the water supply for urban communities from groundwater to surface water (Showers, 2002).

Furthermore, according to Kusangaya et al. (2014), in Southern Africa, climate change will negatively affect the availability and demand for freshwater resources. Typically, Southern Africa has highly spatiotemporally variable rainfall. This phenomenon subsequently manifests as water scarcity. In addition, there are indications that, in Southern Africa, no facet of anthropological welfare will be spared from the negative impacts of climate change on freshwater resources. The susceptibility of the region to freshwater insecurity is worsened by its low capacity to adapt, poverty, and poor access to appropriate technology. Thus, it is envisaged that deterioration of freshwater resources in Southern Africa will impact agricultural, energy, domestic, and industrial water needs, as well as environmental flows (Kusangaya et al., 2014). In Zambia, a study by de Waele and Follesa (2003), which assessed human impacts on a vulnerable karst environment, revealed that demographic changes have led to unrestrained urbanization in Lusaka. This resulted in poor water resource management over the past three decades, putting the future social and economic development agenda at risk.

2 Materials and Methods

2.1 Study area

For data analysis, the NPW was divided into three segments, referred to as watershed positions (WPs). The three WPs are upstream catchment (USC), midstream catchment (MSC), and downstream catchment (DSC). There were three sampling locations (SLs) in each WP. Given the wide variation in the types and sources of pollution at a watershed level and potential uses for water, different types of parameters, including physical, chemical, and biological, can be applied to assess WQ. In this study, chemical WQ parameters were assessed for surface water following a more generalised approach for the final uses of this water. Water samples were collected from nine sampling points within the watershed (Fig. 1).

Map showing the location of Ngwerere watershed, Ngwerere River and sampling sites spread across the watershed

2.2 Sampling technique

The monitoring scheme followed in this study utilised hydrological and ecological monitoring principles (Gruijter et al., 2006). The scheme was designed for status monitoring (Loaiciga et al., 1992; Dixon & Chiswell, 1996). The two factors of interest during the monitoring period were the receding water levels, as monitoring was conducted during the dry season, and the effects of changing environmental on the freshwater ecosystem.

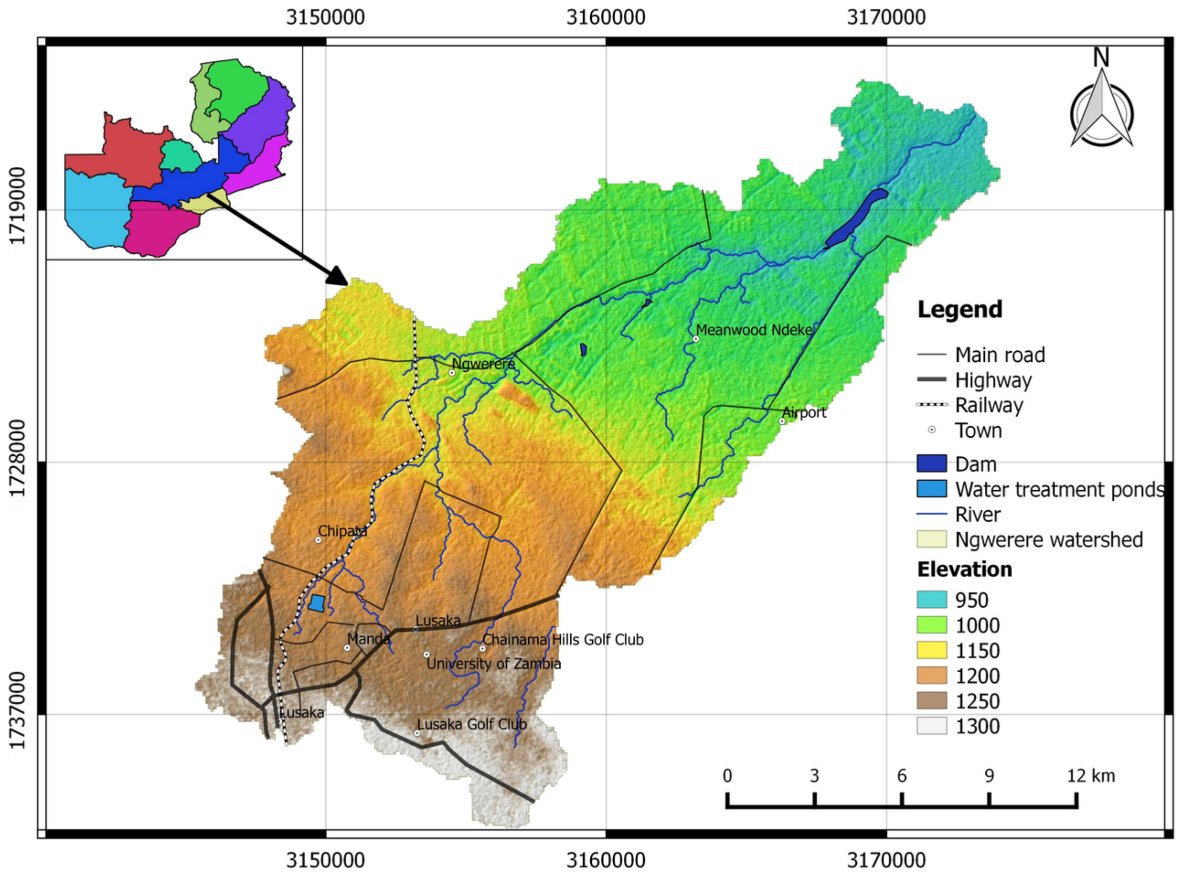

Figure 1: F

2.2.1 Sampling sites

2.2.1.1 Upstream catchment (USC)

The USC constitutes the upland urban areas of the watershed from where drainage and tributary streams to the Ngwerere River originate. These include the northern central business district (CBD) of Lusaka city, the industrial area on the western side, and low- and high-density suburbs northwards. The three sampling sites located in the USC were Garden Olympia Park (GOP), Garden Petroda Filling Station (GPFS), and the LumumbaMandevu Junction (LMJ). GOP is located on the fringe of the Olympia park suburb and Garden compound along Katima Mulilo Road. It receives drainage from the upstream Northmead, Luangwa, and Olympia suburbs. This site was selected as it receives a significant amount of drainage from these locations and channels it into Ngwerere River. The GPFS sampling site was located on the periphery of Katima Mulilo Road in the Garden compound, but in proximity to the Great North Road (GNR) junction. The drainage channel in this location receives runoff and drainage from the CBD areas, areas around the Zambia Electricity Supply Corporation (ZESCO) headquarters, Rhodes Park, Thorn Park, Villa Elizabeth, Chilulu, Emmasdale, and parts of the Garden and Northmead residential areas. This site was selected as it would enable the assessment of water quality attributable to these areas before entering the main channel of Ngwerere River. The LMJ sampling site was located on the periphery of Lumumba Road before the GNR junction. The drainage channel on LMJ receives runoff from parts of the industrial area, Villa Elizabeth, and the western parts of the Emmasdale and Buseko commercial areas. This enabled the assessment of runoff from these locations before merging with the main course of the Ngwerere River.

2.2.1.2 Midstream catchment (MSC)

The MSC primarily contains settlement areas. From the fringes of USC into the Ngwerere area, there are commercial farming settlements. The major land use types in this area are settlements, arable land, savannah, sparse woodlands, andcommercial farms. The sampling sites located in the MSC were Mazyopa Community (MC), Galaunia Roan Farm (GRF), and the Confluence of Chamba Valley Stream and Ngwerere (CCVN) River. The MC sampling site was in the Mazyopa community area on the boundary with the Roma Park residential area, and was the final sampling location before the commercial farm zones. It lies at the bottom of the three sampling sites under USC. The MC site was selected as it is the area where the flow from the three sampling sites combine under USC and thus enabled the assessment of WQ changes arising from the combined effects of the three locations. The GRF site was located along Ngwerere road, on the edge of Galaunia Roan commercial farm. It was located downstream of the MC site. It was chosen as it would allow WQ assessmentafter the introduction of runoff from commercial farming fields. The CCVN site was located further downstream, beyond the GRF site. The CCVN site was selected as it captured flow after merging with the Chamba Valley stream, a major tributary to the Ngwerere River. The Chamba Valley stream collects runoff from Munali, Kaunda Square, and the Minestone residential areas, then traverses some smallholder vegetable gardens before merging into the Ngwerere River.

2.2.1.3 Downstream catchment (DSC)

The DSC is situated in the lower lands of the watershed. Major land use types in this area are forests, savannah, arable lands, and rural dwellings. However, urban settlements such as the Ndeke Mean wood settlement in the north-eastern area have begun to stretch into this catchment, The samplingsites in DSC were Galaunia Ngwerere Farm (GNF), Zambia National Service Airport (ZNSA), and Ngwerere Chongwe Confluence at Kasenga (NCCK). The GNF site is located on a tributary stream that receives drainage from the Galaunia Ngwerere and Dimondale commercial farms. The ZNSA site is situated on another minor stream that receives drainage from the upland areas adjacent to KKIA and the commercial farms for ZNS. The NCCK site is the furthest point downstream of the Ngwerere River before it merges into the Chongwe River, flowing in from the north-west in a south-easterly direction.

2.3 Hypothesis tests

Three propositions were tested in this study, as follows:

i. There are no statistically significant differences for WQ parameters between the watershed positions of USC, MSC, and DSC.

ii. There are no statistically significant differences for WQ parameters between the sampling site locations of GPFS, GOP, LMJ, MC, GRF, CCVN, GNF, ZNSA, and NCCK.

iii. There are no statistically significant differences between WQ parameters associated with the months of sampling, i.e. August, September, October, and November.µ

Thus, the test hypotheses for the three propositions can be symbolically stated as follows:

i. $H_o = x_{usc} = x_{msc} = x_{dsc}$

ii. $H_o : x_{GPFS} = x_{gop} = x_{lmj} = x_{mc} = x_{grf} = x_{ccvn} = x_{gnf} = x_{znsa} = x_{ncck}$

iii. $H_o : x_{Aug} = x_{Sept} = x_{Oct} = x_{Nov}$

2.4 Characterization of pH, Salinity, BOD, TDS, COD, Na and TSS in Ngwerere River

Spatial assessment of the chemical contamination of Ngwerere River was conducted by assessing selected WQ parameters. Data were collected from nine sampling locations within the NPW (Fig. 1). The water quality parameters assessed included pH (Speight et al., 2005), salinity (Clean Water Team (CWT), 2004), total dissolved solids (TDS) (CWT, 2004), chemical oxygen demand (COD) (Domini et al., 2006), Na+ (Hendershot et al., 1993), and total suspended solids (TSS) (United States Geological Survey (USGS), 2000).

3 Results

3.1 Water quality parameter characterization

Table 1 presents a statistical summary of the water quality parameters for NPW. Figure 2 includes box plots for the data characteristic of the WQ parameters considered in this study. Total dissolved solids and TSS data had the largest variation around the mean, with standard deviations (σ) equal to 82.4 and 209.73, respectively.

Parameter	Units	# of samples	Range	Min	Max	Mean	SE	SD
pH	-	33	1	7	8	7.62	0.05	0.3
Salinity	mgl^{-1}	33	103	60	163	118.5	4.07	23.4
TDS	mgl^{-1}	33	309	258	567	437.91	14.35	82.4
COD	$mg\ O_2l^{-1}$	33	32	4	36	17.45	2.04	11.7
Na	mgl^{-1}	33	38	22	60	45.46	1.53	8.8
TSS	mgl^{-1}	20	708	2	710	192.79	46.9	209.7

Table 1: Descriptive stattistics of water quality parameters for NPW

Of the remaining parameters, pH values varied the least, followed by COD, Na+, and salinity, with standard deviations equal to 0.3, 11.7, 8.8, and 23.4, respectively. An understanding of data variation is essential if meaningful comparisons between groups of data are to be made (Gomez & Gomez, 1976; Clewer & Scarisbrick, 2001).

3.1.1 Surface water pH

Surface water pH indicates the level of acidity of the surface water. The pH range measured for Ngwerere River water was 7.0–8.0, with a mean of 7.62 $\pm$ 0.05 (Table 1). Furthermore, pH measurements were highly uniform, with measurements remaining close to the mean (Fig. 2).

3.1.2 Surface water salinity

Salinity is a consistent component of freshwater ecosystems. The salinity values measured in this study ranged between 60–163 mg L-1, and moderatelyvaried around the mean (Fig. 2). Estimation of the effects of

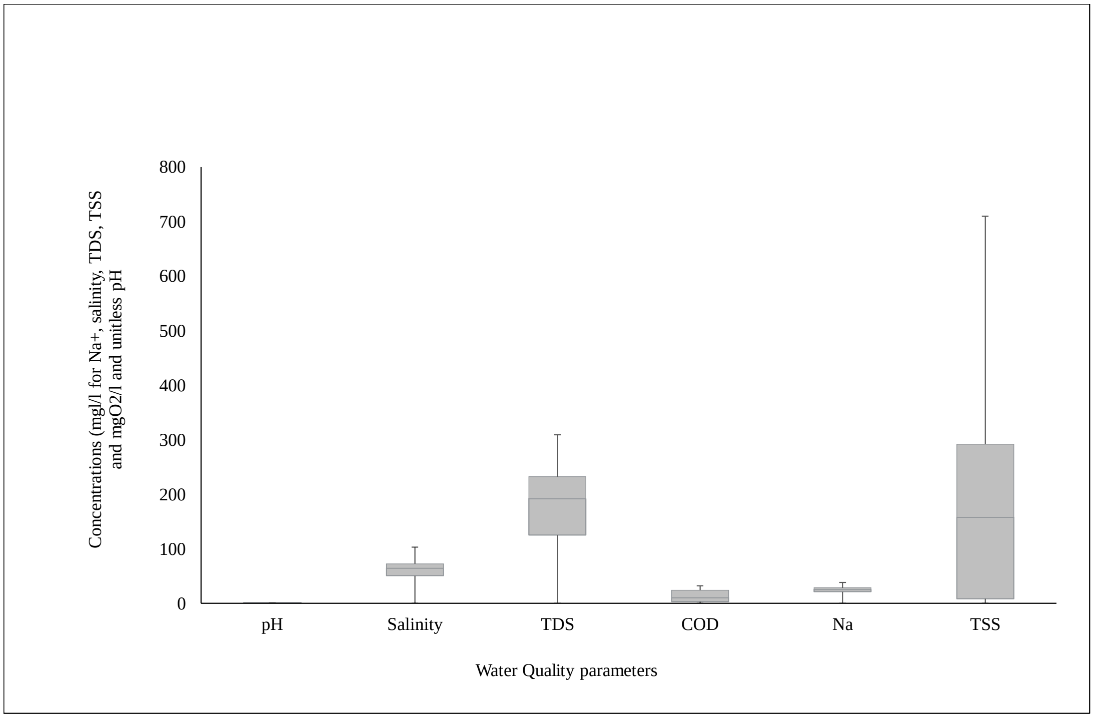

Figure 2: Box plots display of data characteristics for WQ parameters in NPW

salinity is complex as it contains different components that all contribute to a single salinity measure. The composition of individual components that contribute to salinity varies spatiotemporally, based on underlying geomorphology and geology.

3.1.3 Total dissolved solids

In this study, TDS measurements ranged between 258–567 mg L-1, with a mean value of 437.91 ± 14.35 mg L-1. The median value was in the third quartile, with significant extensions of the upper and lower whiskers, suggesting that some values widely varied from the mean (Fig. 2). TDS data had a relatively large spread.

3.1.4 Chemical oxygen demand

The range of COD recorded in this study was 4–36 mg L-1 O2, with an average COD of 17.45 ± 2.04 mg L-1 O2 (Table 1). The COD measurements had intermediate variation (Fig. 2), with a standard deviation of 11.72.

3.1.5 Sodium

Sodium concentration in Ngwerere River water ranged from 22–60 mg L-1 whileaverage concentration was 45.46 ± 1.53 mg L-1 (Table 1). The data for Na+ had a comparatively low variation (Fig. 2). However, 60 mg L-1 Na+ was recorded within the watershed, indicating potential chemical pollution. Furthermore, an average of 45.46 ± 1.53 mg L-1 is within the upper margin of the safe sodium concentration range, indicating that Na+ levels will soon exceed the level expected in surface waters if no interventions are in place.

3.1.6 Total suspended solids

Total suspended solids data had the largest spread. Although most values were within the second and third quartiles, spread around the median was comparative wider than that of other parameters (Fig. 2). Measurements of TSS in this study ranged from 2–710 mg L-1, with a mean of 192.79 ± 46.90.

3.2 Analysis of variance (ANOVA)

Three ANOVA tests were conducted to determine differences in means of WQ parameters according to watershed position, site location, and the month of data collection within the NPW (Tables 2, 3, and 4). The outcomes of the ANOVA are discussed in the following sections.

3.2.1 Influence of watershed position on WQ parameters in NPW

An ANOVA was conducted to determine statistically significant differences in the overall means of WQ parameters, based on watershed position (Table 2).

Location	Measure of dispersion	Water quality parameters					
		pH	Salinity	TDS	COD	Na	TSS
DSC	Mean	7.58	105.14	403.67	16.33	40.78	254.33
	Std. Dev.	0.27	23.98	83	11.01	9.32	353.33
MSC	Mean	7.68	127.33	480	18.33	48.99	242.5
	Std. Dev.	0.28	8.43	38.88	13.65	3.91	57.16
USC	Mean	7.61	125.24	440.58	17.92	47.49	135.98
	Std. Dev.	0.25	25.56	95.1	11.86	9.35	123.3
P value		0.05 (0.7)	0.05 (0.04) *	0.05 (0.11)	0.05 (0.92)	0.05 (0.06) *	0.05 (0.5)

Table 2: ANOVA results for water quality parameters as function of watershed position

The results of the watershed position ANOVA tests revealed statistically significant differences in salinity and Na+ between the three watershed positions. Both USC and MSC contain land use types suspected to be major sources of pollution. USC comprises a built-up area, which includes part of the Lusaka city CBD and an industrial area (point sources of pollution). These locations discharge drainage containing high amounts of dissolved salts and cations, such as Na+. However, apart from receiving runoff with high salinity levels from USC, MSC introduces diffuse sources of pollution from commercial farmland. As runoff proceeds downstream to DSC, sources of emission for salts and Na+ decrease. Loading of colloidal material is also reduced by coagulation, which is enhanced by dissolved organic matter (Wilkinson et al., 1997; Ma et al., 2001; Ma & Liu, 2002), resulting in the comparatively low salinity and Na+ levels observed under DSC.

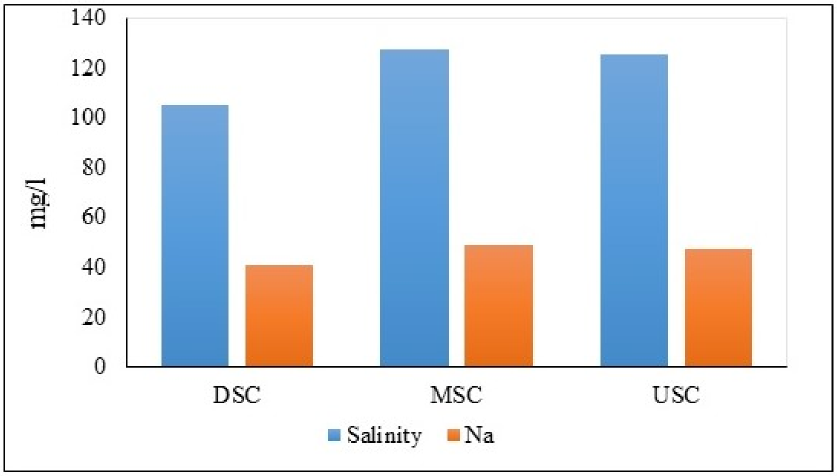

Figure 3: Graphical illustration of watershed position influence on variation of salinity and Na+ concentrations in surface water of Ngwerere River

3.2.2 Influence of site location on WQ parameters in NPW

The second ANOVA test was conducted to determine if site location had a statistically significant influence on the variability of the means of WQ parameters (Table 3). The results obtained from the ANOVA tests showed that there were statistically highly significant differences in salinity, TDS, Na+, andTSS at the 1% level. Therefore, the null hypothesis for site location was rejected. TSS had relatively low values in the upstream zones of USC and MSC, and high concentrations in DSC. Salinity, TDS, and Na+ consistently had higher concentrations in the USC and MSC sites, and lower concentrations in DSC (Table 4). Figure 3 graphically shows the variation of parameters according to site location.

The erratic TSS pattern was expected as it is a highly variable parameter and is influenced by several factors, including discharge rates, soil erosion, runoff source, effluent emissions, decomposing plant and animal material, land use, and plankton, which differ according to physical conditions (WHO, 1996; Fondriest Environmental, Inc., 2014; Anon 2017).

3.2.3 Temporal variability of WQ parameters in NPW

Samples were collected on a monthly basis in this study. To assess if differences in the time of sample collection had a statistically significant influence on the parameters, an ANOVA test was conducted (Table 5). During this period, the water levels of the river were in recession. Thus, the intention of this study was to assess the effect of receding water levels on WQ.

The results of the ANOVA revealed that there were statistically significant temporal differences at $p<0.01$ for pH and $p<0.001$ for COD. Thus the alternative hypothesis was accepted for the means based on the time of sampling. The results of the ANOVA are presented in Fig. 4.

Location	Sampling Site	Measure of dispersion	Water quality parameters					
			pH	Salinity	TDS	COD	Na	TSS
USC	GOP	Mean	7.58	151.1	540.75	13.25	56.47	158
		Std. Deviation	0.2	11.82	30.34	9	4	0
	GPFS	Mean	7.76	114.1	409.25	18	44.2	147.4
		Std. Deviation	0.14	23.3	45.91	11.58	9.67	166.97
	LMJ	Mean	7.49	110.54	371.75	22.5	41.8	113.55
		Std. Deviation	0.34	19.19	95.56	15.61	6.69	128.69
MSC	MC	Mean	7.78	124.18	493.25	17.25	48.52	292
		Std. Deviation	0.13	11.76	51.14	12.47	4.96	0
	GRF	Mean	7.88	128.7	490	4	46.86	.
		Std. Deviation	.	.	.	.	.	
	CCVN	Mean	7.52	130.14	464.25	23	50	193
		Std. Deviation	0.38	5.2	28.59	15.56	3.6	0
DSC	GNF	Mean	7.63	123.33	476.25	17.25	47.77	44.7
		Std. Deviation	0.12	2.68	33.21	12.47	2.63	0
	ZNSA	Mean	7.53	87.92	359	20.5	34.17	710
		Std. Deviation	0.39	32.69	115.47	13.89	12.06	0
	NCCK	Mean	7.57	104.18	375.75	11.25	40.42	8.3
		Std. Deviation	0.32	13.94	9.78	6.08	6.52	0
p value			0.05	0.01	0.01	0.05	0.01	0.0
			0.71	(0.0)**	(.003)**	0.82	(0.01)**	(0.0)***

Table 3: ANOVA results for water quality parameters as a function of site location

pH observations were higher in August and October, at pH 7.78 and 7.77, respectively, while September and November both had pH values of 7.45. In contrast, COD values were lower in August and October at 5.11 and 11.25, respectively. Higher COD observations were observed in September and November, at 29.25 and 25.75, respectively. The high pH observed in August could be attributed to effluent emissions as the flow levels were relatively high. However, as time progressed and temperatures increased, a slight reduction in pH was observed with the onset of the dry season. Furthermore, the flow of the stream was significantly reduced due to some sections of the river being cut off. From September, the site at GRF had completely dried out. Thus, in-stream metabolic processes, such as the formation of fulvic acids rather than effluent emissions could be responsible for the slight decrease in pH observed around September and November. Alternatively, anaerobic conditions resulting from in-stream processes could also be responsible for the variation in COD from September–November.

SL	salinity	SL	TDS	SL	Na^{+}	SL	TSS
GOP	151.1 ± 11.81	GOP	540.75 ± 30.33	GOP	56.47 ± 4	ZNSA	710.0 ± 0.0
CCVN	130.14 ± 5.2	MC	493.25 ± 51.14	CCVN	50.0 ± 3.6	NCCK	8.3 ± 0.0
GRF	128.7 ± 0.0	GRF	490.0 ± 0.0	MC	48.52 ± 4.96	MC	292.0 ± 0.0
MC	124.18 ± 11.76	GNF	476.25 ± 33.21	GNF	47.77 ± 2.63	LMJ	113.0 ± 128.69
GNF	123.33 ± 2.68	CCVN	464.25 ± 28.59	GRF	46.86 ± 0.0	GRF	0
GPFS	114.1 ± 23.3	GPFS	409.25 ± 45.91	GPFS	44.2 ± 9.67	GPFS	147.4 ± 166.97
LMJ	110.54 ± 19.19	NCCK	375.75 ± 9.78	LMJ	41.8 ± 6.69	GOP	158.0 ± 0.0
NCCK	104.18 ± 13.94	LMJ	371.75 ± 95.56	NCCK	40.42 ± 6.52	GNF	44.7 ± 0.0

Table 4: Means ranked in descending order for each location

4 Discussion

Different water uses have a different range of variables that define the suitability of water for these purposes. Thus, a 'holistic' assessment of WQ will include a range of parameters that, therefore, may limit its use (Bartram & Balance, 1996). For most WQ parameters, benchmarks have been established, which are expected to guide the management of river ecosystems and mitigate the effects of pollution (Enderlein et al., 1988). In this study, WQ was assessed to gain insight into the chemical contamination of Ngwerere River water. Hence, rather than discuss WQ parameters in relation to any specific use of water, the ecosystems approach was applied in assessing the suitability of measuring WQ parameters in surface water. The ecosystems approach is based on objectives for preserving the functional integrity of aquatic systems. Typically, the functional integrity of aquatic systems includes chemical, hydrological, and biological factors and interactions between them (Enderlein et al., 1988).

In unpolluted waters, pH is governed by the balance between carbon dioxide, carbonate, and bicarbonate ions and organic acids, such as humic and fulvic acids (de Montety et al., 2011). The natural acid-base balance of a river can be affected by industrial effluent and deposition of acid-forming substances from the atmosphere. Therefore, pH fluctuations can be indicative of river contamination. pH fluctuations over a short duration (24 hours) could be due to photosynthesis and the respiration cycles of algae in eutrophic waters (Menéndez et al., 2001; de Montety et al., 2011). Most natural waters have a pH range of 6.0–8.5. Lower pH values can occur in waters with high organic content, and elevated pH values in eutrophic waters (UNESCO/WHO/UNEP, 1996). The pH values in this study were elevated, within a range of 7.0–8.0, indicating eutrophication. Furthermore, pH observations are consistent with the results obtained by Florescu et al. (2011) for the Arges, Olt, and Jiu Rivers in Romania, which ranged between 7.07–8.5. These ranges

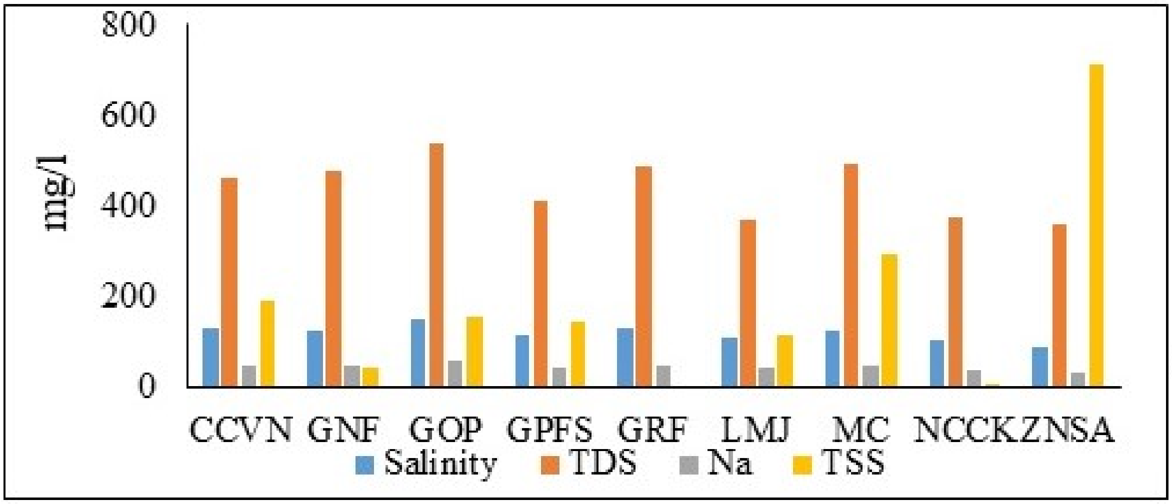

Figure 4: Variation of Salinity, TDS, Na and TSS based on site location

Month	Measures of dispersion	Water quality parameters					
		pH	Salinity (mgl^{-1})	TDS (mgl^{-1})	COD ($mgl^{-1}O_2$)	Na (mgl^{-1})	TSS (mgl^{-1})
Aug.	Mean	7.78	120.09	469.89	5.11	43.85	2.45
	SD±	0.09	17.14	68.17	1.45	6.25	0.5
Nov.	Mean	7.45	117.82	404.88	29.25	47.25	240.37
	SD±	0.3	29.92	87.91	6.59	10.89	216.23
Oct.	Mean	7.77	116	469.88	11.25	46.75	2.45
	SD±	0.09	17.01	72.01	3.41	6.99	0.5
Sept.	Mean	7.45	119.91	403	25.75	44.19	240.37
	SD±	0.3	31.02	87.86	9.63	11.35	216.23
p-value		0.01	0.05	0.05	0.0	0.05	0.05
		(0.0)**	-0.98	-0.15	(0.0)***	-0.82	-0.26

Table 5: ANOVA results for water quality parameters as affected by time

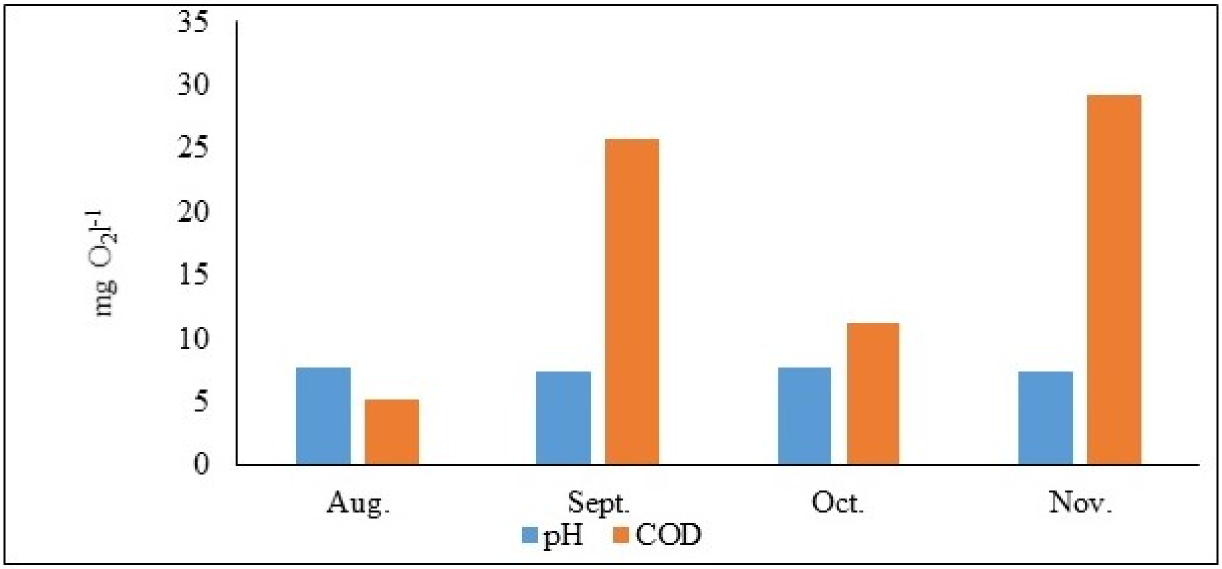

Figure 5: This is a caption Graphical presentation of ANOVA results on variation of pH and COD ($mgl^{-1}O_2$) according to month of sample collection

are characteristic of surface water systems and are suitable for most organisms (UNESCO/WHO/UNEP, 1996; Florescu et al., 2011).

Salinity can profoundly impact riverine ecosystems, resulting in serious environmental issues. Ecosystem degradation due to salinity consequently leads to loss of habitat, biodiversity, native vegetation and water resource value (Nielsen, et al. 2003). Increased salinity reduces the quality of surface water by reducing the levels of dissolved oxygen that life forms depend upon (UNESCO/WHO/UNEP, 1996). According to the Environmental Protection Agency (EPA) (2001), elevated salt concentrations may cause a water system to become unsuitable for domestic, agricultural, or industrial use. Furthermore, according to James et al. (2003), empirical data from ecotoxicological field and laboratory studies attest that there are large variations in salinity thresholds within and between freshwater taxonomic groups. However, generalizations can still be made about salinity thresholds for freshwater biota. The biodiversity of microfauna is inversely related to salinity in freshwater systems (Brock & Shiel, 1983; Halse et al., 1998). Threshold salinity tolerance levels for microinvertebrate species are approximately 2,000 mg l–1(Nielsen et al., 2003). However, according to Hart et al. (1991), Short, et al.(1991), and Kefford (1998), some species can thrive between 5,000 and 10,000 mg l–1. In this study, the salinity ranged between 60–163 mg L-1. These values are below the thresholds for most aquatic biota.

Most authorities such as UNEP, the Water Supply and Sanitation Collaborative Council (WSSCC), or the World Health Organisation (WHO) have no reference recommendations for WQ thresholds of TDS, (Enderlein et al., 1997). However, attempts to develop TDS standards have been conducted. For instance, the North Dakota State University (NDSU) (2015) proposed TDS recommendations for livestock water. According to NDSU (2015), TDS [?]3,000 mg L-1 is suitable for most livestock, and 3,000–5,000 mg L-1 is suitable for adult livestock, although these levels are detrimental for growing livestock. Levels near 5,000 mg

L-1 are intolerable for poultry, while TDS values between 5,000–7,000 mg L-1 are unacceptable for lactating females of most species. High TDS levels of 7,000–10,000 mg L-1 are hazardous to pigs and pregnant or lactating ruminants, including horses, and TDS>10,000 mg L-1 may be fatal. In this study, TDS ranged between 258–567 mg L-1, suggesting that the water is suitable for most livestock species.

For many decades, COD has been an expedient variable for assessing chemical pollution arising from different types of waste, such as agricultural (including pesticides and nutrients) and industrial waste (such as heavy metals and persistent organic pollutants), and emerging pollutants (UNEP, 2016). The advantage of COD is that it can be time-saving due to the promptness of measurements (UNESCO/WHO/UNEP, 1996). In unpolluted surface waters, a typical COD range is [?] 20 mg L-1 O2, while COD will exceed 200 mg L-1 O2 inwater that receives effluent. Industrial wastewaters may have COD values that range from 100–60000 mg L-1 O2 (UNESCO/WHO/UNEP, 1996). Given theCOD range of 4–36 mg L-1 O2 recorded in this study, and considering the CODlimits for unpolluted rivers (UNESCO /WHO/UNEP,1996), COD was indicative of chemical pollution in the Ngwerere River.

The elevated Na+ levels in surface water may be caused by various effluents. In coastal zones, the intrusion of sea water can result in elevated Na+ levels insurface water. Thus, sodium levels in surface waters vary according to local geology, sewage, and industrial emissions. Sodium concentrations can range from [?]1–105 mg L-1 or more in natural brines. The WHO set 200 mg L-1 Na+ asthe threshold value for sodium in drinking water (UNESCO/WHO/UNEP, 1996). Generally, in surface waters, including those receiving wastewater, sodium levels do not exceed 50 mg L-1 (UNESCO/WHO/UNEP, 1996). High Na+ levels can damage soil structure, resulting in reduced hydraulic conductivity and ultimately causing poor plant growth. The sodium adsorption ratio (SAR) is an estimate of the degree to which Na+ will be adsorbed by the soil and can beused as a measure of the suitability of water for irrigation. High SAR values indicate that the sodium in irrigation water may replace calcium and magnesium ions in the soil, thus damaging soil structure. Increased Na+ will typically result in high SAR values (UNESCO/WHO/UNEP, 1996). The resultsof this study indicate that Na+ is still below the 50 mg L-1 level expected in many surface waters (UNESCO/WHO/UNEP, 1996).

Total suspended solids include materials drifting or floating in the water, which could include silt and sand sediments, plankton, and algae. Decomposing organic matter can also be a constituent of TSS (WHO, 1996; Fondriest Environmental Inc., 2014; Anon, 2017). Many authorities have inexplicit TSS standards for surface water. For example, the best available technique/associated emission levels (BAT/AEL) under Standard 872 of the EU imposes a limit of 5–35 mg L-1 on emissions exceeding 3.5-ton yr-1 (Organisation for Economic Co-operation and Development (OECD), 2007). In Moldova, surface WQ standards stipulate that TSS concentrations at the control point should not exceed the natural levels by more than 0.25 mg L-1 and 0.75 mg L-1 for superior first and second-class fishery water bodies, respectively. In streams with TSS levels above 30 mg L-1 during the low water level period,TSS emissions may be exceeded by 5% for both superior first and second-class fishery water bodies. Discharge of wastewater containing TSS levels of 0.2 mg L-1 for lakes or 0.4 mg L-1 for rivers is prohibited for both classes of fishery water bodies (OECD, 2007). In this study, TSS ranged from 2–710 mg L-1.However, it is a challenge to determine proof of suitability as TSS standards set elsewhere are indirectly stated as rates. Moreover, these rates were set considering the most beneficial ecosystem services in those particular locations, which may be inapplicable to the Ngwerere River.

5 Conclusion

This study was undertaken to implement a rapid integrated ecosystem assessment of the Ngwerere River's predisposition to chemical pollution. To achieve this, the study set out to evaluate selected WQ parameters, determine the spatiotemporal vulnerability of the watershed to chemical pollution, and establish linkages between observed pollution and its potential sources.

Findings from this study suggest that there are sources of effluent within the NPW. However, based on the WQ parameters evaluated in this study, the NPW surface water ecosystem is healthy for most ecological functions. This is because some WQ parameters were below the set thresholds, while others were comparatively lower than levels measured in other studies. It was also demonstrated that the position and time of sampling had a significant influence on the variation of some WQ parameters. Salinity and $Na+$ were significantly influenced by watershed position and sampling site at the $p<0.05$ and $p<0.01$ significance levels, respectively. Total dissolved solids and TSS were significantly influenced by sampling site location at the $p<0.01$ and $p<0.001$ significance levels, respectively. pH and COD were significantly influenced by the time of sampling at the $p<0.01$ and $p<0.001$ significance levels, respectively.

Finally, from the findings of this study, it was determined that there was a link between the observed levels of water quality parameters and point and diffuse sources of pollution located in the USC and MSD of the watershed, respectively. To effectively monitor the effects of pollution on freshwater ecosystems, information about existing ecosystem services within river watersheds is required to assist decision-making. Such data is almost non-existent for most watersheds in developing countries, specifically in Zambia. Therefore, there is a need for systematic collection or a repository of data for monitoring and management of freshwater ecosystems. Such repositories will enable the identification of existing ecosystem services, potential pollution threats, and drivers of degradation, as well as physical data for specific watersheds. Further work should be conducted to determine the ecosystem services within the NPW. In this way, ecosystem assessment will be more refined and focus on the environmental concerns of the NPW.

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